SAPSTAIN DEVELOPMENT ON JACK PINE LOGS IN EASTERN CANADA

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ABSTRACT

During 1998–1999, a study was initiated to investigate the influence of seasons, log types, and storage time on the sapstain development of jack pine logs at three sites in Eastern Canada. Jack pine trees (*Pinus banksiana*) were harvested into full-length and cut-to-length logs in spring and in autumn. Sapstain development was examined in these logs at intervals of 2 to 4 weeks after felling. The mean stain coverage and mean maximal radial penetration of stain in wood were measured from the discs of the sampled logs. The spring trial showed that sapstain did not develop significantly on jack pine logs within 4 weeks after trees were felled; however, the severity of stain increased proportionally with storage time. The full-length logs were more stained than the cut-to-length logs in the spring felling. All logs were seriously stained after the 3 months of summer storage. The autumn trial showed that logs felled after September were stored in the sawmills over winter without significant stain, but stain development was rapid after April of the following year. Debarking logs did not reduce stain development on wood. In fact, the growth of stain was more rapid on debarked logs than on logs with the bark. The main fungus isolated from stained wood was *Ceratocystis coerulescens*. Bark beetle attack was found in logs within 4 weeks of the spring harvest. The species of bark beetle was *Ips pini*. After 3 months of summer storage, decay started to develop in these logs. The main causal species was *Schizophyllum commune*.

Keywords: Sapstain, jack pine, log storage, fungal stain, bark damage.

INTRODUCTION

In most Canadian sawmills, logs are stored in a log yard from 1 to 6 months (Clark 1992). This process ensures a continuous supply of logs for the sawmill operation when logging is interrupted during a period of the year. Logs left lying on the ground during warm weather from late spring to mid-fall are vulnerable to attack by many microorganisms, especially by sapstaining fungi (Scheffer 1969; Linares-Hernandez and Wengert 1997).

Wood sapstain is caused by several groups of fungi that penetrate deeply into wood with dark pigmented hyphae (Zabel and Morrell 1992). However, to gain entry through the bark into the xylem, sapstaining fungi require an opening or an insect vector. Intact bark gives good protection against fungal damage. However, from the moment the trees are felled, the cross faces as well as bark damaged from harvesting offer opportunities of colonization by these fungi (Uzunovic et al. 1997). Serious stain may appear in a few weeks to a few months depending on wood species, local climate, and storage conditions (Uzunovic et al. 1996).

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Current methods for sapstain control are targeted mainly at the wood, after the logs are converted to lumber, such as kiln-drying or anti-sapstain chemical treatment (Hansen and Morrell 1997; Wengert and Denig 1995). When logs with sapstain are sawn, the defect is found in lumber, and the fungi continue to spread in wood until the boards are completely dried. In the warm season, the common practice in log protection is based on a principle of processing logs as quickly as possible after they arrive at the sawmill (Linares-Hernandez and Wengert 1997). However, little is known about the maximal storage period of different wood species in various Canadian climates before significant wood value losses occur. In most cases, the infection is already seriously established when logs are sawn. A sawmill survey was conducted in 1997 in which it was found that jack pine is very susceptible to sapstain, and that most stain found was in boards that came from infected logs (Uzunovic et al. 1999; Yang et al. 1999). Since jack pine has potential to be used to a greater extent in value-added wood products, reducing sapstain in this species could have a significant beneficial economic impact. This study was designed, firstly, to investigate the maximal summer storage time for jack pine logs in sawmill yards before significant reduction of wood value; secondly, to examine the influence of felling seasons on sapstain development, mainly spring and autumn; and thirdly, to evaluate the effect of logging method on the severity of sapstain, specifically full-length (whole tree length) versus cut-to-length (5-m-long) logs.

MATERIALS AND METHODS

Experimental setup

In the spring of 1998, two sawmills in Eastern Canada were selected as the sampling sites. One site was located in Northern Quebec, while the other was approximately 500 km south on the north shore of the St-Lawrence River. Jack pine trees (*Pinus banksiana*) approximately 50–85 years old, with a breast diameter of 15–30 cm, were felled in April at site 1 and in May at site 2 (Table 1). One group of trees was cut into whole tree length logs (full-length) and another group was cut into lengths of approximately 5 m (cut-to-length) using a multiple usage harvesting machine. Each group contained 16 logs. These long and short logs were left in the forest for 1 to 3 weeks before being transported to the two sawmills where they were stored side by side in remote parts of the lumberyards to prevent the disturbance from sawmill operations. The inspections were conducted at approximately 4, 6, 8, and 12 weeks after felling, and 4 logs from each group were examined during each inspection.

The second trial was set up at the same sawmills as the first trial, but trees were cut in the autumn of that year. Jack pine trees of similar sizes and diameters as in the first trial were felled in September at one site, and in October at the other site. Two groups of 20 logs each were prepared and stored in sawmills as previously described. At site 1, the autumn trial inspections were done in September and in October after 4 and 8 weeks of storage, respectively. At site 2, one fall inspection was done in October. In November, the average temperature dropped below 0°C at both sampling locations. The inspections were suspended until the following April, when the average temperatures reached above 5°C at both locations. The inspections resumed at 4-week intervals until July.

