*CWPA Proceedings, 2002, pp 32-47*


# STATUS OF ANTI-STAIN TREATING IN CANADA

**Tony Byrne**
**Wood Protection Scientist – Durability and Protection**
**Forintek Canada Corp., 2665 East Mall, Vancouver, B. C. V6T 1W5**

## Abstract

Control of sapstain, mould and decay on green export lumber continues to be an important activity in the Canadian lumber industry, particularly in coastal BC. Available data on the use patterns of sapstain control products in BC are discussed. Examples of where Canadian practices have lead other countries or regions are discussed. Opportunities for development of new uses for surface treatments of wood products are suggested.

## 1 Introduction

"Antistain" or "sapstain control" products have been a mainstay of the BC coastal industry for many years (Eades 1956, Roff and Cserjesi 1985, Byrne 1997a). These products are used for short-term protection of freshly sawn wood from staining fungi, mould, and decay (Scheffer 1958; Roff, *et al.* 1980). The treated lumber is usually used in construction or may be further treated or finished at its service destination. The use of chemicals is traditional where the wood is sold in green condition and the BC coastal forest industry has been by far the largest user. British Columbia probably accounts for between 85 and 95% of the sapstain control products used in Canada from year to year.

This paper is intended to update members of the CWPA on use trends in sapstain control in Canada. A number of milestones from the past and challenges for the future are also discussed.

## 2 Sapstain Control Products in the Pesticide Pie

This paper unashamedly concentrates on BC because reliable data is available and, as mentioned, most of the sapstain control products are used in BC. The last survey of pesticide use in BC was in 1999 (ENKON Environmental 2001**)** when 8,102,384 kg of pesticide active ingredients were used or sold. This works out to be about 2kg per person. Along with wood preservatives, sapstain control products are classed as "anti-microbials". Not only do anti-microbials consist of the lionsshare of the total pesticide use (86.5% -Table 1) but wood treatment chemicals account for over 90% of the total antimicrobial consumption.

**Table 1. Proportions of Pesticide Types Sold or Used in BC in 1999.**

| Pesticide Type | Quantity (kg) | Percent of Total |
|---|---|---|
| Antimicrobials | 7,010,944 | 86.5% |
| Insecticides | 394,630 | 4.9% |
| Herbicides | 335,057 | 4.1% |
| Fungicides | 269,363 | 3.3% |
| All others | 92,485 | 1.2% |

***Source: ENKON Environmental 2001.***

Of the top 10 pesticides, accounting for 92% of the total non-domestic pesticides sold or used in BC, six with highest amounts are used in either wood preservation or sapstain control. Creosote weights these data because it is regarded as being 100% active ingredient for the purposes of reporting.

**Table 2. The 10 Most Heavily Used Pesticides (out of 284 reported) in BC for 1999.**

| Active Ingredient | Quantity (kg) | Percent of Total |
|---|---|---|
| Creosote | 5,387,761 | 66.5 |
| CCA | 923,987 | 11.4 |
| DDAC | 310,051 | 3.8 |
| Pentachlorophenol | 261,645 | 3.2 |
| Mineral oil (insecticidal or adjuvant) | 201,642 | 2.5 |
| Borax | 151,783 | 1.8 |
| Glyphosate | 108,763 | 1.3 |
| Mancozeb | 44,682 | 0.6 |
| Sulphur | 36,393 | 0.4 |
| Mineral oil (herbicidal or plant growth regulator) | 35,260 | 0.4 |

***Source: ENKON Environmental 2001.***

## 3 Trends in BC Use of Sapstain Control Products

Table 3 gives the use or sales of wood preservatives, reportable pesticides and sapstain control products for 1991, 1995 and 1999 (ENKON Environmental 2001). Overall for 1989-1999 the trend has been for lower amounts of anti-stain products to be used. This contrasts with other pesticides, including wood preservatives, where amounts used have been increasing.

