# THE EFFECT OF STEM GIRDLING ON WOOD QUALITY

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## ABSTRACT

Mature trees of three species—tamarack (*Larix laricina*) (n = 2), soft maple (*Acer rubrum*) (n = 4), and red pine (*Pinus resinosa*) (n = 5)—were phloem-girdled one to two years before felling to test the folk wisdom that girdling produces wood with improved properties. The wood from these trees was compared with wood taken from ungirdled control trees felled at the same time. Sapwood and heartwood, from control trees and from above and below the girdle of treated trees, were examined for parenchyma viability, moisture content, various extractive components, and susceptibility to sapstain and mold fungi.

Parenchyma viability was reduced in girdled trees below the girdles. Moisture content was reduced in the conifers, especially below the girdle (> 50% reduction vs. controls), but not in maple. Girdling changed the extractives concentration in the sapwood, although in different ways for the different species. Soluble polysaccharides were reduced in the girdled tamarack trees above and below the girdle, but increased in concentration above the girdle in the pine and maple. Starch was depleted from the girdled tamarack and pine, and below the girdle in treated maple trees. Phenol-type extractives were higher below the girdle in maple.

In general, susceptibility to sapstain and mold fungi was reduced on wood from girdled trees. This effect was most evident below the girdle and in pine trees.

*Keywords*: Girdling, wood quality, heartwood, extractives, sapstain, mold.

## INTRODUCTION

Methods of building with logs in Germany in the 19th century called for girdling trees through the bark to the cambium (phloem-girdling) immediately below the crown, then letting the trees stand in the forest until they died before harvesting them (Phelps 1982). It was suggested that this practice results in wood that is resistant to insects and fungi, because the photosynthates produced in the crown cannot reach the stem and roots below the girdle. Simultaneously, continued respiration in the wood cells depletes the nutrients normally available to insects and fungi in the sapwood below the girdle. Although research has been conducted on phloem and sugar transport in girdled trees (e.g., Parker 1974), there has been little research, to our knowledge, to study the effects of girdling on logs from a timber perspective.

Heartwood is an inner core of xylem that is a normal formation in most tree species. Heartwood is distinct from sapwood in that all the cells (including parenchyma) are dead, and storage compounds (starch, sugar, lipids) are

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absent. Colored, often bioactive extractives are present, and in conifers, the wood moisture content is usually lower than in the sapwood. These differences greatly influence wood properties, including resistance to decay (Hillis 1987).

Phloem-girdling is a method of killing a tree in which a strip of bark is removed from around the circumference of the trunk. The tree continues to live for a while, but the movement of photosynthates to the roots is interrupted and eventually the tree dies (Noel 1970).

One study by Parkin (1938) found that girdling resulted in starch-free sapwood in oak trees and that the wood was unsuitable for the development of the *Lyctus* beetle, a boring insect that can damage lumber. The paper refers to work (Hartig 1859) that indicated that girdling led to an accumulation of starch above, and a depletion of starch below, the girdle. In his own work, Parkin concluded that girdling rendered oak sapwood free from starch, and therefore immune from *Lyctus* powder-post beetle attack.

Because girdling kills the tree and because it has been shown to alter the chemical composition of the wood, girdle-killing a tree may influence 1) the sapwood to heartwood transformation and 2) degradation by sapstain and mold fungi. This study examined the moisture contents, parenchyma viability, and extractive contents of wood of girdled vs. ungirdled trees.

## Materials and Methods

### *Sample selection*

Three species of trees were examined—tamarack (*Larix laricina* (du Roi) K. Koch), red pine (*Pinus resinosa* Ait.), and red maple (*Acer rubrum* L.). All trees were growing on the University of New Brunswick wood lot (45°56′43″N, 66°40′00″W; 16-m elevation). Five red pine and three red maple trees were girdled in October of 1996, after the first frost. The red pine trees were from a plantation and were approximately 48 years old and ranged from 25 to 39 cm in breast height diameter. The girdled trees were selected as a clump on the edge of the plantation in order to avoid any root grafting effects. The girdled maple trees were 50 to 98 years old and 13 to 18 cm in diameter at breast height. Two tamarack trees (46 and 52 years old and 35 and 40 cm in diameter) were girdled in July of 1997 (mid-summer).