In the summer of 1999, a test on debarked logs was set up at a third sawmill. This sawmill was located approximately 160 km from Quebec City. Trees 55 to 80 years old were felled in June (Table 1). The logs were left in the forest for 3 weeks before being transported to their destination. These logs were debarked immediately after arriving at the sawmill. The inspection was conducted at 0, 2, 5, 9, and 13 weeks after debarking.

Sapstain evaluation and data collection

The wood surface moisture content, the stain coverage, and the maximal radial pene-

TABLE 1. *Jack pine log sampling locations and dates.*

Location (trial)	Log type	Tree age (yrs)	Bark damage (%)	Felling date	Storage date	Inspection	Sampling date
Site 1 (spring trial)	Full-length	50–75	5–10	23/4/98	29/4/98	1	20/5/98
						2	11/6/98
						3	7/7/98
						4	28/7/98
	Cut-to-length	50–75	5–10	23/4/98	29/4/98	1	20/5/98
						2	11/6/98
						3	7/7/98
						4	28/7/98
(fall trial)	Full-length	60–80	30–40	3/9/98	15/9/98	1	30/9/98
						2	28/10/98
						3	22/4/99
						4	1/6/99
						5	30/6/99
	Cut-to-length	45–70	20–30	3/9/98	15/9/98	1	30/9/98
						2	28/10/98
						3	22/4/99
						4	1/6/99
						5	30/6/99
Site 2 (spring trial)	Full-length	65–75	10–20	25/5/98	17/6/98	1	25/6/98
						2	8/7/98
						3	29/7/98
						4	18/8/98
	Cut-to-length	60–85	40–60	25/5/98	17/6/98	1	25/6/98
						2	8/7/98
						3	29/7/98
						4	18/8/98
(fall trial)	Full-length	65–110	15–20	25/9/98	2/10/98	1	29/10/98
						2	23/4/99
						3	27/5/99
						4	22/6/99
						5	21/7/99
	Cut-to-length	65–110	25–30	25/9/88	2/10/98	1	29/10/98
						2	23/4/99
						3	27/5/99
						4	22/6/99
						5	21/7/99
Site 3	Debarked (cut-to-length)	55–80	95–100	1/6/99	21/6/99 (debarked)	1	22/6/99
						2	6/7/99
						3	21/7/99
						4	19/8/99
						5	23/9/99

tration of staining fungi were measured in these sampling logs. In each inspection, four logs from each harvesting group were examined at random. Logs were sectioned destructively. Six to ten, 3-cm-thick, discs were taken along each log, with two discs cut from sections at 20 cm away from each end of the log, and the other discs sawn at approximately 1-m intervals along the remainder of the log. Each wood disc was placed in a separate plastic bag, properly labeled, and brought back to the laboratory within 24 h. After arriving, these wood discs were immediately placed in a cold room set at −30°C until sapstain evaluation.

Five wood blocks, of approximately 20-× 20-× 15-mm dimensions, were taken from sections with bark and sections without bark on each log. Each block was immediately labeled and placed in a sealed plastic bag. These wood blocks were brought back to the laboratory for the determination of the surface moisture content (SMC) of logs at each inspection time.

In the laboratory, the total wood surface area and stained area of each disc were traced with transparent grid paper of 1-mm^2 units. Units were counted, and the percentage of stained area on each disc was calculated. Then, discs were debarked and examined. The stain development that occurred from different areas was noted, such as areas without bark, areas of intact bark without beetle infestation, and areas of intact bark with beetle infestation. The average value of 6 to 10 discs from each log described above was used to estimate the degree of stain development in each log. The mean stain coverage obtained from 4 replicate logs of each harvesting group provided a measure of the severity of stain development for each inspection time and location. The maximal radial penetration of stain in wood was determined on each disc by measuring a straight distance from the wood just under bark to the deepest point of stain reached in the inner wood. The total mean maximal radial penetration of stain in logs was calculated by averaging 24 (cut-to-length logs) to 40 (full-length logs) measurements of the maximal radial penetration taken from 4 replicate logs in each inspection time. The mean maximal radial penetration of stain was also determined from different log areas, such as areas without bark, areas of intact bark, and areas of intact bark with beetle infestation, in a similar way as the total mean maximal radial penetration described above.

Wood blocks used for SMC measurements were promptly weighted to determine the wet weight of each sample. The wood blocks were then placed in a forced draft oven set at 103°C until they had reached a constant moisture equilibrium and were weighed to the nearest 0.01 g. The wood surface moisture content of each log was determined by averaging moisture contents of these samples.

After 4 weeks of storage, the logs were examined for bark beetle colonization. The young adult beetles were captured, and the main species was identified. Sapstain areas resulting from beetle infestation were measured on logs at every inspection.