**Table 3: Summary of Changes in Pesticide Sales or Use in British Columbia 1991 to 1999**

| Survey Category | 1991 (kg) | 1995 (kg) | 1999 (kg) | Change 1991- 1999 (kg) |
|---|---|---|---|---|
| Wood Preservatives | 3,685,955 | 6,905,728 | 6,529,878 | +2,843,923 |
| Sapstain Control Chemicals | 838,319 | 754,314 | 479,251 | -359,067 |
| Reportable Pesticide Sales | 916,933 | 1,005,086 | 1,093,195 | +176,262 |

***Source: ENKON Environmental 2001***

Annual surveys by Environment Canada for the years up to 1999 enable us to see trends in the use of sapstain control products. Figure 1 shows the total amount of sapstain control additives reported to Environment Canada annually over the years 1991-1999. The gradual reduction in the number of mills using sapstain control products is apparent. In BC 100 sawmills used chemicals for sapstain control in 1986 compared with 50 in 1996 and probably less than 40 today (unpublished Environment Canada data). This reduction came about mainly because sawmills which only treated small amounts decommissioned older diptanks, while smaller sawmills closed or were consolidated, or became largely producers of kiln-dried wood. A similar number of Eastern Canadian (~ 35) sawmills currently use sapstain control products but use is seasonal or confined to certain species which most easily develop fungal problems (e.g. white and red pines) or for certain markets (e.g. heat-treated green wood bound for Europe).

Figure 1 also shows the decline in BC chemical use referred to in Table 3. However the total weight of active ingredient alone can be misleading as some chemicals must be used at higher levels than more effective actives. Until 1988 the highly effective chlorophenates were almost exclusively used in Canadian mills for sapstain control. Because of environmental persistence and contamination of the chlorophenates with dibenzo-*p*-dioxins, during the mid-1980s the industry voluntarily stopped using chlorophenates and switched to products with narrower toxicity ranges. Since that time a number of different products have been used as the chemical industry developed better products for this end use and as pesticide registrations were obtained. The trends in the use of six active ingredients for the period 1990-1999 are shown in Figure 2. TCMTB was the product most mills switched to from chlorophenates in the late 1980s. The switch in the early 90s from TCMTB, to products based on DDAC, particularly one also containing IPBC, is illustrated in Figure 2. A steep decline in sodium carbonate (a component of a borax-based product) in the early 90s is also seen. “Borax” covers both disodium octaborate tetrahydrate, used in combination with DDAC, and disodium tetraborate decahydrate which was used alone at one mill.

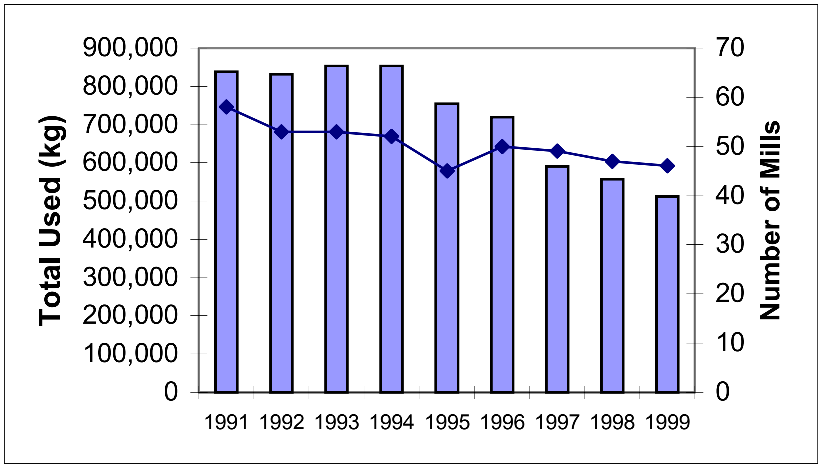


**Figure 1: Total Sapstain Control Actives Used or Sold in BC, (as reported to Environment Canada), and Number of Mills Treating with Antistain 1991-1999.**

Table 4 shows the quantities of sapstain control active ingredients used in BC in 1999, the latest year for which survey data are available. The total is estimated to be a 6-8% total underestimate because two sawmills would not provide data; one of these used a product based on azaconazole, an active ingredient not listed in the table.

**Table 4. Quantities of Sapstain Control Active Ingredients Used in BC in 1999.**

| Active Ingredient | Kg | Percent of Total |
|---|---|---|
| Didecyldimethyl ammonium chloride (DDAC) | 310,044 | 64.7 |
| Disodium octaborate tetrahydrate (DOT) | 115,254 | 24.0 |
| Disodium tetraborate decahydrate (DTD) | 26,250 | 5.5 |
| 3-iodo-2-propynyl butyl carbamate (IPBC) | 26,569 | 5.6 |
| 2-(thiocyanomethylthio)benzothiazole (TCMTB) | 1,134 | 0.2 |
| **Total** | **479,251** | **100.0** |

***Source: ENKON Environmental 2001***

The situation with chemical sapstain control products remains fairly static, if somewhat fluid, with mills switching between products only as newer, better, cheaper or more worker/environmentally benign products are offered. Since the data shown in Table 4 were compiled, some of the seven products registered since 1999 have been introduced into sawmills.