The girdles were cut with a chisel, four meters from the ground to provide wood for analysis above and below the girdle. A 4-cm-wide strip of bark was removed from around the bole. The girdles were not sealed or protected in any way.

The girdled trees and an equal number of untreated trees of the same species, of a similar size, and growing in the same area, were felled. One-m-long log sections were taken 50 cm above and below the girdle on treated trees and at 4 m from the ground on the control trees. The tamarack trees were harvested August 31, 1998; the maple on September 17, 1998; and the pine on November 24, 1998.

### *Moisture content*

Immediately after felling, full cross-section samples ("disks") of wood were cut from each end of the 1-m segments and wrapped in plastic to prevent drying. The disks were subdivided using a band saw. Four wedges (approximately 4-cm wide at the cambium, with the pointed end coinciding with the pith) were cut from each disk. Each wedge was further divided into sapwood and heartwood. Sapwood sub-samples covered the whole sapwood region (as judged by color) except for 1 cm at the heartwood/sapwood transition zone, which was discarded; the rest of the heartwood region was included in the sample. Moisture content of sapwood and heartwood sub-samples was measured using the oven-dry method.

### *Parenchyma viability*

Wedges were cut from disks in a manner similar to the method used in the analysis of moisture content described above. Sapwood

sub-samples consisted of 2-cm-thick pieces taken 1 cm into the sapwood from the cambium. Heartwood sub-samples consisted of 2-cm-thick pieces taken 1 cm in towards the pith from the sapwood/heartwood boundary. Prior to testing, the samples were wrapped in plastic and stored in a refrigerator, then tested within one day after felling. A tetrazolium salt indicator method was used to determine whether the parenchyma cells were living (Ruetze and Liese 1985). This test was initiated within one day after felling. Samples were soaked in a 1% aqueous solution of TTC for 2 h. After soaking, the intensity of red staining on the tangential surfaces of the samples was assessed visually and with a Hunterlab Ultrascan Model US8000 light reflectance spectrometer.

The light reflectance spectrometer was used in slightly different ways for each of the three species studied. For the tamarack, the "A" setting was used. This setting is a composite measurement, and in this case, a *higher* value indicates an *increased* level of red color. For the maple, measuring the reflectance at 650 nm more accurately corresponded with visually perceived gradations in red color, with a *lower* number indicating *increased* red color. For the pine, a single wavelength measurement was again used, although 570 nm was found to be optimal for that species. Again, a *lower* value indicates *increased* red color. A visual grading scale was used also for the maple and pine samples, where (0) corresponded to no visible reaction, (1) indicated only slight staining, and (2) meant heavy pink stain.

### *Chemical anlyses*

The analyses of soluble polysaccharides, phenolics, and chloroform/methanol soluble extractives (lipids and phenolics) were conducted on ground wood. Samples of wood were taken from the trees shortly (within 48 h) after felling and dried in an oven at 50°C. Sub-samples of sapwood and heartwood were collected as described above for parenchyma viability, and the entire sample was then ground in a Wiley mill to pass a 20-mesh screen. Three replicates samples were analyzed for each tree and location in the tree.

*Soluble polysaccharides.*—Samples of milled wood were prepared as above for each tree and location within a tree. The milled wood was evaluated for moisture content, using the oven-dry method. Approximately 1-g samples (three replicates per variable tested) of milled wood were placed in test-tubes and extracted with distilled water in a hot water bath for 10 min. The test-tubes were removed from the bath and cooled in a cold-water bath for 5 min. The tubes were then centrifuged (5 min at 4000 rpm), and the decanted water was collected for analysis of sugar content by the phenol/sulfuric acid method (Dubois et al. 1956). A calibration curve was constructed using d-glucose. Percent soluble polysaccharide was calculated for the wood flour on a dry mass basis (soluble starches are also included in this analysis).

*Chloroform/methanol soluble extractives (lipids, phenols).*—Three milled wood samples from each tree and zone were prepared as above. Chloroform/methanol soluble extractive content was quantified by measuring the mass loss of the wood after extraction in chloroform and methanol for 10 h (Savidge 1998). The extracted milled wood was oven-dried, and extractive content was calculated, with a correction for moisture content.