Eight weeks after felling, wood samples with bark beetle infestation, sections of bark beetle bodies, and stained sapwood samples were aseptically removed from discs and were transferred to Petri plates of 2% malt extract agar (20 g malt extract and 20 g Difco agar in 1 liter distilled water). The plates were incubated at 25°C for 4 to 14 days. When fungal colonies formed in agar plates, identification of the major fungi were performed directly on the isolation plates or from purified cultures, based on their colony morphologies and microscopic examinations (Ainsworth et al. 1973).

The weather condition data including temperature, relative humidity (RH), and total precipitation were monitored throughout the test year at the three test sites using data loggers. The average temperature and percent RH were obtained by averaging readings of every hour over the entire testing period. Some data were also provided by Environment Canada.

RESULTS

Environmental conditions at test sites

The three test locations were more than 800 km apart. For these sites, the growth season starts in April and ends in October. In 1998, the average monthly temperatures throughout the year were approximately 1°C lower at site 1 than at site 2 (Table 2). The average temperature in July, the warmest month, was 17.7°C at site 1 and 18.1°C at site 2. The average monthly relative humidity ranged from 61 to 86% at site 1, and from 65 to 75% at site 2. The average minimal and maximal RH recorded were 35 and 97% at site 1, and 36 and 96% at site 2. The total monthly precipitation ranged from 33.5 to 173.5 mm at site 1, and 36 to 100 mm at site 2. The highest

TABLE 2. *Monthly weather conditions at study sites in 1998.*[a]

	Site 1			Site 2		
Month	Temp. (°C)	RH (%)	Precip. (mm)	Temp. (°C)	RH (%)	Precip. (mm)
Apr.	4.2 (10.9, −2.5)[b]	61 (85, 37)	33.5	4.8 (11.3, −1.8)	65 (90, 39)	36.0
May	12.5 (20.7, 4.2)	62 (88, 35)	47.0	13.7 (21.1, 6.2)	68 (95, 40)	/[c]
Jun.	15.9 (21.1, 10.7)	76 (96, 56)	173.5	16.9 (21.7, 12.0)	71 (96, 46)	39.0
Jul.	17.7 (23.7, 11.6)	70 (94, 46)	80.5	18.1 (24.1, 12.0)	69 (96, 41)	100.0
Aug.	16.2 (22.5, 9.8)	75 (96, 53)	81.0	17.4 (24.3, 10.5)	66 (96, 36)	/
Sep.	11.2 (16.5, 5.9)	79 (97, 60)	85.0	12.3 (17.9, 6.7)	70 (96, 43)	67.0
Oct.	5.1 (9.5, 0.6)	79 (96, 62)	34.5	6.0 (10.3, 1.6)	72 (95, 49)	/
Nov.	−2.3 (0.7, −5.3)	86 (95, 77)	114.5	−1.4 (1.5, −4.3)	75 (93, 57)	/

[a] Data were provided by Environment Canada.
[b] Values are means of each month; average monthly maxima and minima are in parentheses.
[c] / = No data available.

precipitation was recorded in June at site 1 and in July at site 2.

In 1999, from April to July, the average temperature was 14.9°C at site 1 and 17.3°C at site 2 (Table 3). The minimal and maximal temperatures were −5.3°C and 33.6°C, respectively at site 1, and −4.8°C and 36.1°C, respectively at site 2. The average relative humidity was similar at these two tests sites, 65.5% and 65%. The recorded maximal RH reached 100% at site 1 and 99.7% at site 2. At site 3, the test was conducted from June to September. During this period of time, the average temperature was 18.2°C, and the minimum and maximum were 0.7°C and 34.9°C, respectively. The relative humidity was higher at site 3 than at the other two sites. At this site, the average RH was 82.2%, and the minimum and maximum were 23% and 100%, respectively.

Wood surface moisture content of logs

The surface moisture contents (SMC) of spring trial logs are shown in Fig. 1. In general, the SMC of logs decreased with storage time; however, the humidity in wood increased after a period of rain or of increased air humidity. For example, at site 1, the log SMCs detected at the fourth inspection were higher than at the third inspection. The SMC of wood with bark was higher than without bark. At site 1, the SMCs in full-length logs were similar to that of cut-to-length logs, but at site 2, the SMCs in cut-to-length logs were lower than those of full-length logs. At site 2, the SMC of wood without bark in cut-to-length logs had dropped to approximately 20% by the first inspection, 4 weeks after being cut, while it took another month for cut-to-length logs with bark to decrease to a similar level of SMC.

Compared to spring-cut logs, those felled in autumn had higher moisture contents (Fig. 2). The SMCs of logs in the fall trial at site 1 decreased also with storage time before the winter; however, they increased after the winter because of the impregnation of water from melting snow. For example, the SMC of wood

TABLE 3. *Average temperature and relative humidity during log storage in 1999.*[a]

Location	Period	Factor	Minimum	Average	Maximum
Site 1	22/4–30/6/99	Temperature °C	−5.3	14.9	33.6
		RH %	10.2	65.5	100.0
Site 2	23/4–21/7/99	Temperature °C	−4.8	17.3	36.1
		RH %	9.5	65.0	99.7
Site 3	22/6–23/9/99	Temperature °C	0.7	18.2	34.9
		RH %	23.0	82.2	100.0

[a] Data were detected by data loggers.