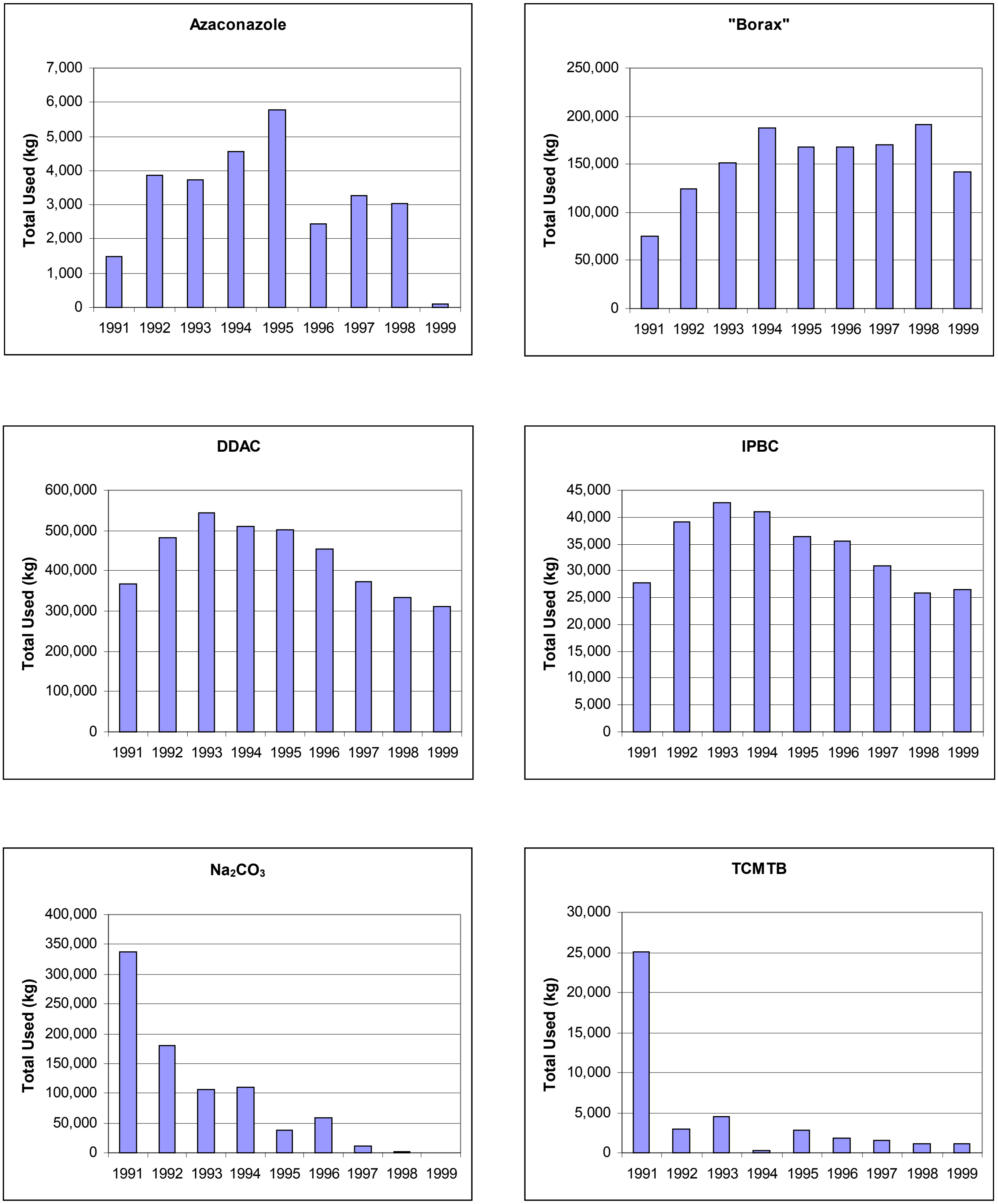


**Figure 2. Amounts of Individual Active Ingredients Sold or Used for Sapstain Control in BC 1991-1999 (Environment Canada Unpublished data).**

Table 5 lists currently registered products and their active ingredients. As of Sept 2002, 19 sapstain control products are listed as registered for Canadian use, however most of these have only temporary registration and are subject to filing of additional data with the Pest Management Regulatory Agency. About a third of these products use two active ingredients. The benefits of mixing two active ingredients have been described (Smith 1991; Byrne 1998). In the future more complex mixtures with several active ingredients, and relatively sophisticated formulations of these, will hopefully be developed for this end-use. Some traditional fungicides, which have been overlooked because of their narrow spectrum of activity, could be used in multi-component formulations. Some of these actives were strong against mold, a subject discussed later in this paper.