*Phenolics.*—Phenolic content was quantified according to the method described by Julkunen-Tiitto (1985). The method uses the Folin-Ciocalteu reagent in a colorimetric test. A calibration curve was prepared with known concentrations of p-hydroxyphenyl acetic acid (HPAA). "Phenolic" is used in this case as a descriptive term for comparing the wide variety of different phenolic extractions. Three replicate samples were analyzed for each tree and zone as above.

*Starch.*—Using the blocks used previously for moisture content evaluation (four samples per tree and zone), the presence of starch was determined using iodine as an indicator. One percent iodine solution was sprayed on the tangential surface of the block and the relative

starch content inferred from the intensity of the blue-black reaction. The degree of blue-black staining on the samples was analyzed using a light reflectance spectrometer, with the reflectance at 650 nm measured for each block.

### *Sapstain fungi resistance*

Differences in the susceptibility of wood to mold and sapstain fungi were assessed using ASTM D4445-84 (1984), with the modification that no fungicides were used. This test is normally used to rate the relative effectiveness of preservatives on standard pieces of wood. In this case, the test used standard conditions and fungi to rate the resistance of different pieces of wood. Fresh green quarter-sawn sapwood samples were sterilized and spread with spore suspensions of the test fungi. The specimens (two replicates) were incubated at 25°C and 70% RH for two weeks, then visually assessed as specified in the standard. Four fungi species were used in this test: *Gliocladium virens, Aspergillis niger, Trichoderma pseudokoningii,* and *Aureobasidium pullulans*. The first three species are molds, while *Aureobasidium* is a sapstainer.

### *Statistical analyses*

A two-tailed paired *t*-test with unequal variance was used to test for differences. Comparisons were made among wood from ungirdled trees, wood from above the girdle, and wood from below the girdle. For each analysis, the measured values within a tree and zone were averaged and different trees served as replicates. In the following analyses, "statistically signficant" differences in average values are those where the *t*-test determined the probability that the two samples came from the same population to be 5% or less.

## RESULTS

### *General observations of trees sampled*

The girdled trees were generally not dead at the time of cutting; thus these results indicate trends that result from girdling a tree, rather than an analysis of girdle-*killed* trees. Also, due to the needed processing time, the three species were not girdled nor harvested at the same time, so some of the observed differences between species may have resulted from seasonality. Seasonal changes in sapwood extractive quality and quantity have been observed in a number of species (Hillis 1987). One of the girdled tamarack trees had sapstain in the sapwood, but there was no other obvious fungal or insect damage to any of the girdled or control trees.

TABLE 1. *Percent moisture content values for the three species (averages—standard deviations in brackets).*

| | | Tamarack | Maple | Pine |
|---|---|---|---|---|
| Sapwood | Control | 112 a[1] | 68 a | 151 a |
| | | (13) | (3) | (31) |
| | Above girdle | 69 b | 66 a | 131 a |
| | | (11) | (10) | (11) |
| | Below girdle | 41 b | 63 a | 64 b |
| | | (24) | (3) | (22) |
| Heartwood | Control | 54 a | | 34 a |
| | | (16) | | (2) |
| | Above girdle | 48 a | | 35 a |
| | | (1) | | (5) |
| | Below girdle | 52 a | | 33 a |
| | | (3) | | (1) |

[1] In this table and the tables that follow, sample groups that were determined to be statistically significantly different are labeled with a different letter (a, b, or c).

### *Moisture content*

Girdling caused a significant decrease in sapwood moisture content for both tamarack and pine, but not maple (Table 1). In pine, the wood below the girdle had lower moisture content than above the girdle. Heartwood moisture content was unaffected by the girdling treatment.

### *Parenchyma viability*

For tamarack, the intensity of the red color produced by the TTC was significantly greater in the sapwood of the control trees than in the sapwood of the girdled trees, indicating greater cell viability in the ungirdled trees (Table 2). The soaking solution itself turned red, and