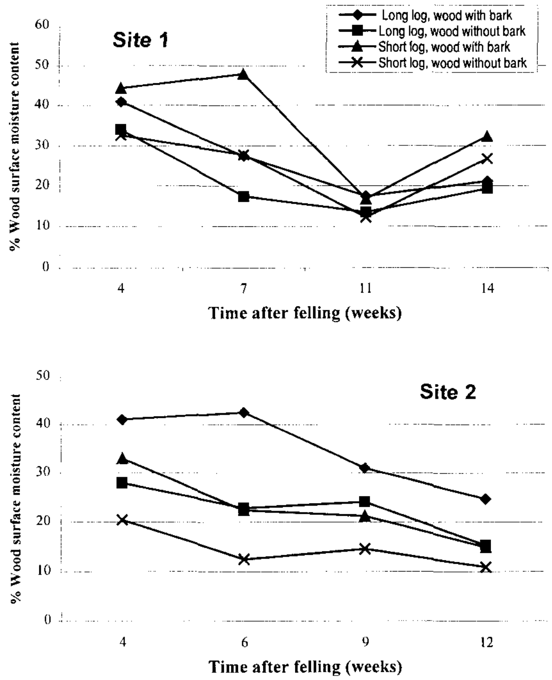

FIG. 1. Wood surface moisture content of logs felled in spring.

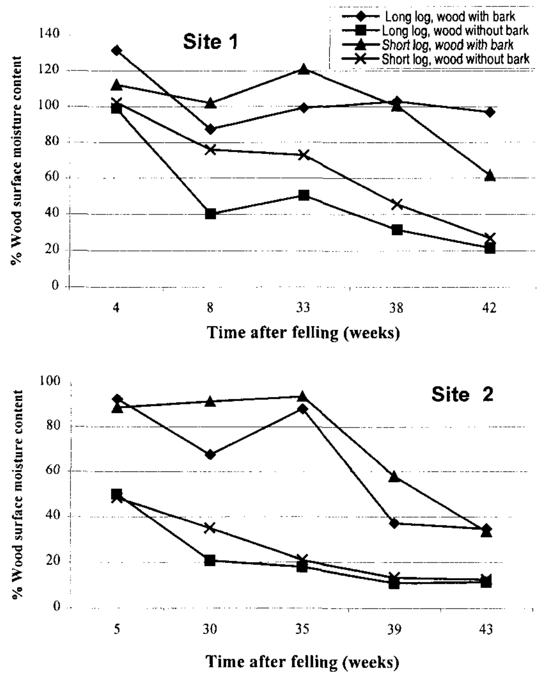

FIG. 2. Wood surface moisture content of logs felled in autumn.

with bark in cut-to-length logs at site 1, which was detected as 112% at the first inspection, had dropped to 102% by the second inspection. On the third inspection, immediately following winter, the SMC of logs increased to 121%. A large difference of SMCs was recorded between exposed wood and wood covered with bark within the same log. For example, on the third inspection, the average SMC of full-length logs at site 2 was determined as 88% for bark-covered wood, and 18% for wood free of bark.

The SMC of wood dropped rapidly on debarked logs (Fig. 3). It decreased from 63% to 27% in 2 weeks after debarking. For these logs, the SMC of wood dropped continuously until rain brought it back up, as the data showed on the fifth inspection at site 3.

Stain development in spring-cut logs

The results of the spring trial showed that sapstaining fungi did not cause significant stain on jack pine logs 4 weeks after trees were cut. However, the severity of sapstain increased proportionally with storage time (Fig. 4). The full-length logs were slightly more stained at site 2 than those at site 1, whereas the opposite was true for cut-to-length logs. At both sites, full-length logs were more stained than cut-to-length logs. All logs were seriously stained after 12–14 weeks of storage. At site 1, 15.6% of wood was stained in full-length logs compared with 9.9% in cut-to-length

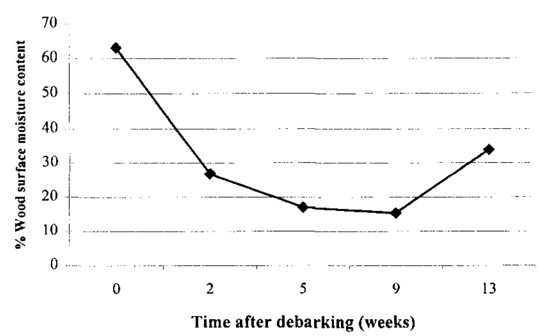

FIG. 3. Wood surface moisture content after debarking logs.