**Table 5. Sapstain control products registered as of October 2002**

| Regn # | Product Name | Year Registered | Active Ingredients[1] |
|---|---|---|---|
| 12143 | PQ-8 liquid fungicide concentrate | 1973 | Copper 8-quinolinolate (Cu-8) 5.4% |
| 14506 | Busan 30 liquid microbicide concentrate | 1980 | TCMTB 30% |
| 15314 | PQ-57 wood preservative | 1979 | Cu-8 5.0% |
| 17990 | Busan 1030 liquid microbicide | 1984 | TCMTB 30% |
| 18925 | Busan 30L liquid microbicide concentrate | 1985 | TCMTB 30% |
| 19729 | TCMTB 1030 liquid microbicide concentrate | 1990 | TCMTB 30% |
| 20718 | Ecobrite liquid sapstain & mold preventative (for lumber) | 1988 | Sodium Carbonate 20%<br>DOT 4% |
| 21753 | Kop-Coat NP-1 sapstain control chemical | 1990 | DDAC 64.5%<br>IPBC 7.6% |
| 21822 | Rodewod 200EC sapstain control chemical | 1991 | Azaconazole 0.2% |
| 21939 | Fe concentrate T2154 liquid microbicide | 1991 | DDAC 11.4%<br>DOT 16.8% |
| 25697 | Troy solvent based wood preservative | 1999 | IPBC 0.5% |
| 25769 | Boracol 10-2 BD-A | 1999 | DDAC 2.0%<br>DOT 9.8% |
| 26250 | Maquat SSC sapstain control | 2000 | DDAC 50% |
| 26500 | Mycostat-P sapstain control chemical | 2000 | Propiconazole (PCZ) 4.5% |
| 26583 | Prosan 24 sapstain control chemical | 2002 | PCZ 22.9% |
| 26584 | Wocosen 250 EC sapstain control | 2001 | PCZ 22.9% |
| 26933 | F-7 concentrate T 2157 antimicrobial agent | 2001 | DDAC 32.1%<br>DOT 45.0% |
| 26985 | NP-2 sapstain control chemical | 2001 | DDAC 70.48%<br>IPBC 4.76% |
| 27136 | Mycostat P20 wood preservative treatment | 2002 | PCZ 20% |

***Source: Pest Management Regulatory Agency Registered Product Database, September 2002.***

[1] For active ingredient abbreviation explanations see Table 4.

# 4 Past Milestones in Canadian Sapstain Control

Canada is proud to have been a global leader in the use of sapstain control products and has a number of firsts to its name, some of which are summarised below.

## 4.1 Developing a "code of good practice"

Concerns about possible human health problems and environmental contamination were addressed in a document titled "Chlorophenate Wood Protection—Recommendations for Design and Operation" produced in 1983 (superseded by Konasewich and St. Quintin 1994). The Council of Forest Industries of BC played a major role in implementing this code by giving seminars and monitoring industrial conformity. The document has received wide distribution in other Canadian and international jurisdictions and has been regarded as a model code.

## 4.2 Pioneering spray systems

The suppliers of sapstain control products in BC were instrumental in developing spray systems for applying the chemicals. Spray systems have advantages over diptanks in that the amount of chemical applied can be more controlled and there is less drip from the treated wood. Generally, less contamination of the environment results from substituting sprays for diptanks. Spray systems have since been adopted in other regions and countries.

At Forintek's western laboratory, research work has improved knowledge about the fundamentals of in-line hydraulic spraying. Forintek and Forest Research New Zealand have also looked at more advanced technologies such as electrostatic application and there is a considerable body of knowledge on how these perform (Groves *et al*. 1994). However, it may well be some time before this type of technology is adopted.

Some diptanks remain, particularly in eastern Canada where treatment is required only for packages to be exported or for certain loads prior to kiln drying when there is backup at the kilns or when the stain hazard is particularly high. In BC there are approximately 10 diptanks at export terminals or sawmills. For several years new tanks have had to comply with strict provincial requirements and guidelines to prevent escape of chemical into the environment. Such requirements are for impervious containment areas or double walled tanks and also for a roofed primary drip area.