TABLE 2. *Parenchyma viability of the sapwood of the three species, as indicated by a red color reaction with TTC. For the tamarack and pine, higher values indicate an increased level of red color. For the maple, lower numbers indicate increased red color. A visual grading scale was used also for the maple and pine samples, where (0) corresponded to no visible reaction, (1) indicated only slight staining, and (2) meant heavy pink stain. (averages—standard deviations in brackets).*

| | Tamarack | Maple | | Pine | |
|---|---|---|---|---|---|
| | "A" | 650 nm | Visual | 570 nm | Visual |
| Control | 26.6 a | 37.0 a | 1.0 a | 24.4 a | 2.0 a |
| | (3.2) | (4.9) | (0.0) | (5.0) | (0.0) |
| Above girdle | 20.0 b | 38.1 a | 1.0 a | 29.4 a | 2.0 a |
| | (2.7) | (5.9) | (0.0) | (4.0) | (0.0) |
| Below girdle | 19.5 b | 30.5 a | 0.8 a | 44.0 b | 1.4 b |
| | (1.6) | (8.8) | (1.0) | (6.0) | (0.5) |

this solution stained substances it came in contact with. Thus pieces of wood where the parenchyma were less active may have given a false red reaction and the differences may have been greater than those noted. The tamarack heartwood did not produce any red coloration characteristic of the TTC indicator.

There were no clear statistically significant differences in the reaction of the maple wood samples to the stain. However, two of the three girdled maple trees visually showed reduced parenchyma activity below the girdle, while in all cases parenchyma were viable above the girdle. All the control samples stained positive for parenchyma activity.

Parenchyma activity, as evidenced by red color, was evident in almost all the pine sapwood samples. There was an obvious reduction in the intensity of the stain in the below-girdle sections, and these differences were reflected in both the visual and colorimeter evaluations. Differences between the above-girdle sections and the controls were not apparent to the naked eye, but the colorimeter analysis yielded a consistent but not statistically significant reduction in the activity of the parenchyma cells above the girdle as compared with the controls.

### *Extractive analyses*

*Simple polysaccharides.*—Sapwood hot-water-soluble polysaccharide content was lower in the tamarack and pine trees than in the maples (Table 3). The sapwood of the girdled tamarack trees contained less than half as much as the control trees. Differences between the control and both the above- and below-girdle samples were statistically significant. There was no significant difference between the above- and below-girdle samples. In both the maple and pine, levels of soluble polysaccharides above the girdle were higher than either the below-girdle or control samples, although the differences were statistically significant only for red pine. In both cases, there was no difference between the below-girdle and control samples.

Tamarack heartwood soluble polysaccharide content was much higher than in the sapwood, consistent with the well-known high arabinogalactan content of this species, but there were no statistically significant differences between the treated and control samples. The heartwood of the girdled pines had a slightly lower polysaccharide content than the heartwood of the control trees, both above and below the girdle. These differences, though slight, were statistically significant.

*Chloroform/methanol soluble extractives (lipids and phenolics).*—Girdling did not result in any statistically significant changes in chloroform/methanol soluble extractives content in tamarack (Table 3), although there was a trend to lower levels in the below-girdle wood. In maple, chloroform/methanol soluble extractive contents were not significantly different in the girdled trees and the control trees. Levels were elevated in the above-girdle sapwood and both above and below-girdle heartwood of treated pines.

*Phenolics.*—The maple sapwood had much higher levels of phenol-type compounds than the sapwood of the conifers, which had roughly equivalent levels (Table 3). The heartwood of the conifers had much higher levels than the sapwood, as expected. In maple, the below-girdle wood in the treated trees had higher levels of phenolics than the above-girdle wood and the controls. None of the differences were

TABLE 3. *Percent extractive content of the three species. (averages—standard deviations in brackets).*