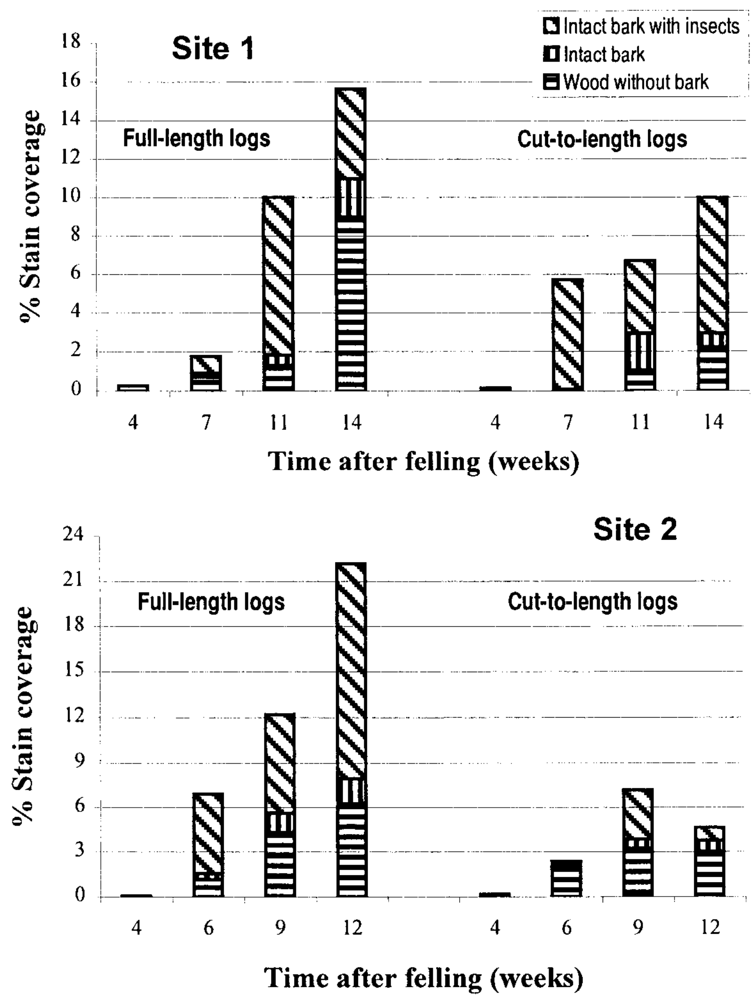

FIG. 4. Stain development in logs felled in spring.

logs. At site 2, 22.1% of full-length logs and 4.6% of cut-to-length logs were stained on the fourth inspection. On both types of logs, most of the stain developed from log wounds, or from insect infestation. Sapstain was much less developed on wood with intact bark and free of bark beetle infestation. For example, on full-length logs at site 2, 64.3% of the stain came from wood of intact bark that displayed insect infestation, 28.2% came from wounds, and only 7.5% came from wood of intact bark, free of insect attack.

At both sampling sites, the mean maximal radial penetration by fungi was deeper in full-length logs than in cut-to-length logs (Table 4). After 3 months of summer storage, the mean penetrations in full-length logs reach 2.2 cm at site 1 and 3.1 cm at site 2, whereas in cut-to-length logs, the mean penetrations were 1.8 and 2.0 cm, respectively. Similar to the stain coverage pattern, the average deepest radial penetrations were obtained from areas of intact bark with insect attack, or from exposed areas of wood free of bark.

Stain development in autumn-cut logs

Compared to the spring trial, sapstain development in logs felled in autumn was much

TABLE 4. *Mean maximal radial penetration of stain in spring-felled logs.*

Location	Log type	Inspection (weeks since felling)	Mean maximal penetration (cm)[a] Total	Without bark	Intact bark	Intact bark with insects
Site 1	Full-length	1 (4)	0.5	0.5	0.0	0.0
		2 (7)	0.8	0.1	0.1	0.7
		3 (11)	2.3	0.9	0.7	2.1
		4 (14)	2.2	1.7	0.7	0.8
	Cut-to-length	1 (4)	0.2	0.2	0.0	0.0
		2 (7)	1.8	0.0	0.0	1.7
		3 (11)	1.6	0.3	0.6	1.2
		4 (14)	1.8	0.4	0.7	1.5
Site 2	Full-length	1 (4)	0.1	0.0	0.0	0.0
		2 (6)	1.6	0.6	0.4	1.4
		3 (9)	2.2	1.3	0.6	1.4
		4 (12)	3.1	2.0	0.9	2.6
	Cut-to-length	1 (4)	0.2	0.2	0.0	0.0
		2 (6)	1.1	0.8	0.4	0.2
		3 (9)	2.4	1.7	1.0	1.6
		4 (12)	2.0	1.6	0.7	0.9

[a] Data are means of 24 (cut-to-length logs) to 40 (full-length logs) measurements taken from 4 replicate logs.

slower (Fig. 5). After 8 weeks of storage, the stain covered merely 0.06% of the wood in cut-to-length logs at site 1. However, 5.7% of wood was stained in the same type of logs felled in spring at the same location. At site 1, logs were felled at the beginning of September. After winter's storage (33 weeks in storage), the stain development was 8.9% in full-length logs, and 6.6% in cut-to-length logs. For the logs felled at the end of September at site 2, the stain development was 1.9% in full-length logs and 3.3% in cut-to-length logs. From mid-September to mid-April, the stain development in logs was slow at both sites.