## 4.3 Developing treatment retention "standards", analytical methods, retention tests and quality assurance

As in other locations appropriate levels of use of the products for use on Canadian woods have been determined by efficacy testing in field tests and by industrial experience. Canada was the first country to change from a liquid treatment concentration to a retention based on the amount deposited on the wood firstly for chlorophenates. In the early 1980s the Western Forest Products Laboratory (predecessor of Forintek Canada Corp. western division) and Council of Forest Industries of BC was the first to test application levels of sapstain control chemicals on wood. Chemical analytical methods for subsequent generations of active ingredients were developed at Forintek and the concept of surface deposition and retentions has since been adopted by other countries. In 1989 an antisapstain quality control program was introduced wherein mills regularly sent samples to Forintek to verify that application was being done effectively.

## 4.4 Controlling environmental runoff

In the 1980s there was increased realisation that data on environmental impact of sapstain control chemicals was inadequate. The toxicity of the non-chlorophenate chemicals to fish and their food sources (aquatic invertebrates) was particularly important because most of the BC sawmills using sapstain control products are located on fish-bearing waterways. Detection of low levels of chlorophenates from earlier times in sediments of the Fraser River, which flows by Vancouver, generated further research by government regulators. The fish toxicity of the active ingredients being used for sapstain control resulted in a regulation appended to the BC Waste Management Act. This regulation specifies the maximum level of sapstain control chemicals permitted in sawmill yard discharge. However the BC Ministry of Environment has not updated these regulations for newly registered active ingredients. This is possibly partly because sawmills are generally able to stay within the maximum allowable runoff and yet the runoff remains toxic to fish i.e. there is no correlation between concentration of pesticide chemical and fish toxicity (Konasewich 1997). In fact it has been shown that zinc, mainly from galvanised roofing on buildings, paradoxically, being proposed by regulatory agencies for protecting chemically treated lumber from leaching chemicals, is a major source of fish toxicity in stormwater runoff (Bailey *et al.* 1999). The latter study was proposed in a report to the BC Stakeholder Forum on Sapstain Control (Brooks *et al.* 1996).

## 4.5 Consulting stakeholders

In 1989 the BC Stakeholder Forum on Sapstain Control was formed to discuss issues of mutual interest to the public (represented by environmental advocates), government regulators, workers' organisations, industrial users, and suppliers of sapstain control products. This forum has deliberated a number of important issues, such as proposing temporary registration to more environmentally benign control products, worker exposure studies, and issues around the fish toxicity of stormwater runoff from sawmill yards. The discussions have enabled all views to be aired and have resulted in consensus and near-consensus recommendations such as the one to cancel the federal registration of chlorophenates for sapstain control uses in 1990. The recommendations from this committee that new products based on triazoles, such as azaconazole, and on DDAC and IPBC were also acted upon when these products were given temporary registration in 1990.

## 4.6 Determining the health effects of historic chlorophenate exposure

The large BC sawmill workforce and the extensive medical records available has enabled a team of UBC health care professionals and epidemiologists to study the effects of exposure to chlorophenates, later discovered to be dioxin contaminated, on the health of workers and their children. A study of 26,487 sawmill workers found no relationship between cumulative exposure to chlorophenate fungicides and fertility (Heacock *et al.* 1997). However a borderline positive link between chlorophenate exposure and the incidence of non-Hodgkin's lymphoma was also found (Hertzman *et al.* 1994). High exposures of tetrachlorophenol, pentachlorophenol and dioxins have demonstrated fetotoxicity in laboratory tests and some chemicals can have effects on offspring through the sperm. While most characteristics of offspring of male sawmill workers were not affected by the exposure there was increased risk of some birth defects but there was no linkage between childhood cancer and parental occupational exposure to chlorophenates (Heacock *et al.* 2000). These studies are statistically very powerful because of the large sample size.

## 4.7 Assessing the risk of worker exposure to sapstain control chemicals

About 1990 it was identified that a data gap in the risk assessment of sawmill workers to sapstain control chemicals was the degree of exposure of workers to the chemicals. Discussions ensued about how best to measure this because there was no standard method. In 1995 a worker exposure study, funded by a consortium of chemical suppliers was initiated. Attempts to use fluorescent tracers to denote contact with the chemical proved to be unreliable indicators of dermal exposure. The protocol was revised to measure actual exposure to DDAC, the primary active ingredient used at that time, collected on body patches and clothing. The main study was done at 11 BC sawmills in 1998/1999 with 86 workers. Results confirmed the low potential for airborne exposure to the active. Of the four strata of workers tested the highest dermal exposure occurred in maintenance workers followed by workers who handled the wet treated wood. The importance of wearing personal protective clothing is therefore highlighted for these workers. The study concluded that the overall levels of exposure are not unexpectedly high, nor are they suggestive of any unreasonable risk. PMRA's review of the study was completed in 2001; the study was found to be well-conducted and good quality for risk assessment purposes (Goodwine 2002). Risk assessment of DDAC and other sapstain control chemicals, using the worker exposure data is ongoing at PMRA.

### 4.8 Biological control of sapstain

Forintek has taken a leading role in researching biological control of sapstain over the last 15 years. Much of the research has concentrated on the use of *Gliocladium* sp. (Seifert 1989). A new concept, using pasteurisation prior to inoculation with *Gliocladium*, was introduced, thereby reducing the level of fungi that would normally compete (McAfee and Gignac 1997). Control of stain and mould fungi has been demonstrated in the laboratory with this combination.

In a field test of Cartapip™, an albino strain of a staining fungus *Ophiostoma piliferum* (Fr.:Fr.) Syd. & P.Syd, the fungus successfully protected heat-treated Canadian softwood lumber but in a second test the results could not be repeated (Byrne 1998). The challenge with biological control is to define the conditions under which it can and cannot protect wood and to use the information to develop consistent industrial performance. This may be a particularly onerous task for pre-infected lumber but for protection of freshly cut logs the challenge should be significantly less (Behrendt *et al*. 1995). Forintek has done field tests on logs with promising results (Uzunovic *et al*. 2002). An integrated biological/chemical technique, involving *G. roseum* combined with an alkali, also showed promise for protection of green lumber in recent laboratory and field tests (Yang 1997; Yang and Rossignol 1999). Forintek is hoping to proceed with commercialization of this technology (Yang and Gignac, 2002).

## 5 Emerging Issues

It is clear that the protection of green lumber from mould stain and decay is a mature and declining business in Canada. However a number of newer issues are emerging that require methods of controlling fungi on non-traditional (i.e. not green lumber) products and this offers opportunities in pest management on forest products.

## 5.1 Preventing log infection

The increasing need to maximise value from increasingly expensive logs is driving a need to prevent logs from bluestaining. Since this subject is covered by a parallel paper in this meeting (Uzunovic *et al*. 2002) I will merely mention this here.

## 5.2 Protection of dried lumber and wood products from mould

It is well known that wood, once dried and kept dry, is no longer vulnerable to fungal attack. Historically, kiln drying was introduced in Canada mainly in order to reduce the weight of wood sent by railcar. However, factors such as increased market demand for dried lumber, have made inroads into traditional green markets and most building is now done with kiln-dried lumber. An emerging issue is the growth of mould on lumber, particularly on dried lumber. There has been a lot of media publicity about mould recently, particularly in the USA, our major customer (Waldman *et al*. 2002).

The forest products industry is under pressure to supply products which are free of visible mould. Unfortunately once the product has left the sawmill or factory it can be subjected to adverse moisture conditions in transit and storage. Based on the small amount of products upon which claims or returns are made the amount of "problem" pieces of wood products is believed to be very small.

Dried lumber is commonly stored outdoors while it is awaiting shipment, often in west coast shipping terminals where they may be exposed to heavy rainfall. Storage is largely made possible by plastic or plastic/paper wrappers which protect the dried wood from the rain. At the same time these wrappers can cause "sweating" and condensation to occur in the pack. Sometimes this results in mould growth.

There is increasing interest in applying biocides to dried lumber and also to panel products to limit the development of mould. While the products currently registered for sapstain control of green lumber are expected to control mould, they are often weak against these organisms (Byrne 1997b). There is therefore an opportunity to develop new products specifically to prevent mould growth on dried wood in transit, storage and, if there is a long-term residual effect, when the wood is used in buildings, if the building subsequently develops water problems.

In Canada, wax-based water repellents were commonly used on some dried lumber (Byrne and Smith 1987). Although the formulations visibly cause liquid water to bead on the wood surface, data on their efficacy in preventing the uptake of rain by dried wood are limited. Unpublished Forintek data indicate that commercial water repellents offer only a small degree of protection to dried lumber compared with intact wrappers. These water repellents do not prevent mould growth and an in-can biocide has to be added to wax emulsions to prevent mould growing on the liquid.