The initial fungal infection of logs felled in autumn started on exposed wood, absent of bark protection, and the stain grew slowly around that area. After the winter, fungi began to attack wood with intact bark. For example, on the initial 8 weeks at site 1, 100% of the stain development on full-length logs came from exposed wood. However, the infection rate on these logs decreased to 40.9% by the fifth inspection. Opposingly, the infection of wood with intact bark was 0% at the start of 8 weeks, and increased to 22.2% at the end of the test. Bark beetles started to make galleries in these logs in the following spring. The stain development from the beetle infestation areas reached 36.9% by the fifth inspection.

The mean maximal radial penetration of fungi in autumn-felled logs corresponded to the stain coverage pattern described above (Table 5). Initially, the fungi penetrated the exposed wood, and the stain slowly developed in the surrounding area. During the winter storage (over 30 weeks after felling), the stain penetrated 0.8–2.6 cm in the radial direction. This depth of penetration could be partially removed from logs during the sawing process. After winter, the infection progressed to areas of intact bark and areas of insect infestation. At the end of the test, the stain penetrated the entire sapwood of the logs in the radial direction.

Stain development in debarked logs

Stain development in debarked logs was evaluated during favorable conditions for such development: from June to September. As the common forest practice, logs felled for the test were left in the forest for 3 weeks before being transported to the sawmill. By the time they arrived at the sawmill, the initial infection had occurred on these logs, mostly from wounds

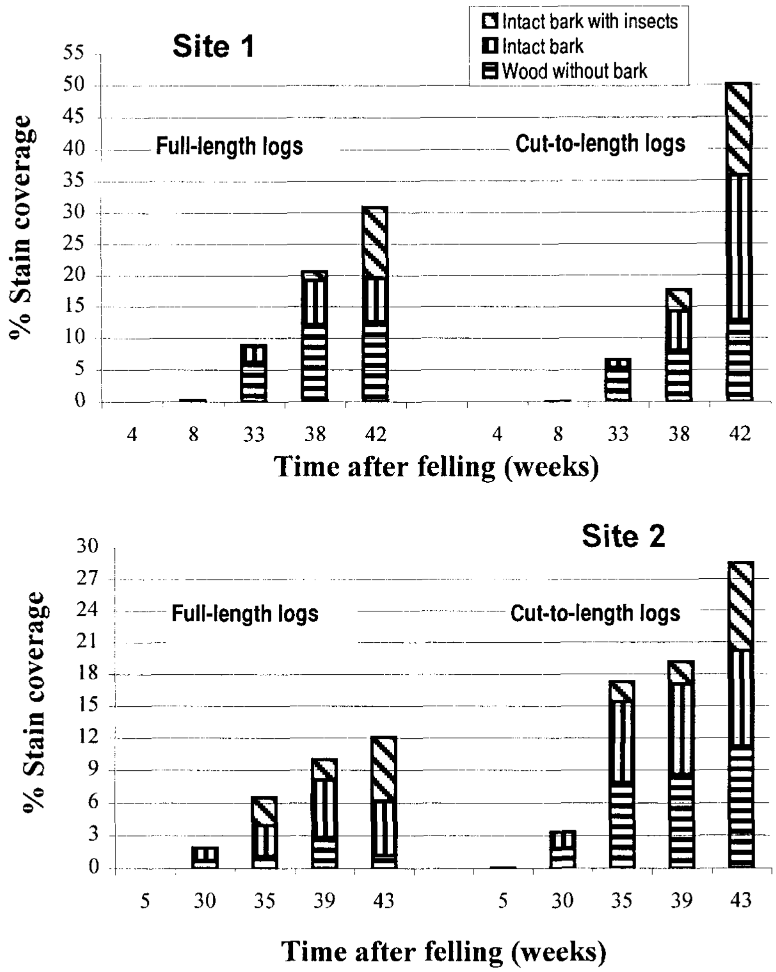

FIG. 5. Stain development in logs felled in autumn.

caused during harvesting. At the time of debarking, the stain covered 0.02% of wood, and the mean maximal radial penetration reached 0.2 cm (Fig. 6). Subsequently, the stain development was rapid on debarked logs. Two weeks after debarking, the stain had covered 4.7% of the wood. At 5 weeks, the stain extended to 15% of the area. The mean maximal radial penetration reached 3.9 cm into the wood by 5 weeks after debarking, which was almost the entire depth of sapwood in these logs.