A related issue is that log homes often develop mould or stain problems during seasoning or when they are shipped offshore in containers. While the currently registered sapstain control products are sometimes used by log home manufacturers the labels do not strictly cover this end use. There is therefore a need to develop effective treatments for log homes.

### 5.3 Phytosanitary issues

The Australian Quarantine Inspection Service has been closely examining imported forest products at the incoming port for signs of forest insect pests or potential tree pathogens. BC ships a significant amount of green Douglas fir and western redcedar to Australia. The incidence of infestation of the wood with insect pests is relatively low but packages of wood are vulnerable to attracting “hitch hiking insects” which land on the packages and crawl between boards. To overcome this problem the coastal industry is doing trials of insecticide additives to sapstain control products in the spray system. A permethrin inscticide was recently registered specifically for this end-use.

For the last decade green wood being shipped to Europe has had to be heat treated to 56°C for 30 minutes in order to kill the pinewood nematode and its vectoring insects (Task Force on Pasteurization of Softwood Lumber, 1991; Morris and Cook 2002). This wood is also treated with sapstain control products to prevent unsightly stain and mould problems. The 56°C /30 minutes heat treatment has also been adapted for wood packaging material. There has recently been international agreement to require that wood destined for packaging is heat treated or chemically treated to ensure pests of concern are dead. Canada, the USA and Mexico are committed to implementing this regulation in June 2003. While preservative treatment is permitted in the regulation if it can be shown that the preservative is effective, there is little data on the efficacy of chemical treatments against insects and fungi on packaging materials.

## 6 Conclusions

- Sapstain control product use in Canada is declining as markets for green lumber are drying up.

- Currently about 70 sawmills are using sapstain control products across Canada though the bulk of the market is in about 35 mills in BC.

- Although 20 sapstain control products are registered only a few are being used industrially with mills changing chemicals for cost, efficacy, environmental or other factors.

- Canada (BC) has been a world leader in developing a "code of good practice" pioneering spray systems, development of treatment retention "standards", pioneering analytical methods, retention tests and quality assurance checks, controlling environmental runoff, consulting stakeholders, determining the health effects of historic chlorophenate exposure, assessing the risk of worker exposure to sapstain control chemicals and biological control of sapstain.

- Preventing log infection, protection of dried lumber and wood products from mould and phytosanitary issues such as wood packaging material are future opportunities for development of topical chemical treatments.

## 7 Acknowledgements

Annette Smith, of ENKON Environmental Ltd., kindly supplied Figure 2. Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), and the provinces of British Columbia, Alberta, Sakatchewan, Quebec, Nova Scotia, New Brunswick and Newfoundland and Labrador for their guidance and financial support of our research.

## 8 Literature cited

1. Anderson, R.C., Hansen, E., Morrell, J. 2002. Use of antistain chemical treatments by the western US softwood lumber industry, 1999. For. Prod. J 52(4). 69-71.

2. Bailey, H.C., Elphick, J.R., Potter, A., Chao, E., Konasewich, D. and Zak, J.B. 1999. Causes of toxicity in stormwater runoff from sawmills. Environmental Toxicology and Chemistry: 18 (7). 1485–1491.

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

4. Brooks, K.M., Konasewich, D.E., Bailey, H.C., Szenasy, E.B., and Bruderman, G.E. 1996. Antisapstain chemical technical review. Report to B.C. Stakeholder Forum on Sapstain Control. Envirochem Special Projects, Vancouver BC.

5. Byrne, A. 1997a. Sapstain control in Canada – Can New Zealand learn anything from the frozen north? *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. 7-15.

6. Byrne, A. 1997b. Mould problems in sawmills—the fungi and their management. Unpublished report. Forintek Canada Corp. Vancouver BC. 9 p.

7. Byrne, A. 1998. Chemical control of biological stain: past, present and future. *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. 63-69.

8. Byrne, A., and Smith, R.S. 1987. Protection of lumber in Canada: Current practices, future trends. Presentation International Union of Forest Research Organizations. Session on Storage of Softwoods. Honey Harbour ON. Forintek Canada Corp. Vancouver BC. 15 p.

9. Eades, H.W. 1956. Sap-stain and mould prevention on British Columbia softwoods. Dept. Northern Affairs and Natural Resources. Forest Products Lab. Div., Bulletin 116. Vancouver BC.

10. ENKON Environmental Ltd. 2001. Survey of pesticide use in British Columbia: 1999. Report to Environment Canada, North Vancouver BC.