Insect infestation and decay development

At test sites 1 and 2, there was evidence of bark beetles in logs 4 weeks after they were felled in spring. Stain development was observed around the beetle galleries. The bark beetle species was identified as *Ips pini.* No bark beetles were found on autumn-felled logs prior to winter, but by the third inspection on April 22, young larvae were found in these logs at site 1. On May 27, young beetles were found on logs located at site 2. On debarked logs, no beetles were found during the entire testing period. The main fungal species isolated from stained wood infested by beetles was *Ceratocystis coerulescens.*

After 3 months of storage, some decay started to develop in the spring-felled logs. As fruiting bodies of decay fungi grew out from

TABLE 5. *Mean maximal radial penetration of stain in autumn-felled logs.*

Location	Log type	Inspection (weeks since felling)	Mean maximal penetration (cm)[a] Total	Without bark	Intact bark	Intact bark with insects
Site 1	Full-length	1 (4)	0.0	0.0	0.0	0.0
		2 (8)	0.4	0.4	0.0	0.0
		3 (33)	2.6	2.2	1.5	0.2
		4 (38)	4.4	3.7	3.5	1.1
		5 (42)	4.1	3.5	3.0	3.3
	Cut-to-length	1 (4)	0.0	0.0	0.0	0.0
		2 (8)	0.1	0.1	0.0	0.0
		3 (33)	1.6	1.5	0.7	0.0
		4 (38)	3.7	2.5	2.8	2.2
		5 (42)	4.5	2.7	3.6	2.7
Site 2	Full-length	1 (5)	0.0	0.0	0.0	0.0
		2 (30)	0.8	0.4	0.6	0.0
		3 (35)	1.5	0.5	1.1	0.9
		4 (39)	1.7	1.5	1.2	1.0
		5 (43)	1.5	0.7	1.2	1.1
	Cut-to-length	1 (5)	0.1	0.1	0.0	0.0
		2 (30)	2.5	1.8	1.6	0.0
		3 (35)	2.9	2.4	2.6	1.0
		4 (39)	3.4	2.4	3.1	1.3
		5 (43)	3.6	3.2	3.1	3.2

[a] Data are means of 24 (cut-to-length logs) to 40 (full-length logs) measurements taken from 4 replicate logs.

some of the test logs, the main species was identified as *Schizophyllum commune.* Decay in autumn-felled logs was detected in June, 35 weeks after felling. Decay development was also detected on debarked logs after 3 months of storage.

DISCUSSION

Recently, several studies have been conducted to determine the relationship between harvesting practice and blue stain development in logs (Lee and Gibbs 1996; Uzunovic

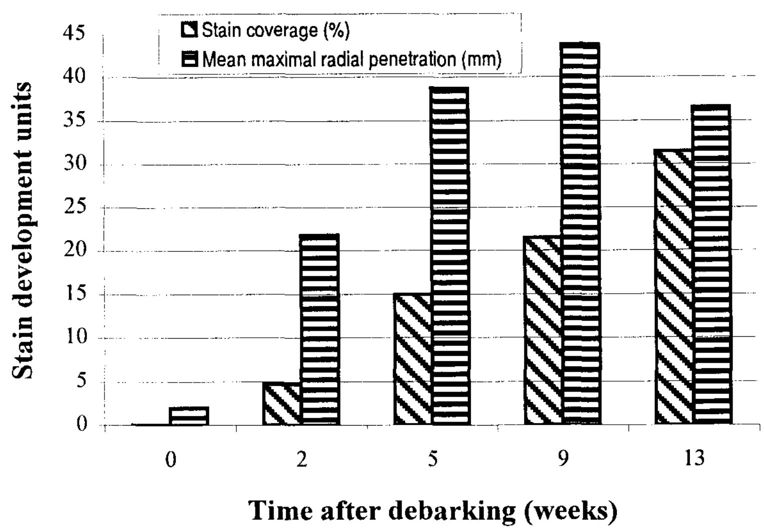

FIG. 6. Stain development in debarked logs.

et al. 1996, 1997). There is a concern that increased bark damage by current harvesting machinery may facilitate stain development in logs. However, there is some controversy on whether sapstain development increases proportionally with bark damage. The present study compared two types of harvested logs commonly cut in Canadian sawmills: full-length and cut-to-length. The latter type of logs may suffer more bark damage caused by spiked rollers during cutting. Surprisingly, we did not find that stain development was more serious on cut-to-length logs than on full-length logs, especially for the spring trial. At test site 2, bark damage on cut-to-length logs was 3 times more than on full-length logs, but stain development was less predominant on the former than on the latter. There are three possible explanations for these results. Cut-to-length logs dry faster than full-length logs. Low moisture content in cut-to-length logs may reduce sapstain development. Secondly, cut-to-length logs normally display more bark damage, therefore making them less suitable for bark beetle infestation. Thirdly, the exposed wood is rapidly colonized by various airborne molds that may have antagonistic activities against sapstaining fungi. In our experiment, the bark damage on logs ranged from 5% to 100% in the spring and autumn trials at the three locations (Table 1). We did not see a proportional increase between the percentage of bark damage and the stain development in logs of this wood species; however, exposed wood was more likely to be stained than wood with intact bark. Because our main objective and experimental design were not intended to investigate this relationship, this observation must be considered inconclusive.

Wood surface moisture content was measured because it is critical to fungal invasion. When wood moisture content drops below 20%, the staining fungi are unable to affect wood, and stain development is restricted (Zabel and Morrell 1992). This test indicates that with increased bark damage, the wood surface moisture content in logs decreases more rapidly. Theoretically, this may imply that logs with bark damage may help in reducing the period of wood susceptibility to sapstaining fungi. However, in reality, the time needed for wood moisture to naturally reduce to this point will be enough to allow the fungi to penetrate deeply into the wood and, thereafter, the growth of these fungi will no longer be affected by wood surface moisture content.

A major factor that influences the severity of stain in logs is the involvement of bark beetles (Gibbs 1993). Undoubtedly, the intact bark protects logs from stain; however, bark also invites bark beetle attacks. Once a log has been attacked by bark beetles, the bark no longer protects the wood from fungal infection. On the contrary, bark reduces water evaporation from wood and therefore facilitates sapstain development in logs. Our test indicates that bark beetles affect logs only in spring and summer, but do not attack autumn-felled logs in Eastern Canada. These beetles may lie dormant over winter under the bark of logs or under the forest litter. In spring, they start to lay eggs under the bark. Hatched larvae make galleries and spread sapstaining fungi. The infection of staining fungi occurred mainly on the exposed wood of the logs felled in autumn. This may imply that less bark damage results in less stain in logs. However, over winter, when bark loses moisture, it becomes partially detached from logs and no longer protects wood from fungal invasion. The lack of bark beetle activity combined with the low temperatures of the season may contribute to the slow stain development in autumn-felled logs.

At test sites 1 and 2, bark beetle infestations were found in logs as early as 4 weeks after trees were felled in spring. At site 2, the logs were left in the forest for 3 weeks before they were transported to a remote area of the sawmill yard. The area had never been used to store logs before and was clean. When the logs were inspected a week later, we found beetle larvae beginning to bore galleries beneath the bark. Therefore, we believe that bark beetles come from the forest rather than the sawmill environment.

Based on this important information, the following suggestions are made to prevent sapstain on jack pine logs. It is preferable to rapidly process logs into lumber within 4 weeks of cutting in spring and summer. If bark beetle populations can be controlled in the area, the logs should be harvested with caution in order to reduce bark damage. The control of bark beetles must start at the forest, as soon as trees are felled. Once beetles invade the logs and lay eggs beneath the bark, they are difficult to control. If bark beetles cannot be controlled, partially stripping the bark may help to reduce bark beetle attack and stain severity. However, further studies may be necessary to determine the amount of bark that should be removed from logs to prevent bark beetle invasions.

Furthermore, our data show that once trees are cut, wounds are the first entry points of fungi that cause surface stain. Intense and expansive stain developed under bark that showed beetle infestation. As mentioned above, airborne molds, such as species *Trichoderma* and *Penicillium,* rapidly occupied the areas of the log where the bark had been stripped off during logging operations. Some of these species such as *T. harzianum* are antagonistic to sapstaining fungi (Behrendt et al. 1995), and thus may contribute to the reduction of the sapstain development in logs.

Ophiostoma piceae is considered as the most important sapstaining fungus on softwood lumber in Canadian sawmills (Uzunovic et al. 1999). The present study shows that the main fungus associated with bark beetle infestation and stained wood in jack pine logs is *Ceratocystis coerulescens.* This study reveals that the causes of sapstain on logs may differ from those on lumber. These results coincide with observations by Uzunovic et al. (1996).

Comparing data from the spring and autumn trials described above, the maximal storage times for jack pine logs in Eastern Canada can be defined. There are 3 periods of sapstain development in logs over the years of 1998–1999: a safe period from mid-September to mid-April; a period of reduced development from mid-April to mid-May, followed by mid-August to mid-September; and a period of rapid development from mid-May to mid-August. In the safe period, logs can be safely stored without any significant degradation, whereas in the period of reduced development, logs can be stored a maximum of 6 weeks. During the rapid development period, logs may be stored up to 4 weeks after felling. From mid-May to mid-August, logs should not be stored more than 2 weeks after they are debarked. Because weather conditions vary from year to year, safe storage times and time for stain development may vary from year to year.

A certain variation of stain development on individual logs appears in the data. These differences may not be caused by environmental conditions but rather by intrinsic factors in logs such as the susceptibility of individual trees to staining fungi. A chemical analysis of logs showing minimal stain development may be worth investigating in a future study.

CONCLUSIONS

Sapstaining fungi did not cause significant stain on jack pine logs in 4 weeks following the spring harvest. The stain severity increased proportionally with storage time. All logs were seriously stained after 3 months of summer storage. In Northern Quebec, logs felled in September or later can be safely stored in sawmills over winter, but should be processed before the end of April of the following year. In summer, the debarked logs should not be stored more than 2 weeks. The main fungus, isolated from stained logs, was *Ceratocystis coerulescens.* Bark beetle infestation in logs was primarily due to *Ips pini,* whereas *Schizophyllum commune* caused early log decay.

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