11. Environment Canada. 1991-98. Annual surveys of anti-sapstain use (unpublished). North Vancouver BC.

12. Goodwine, W. 2002. Personal communication to author.

13. Groves, C.K., Johnson, E.L. and Smith, R.S. 1994. Development of an electrodyn spray system for sawmill operation. Pesticide formulation and application systems: 14th volume. ASTM STP 1234. American Society for Testing and Materials. Philadelphia. 49-62.

14. Heacock H., Hogg, R., Marion, S.A., Hershler, R.. Teschke, K., Dimich-Ward, H., Demers, P., Kelly, S., Ostry, A., and Herztman, C. 1997. Fertility among a cohort of male sawmill workers exposed to chlorophenate fungicides. Epidemiology. 9(1). 56-60.

15. Heacock H., Herztman, Demers, P.A., Gallagher, R., Hogg, R.S., Teschke, K., Hershler, R., Bajdik, C.D., Dimich-Ward, H., Marion, S.A., Ostry, A., and Kelly, S. 2000. Childhood cancer in the offspring of male sawmill workers occupationally ex[osed to chlorophenate fungicides. Environmental Health Perspectives. 108(6). 499-503.

16. Hertzman, C., Teschke, K., Ostry, A., Hershler, R., Dimich-Ward, H., Kelly, S., Spinelli, J., Gallagher, R., and McBride, M. 1994. Cohort study of sawmill

workers exposed to chlorophenates. Final report. Department of Health Care and Epidemiology, University of BC, Vancouver BC. 34 p.

17. Konasewich, D.E. 1997. Stormwater environmental issues at wood preservation/wood protection facilities. *in* Proc. Can. Wood Preservation Assn. 18th annual meeting. CWPA, Vancouver BC. 83–92.

18. Konasewich, D.E. and St. Quintin O.N.C. 1994. Antisapstain wood protection: recommendations for design and operation. Envirochem Special Projects Inc. prepared for Environment Canada, Ottawa ON/BC Environment Victoria BC. approx 200 p.

19. 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*. Material und Organismen 31(1): 45–61.

20. Morris, P.I., and Cook, J.A. 2002. Thermal death time for the pinewood nematode in Canadian softwoods. Forintek Canada Corp. manuscript in preparation.

21. Roff, J.W., and Cserjesi, A.J. 1965. Chemical preventives used against mould and sapstain in unseasoned lumber. B.C. Lumberman 49(5): 90–98.

22. Roff, J.W., Cserjesi, A.J., and Swann, G.W. 1980. Prevention of sap stain and mold in packaged lumber. Tech. Rept. No. 14R. Western Forest Products Lab., Forintek Canada Corp., Vancouver BC. 43 p.

23. Scheffer, T.C. 1958. Control of decay and sap stain in logs and green lumber. USDA For. Serv. No. 2107. 13 p.

24. Seifert, K.A. 1989. Biological control and wood protection. *in* Proc. Can. Wood Preservation Assn. 9th annual meeting. CWPA, Vancouver BC. 124–137.

25. Smith, R.S. 1991. Lumber protection today. *in* Lumber Protection in the 90s. Special publication No. SP 33 Forintek Canada Corp. 3-13.

26. Task Force on Pasteurization of Softwood Lumber. 1991. The use of heat treatment in the eradication of the pinewood nematode and its vectors in softwood lumber. Forintek Canada Corp. Vancouver BC. 72p.

27. Uzunovic, A., Byrne, A. and Minchin, D. 2002. Alternatives to chemicals for control of bluestain in logs. *in* Proc. Can. Wood Preservation Assn. 22nd annual meeting. CWPA, Vancouver BC (in press).

28. Waldman, J. M., Macher, J. M., McNeel, S., Wersinger, E. and Gilliss D. 2002. How public agencies address indoor mold hazards in California. *in* Levin, H. (Ed). "Indoor Air 2002". Proc. 9th International Conference on Indoor Air Quality and Climate. International Academy of Indoor Air Sciences (CD ROM)..

29. Yang, D.Q. and Rossignol, L. 1999. Integrated control of moulds and sapstain. Canadian Forest Service Report No. 30. Forintek Canada Corp., Sainte-Foy, Canada. 63 p.

30. Yang, D.Q. and Gignac, M. 2002. Technical and economical feasibility of a new bioprotectant. Forintek Canada Corp. Report, Sainte-Foy, Canada. 30 p.

31. Yang, D.Q. 1997. New approach for potential integrated control of wood sapstain. *In* Proc. "Biology and Prevention of Sapstain", 27 May 1997, Whistler BC. Forest Products Society, Madison WI. 45-51.