| Sapwood | Tamarack | Maple | Pine | Heartwood | Tamarack | Pine |
|---|---|---|---|---|---|---|
| | | | *Soluble polysaccharide content* | | | |
| Control | 0.67 a | 1.85 a | 0.54 a | Control | 11.85 a | 0.55 a |
| | (0.06) | (0.16) | (0.04) | | (6.17) | (0.07) |
| Above girdle | 0.22 b | 2.18 a | 0.72 b | Above girdle | 11.81 a | 0.48 b |
| | (0.04) | (0.28) | (0.03) | | (2.70) | (0.05) |
| Below girdle | 0.20 b | 1.82 a | 0.52 a | Below girdle | 11.04 a | 0.48 b |
| | (0.05) | (0.16) | (0.03) | | (5.82) | (0.04) |
| | | | *Chloroform/methanol extractives (lipids and phenolics)* | | | |
| Control | 2.82 a | 2.58 a | 1.40 a | Control | 1.45 a | 6.85 a |
| | (1.3) | (0.20) | (0.85) | | (1.36) | (3.47) |
| Above girdle | 2.65 a | 2.80 a | 2.67 b | Above girdle | 2.29 a | 9.36 b |
| | (0.0) | (0.21) | (0.80) | | (1.04) | (3.23) |
| Below girdle | 1.76 a | 2.99 a | 1.44 ab | Below girdle | 1.90 a | 10.52 b |
| | (0.53) | (0.30) | (2.37) | | (0.59) | (3.22) |
| | | | *Phenolic content* | | | |
| Control | 0.05 a | 0.99 a | 0.02 a | Control | 0.34 a | 0.60 a |
| | (0.01) | (0.09) | (0.01) | | (0.49) | (0.12) |
| Above girdle | 0.04 a | 0.97 a | 0.05 a | Above girdle | 0.52 a | 0.69 a |
| | (0.01) | (0.18) | (0.03) | | (0.05) | (0.10) |
| Below girdle | 0.02 a | 1.36 b | 0.07 a | Below girdle | 0.64 a | 0.70 a |
| | (0.02) | (0.23) | (0.10) | | (0.33) | (0.14) |

statistically significant in tamarack and red pine.

*Starch.*—Table 4 lists the values recorded by the light reflectance spectrometer in the test to determine the presence of starch. For all three species, the reflectance at 650 nm was used. However, the meaning of the values for each species differs:

- For the tamarack and pine, the post-stain reading was used. *Lower* values corresponded to those blocks that visually had *more of the blue-black color* indicative of the presence of starch.
- For the maple, which had greater natural variations in color of the wood, the *difference* in the reflectance (Δ reflec.) at 650 nm, before and after staining, was used. In this case, the *higher* differences corresponded to *greater* blue-black color.

The tamarack did not stain positive for the presence of starch except for the sapwood from one of the control trees (C1 in Table 4),

TABLE 4. *Light reflectance values at 650 nm for the iodine-stained sapwood samples (starch indicator). For values at 650 nm, lower values indicate a stronger blue/black color and higher starch contents; a larger difference in reflectance reading at 650 nm for maple indicates a greater blue/black coloration and more starch. (averages—standard deviations in brackets).*

| | Tamarack—all 650 nm | Tamarack—C1 only 650 nm | Maple Δ reflec. | Pine 650 nm |
|---|---|---|---|---|
| Control | 57 a | 53 | 31 a | 62 a |
| | (0.34) | | (4.3) | (1.43) |
| Above girdle | 62 a | | 30 a | 66 b |
| | (6.3) | | (0.4) | (2.29) |
| Below girdle | 63 a | | 13 b | 70 c |
| | (5.0) | | (5.5) | (1.88) |

TABLE 5. *Growth ratings of sap-stain fungi (*Aureobasidium pullulans*) and mold fungi (*Gliocladium virens, Aspergillis niger, Trichoderma pseudokoningii*) on wood. Higher numbers, in the range from 0–5, indicate better growth, i.e. that the wood was more susceptible to infection. (averages − standard deviations in brackets).*

| | | *Gliocladium virens* | *Aureobasidium pullulans* | *Aspergillis niger* | *Trichoderma pseudokoningii* |
|---|---|---|---|---|---|
| *Tamarack* | Control | 1.0 a | 3.5 a | 4.0 a | 2.3 a |
| | | (0.4) | (0.4) | (0.0) | (0.4) |
| | Above girdle | 1.0 a | 3.3 a | 3.8 a | 2.5 a |
| | | (0.0) | (1.4) | (0.0) | (0.4) |
| | Below girdle | 1.3 a | 1.3 b | 1.0 b | 1.8 a |
| | | (0.0) | (1.8) | (0.4) | (0.0) |
| *Maple* | Control | 3.5 a | 4.8 a | 1.0 a | 1.9 a |
| | | (0.6) | (0.3) | (0.6) | (0.3) |
| | Above girdle | 3.2 a | 4.3 a | 1.3 a | 1.8 a |
| | | (0.3) | (0.3) | (1.0) | (0.3) |
| | Below girdle | 2.7 a | 4.0 a | 0.5 a | 1.3 a |
| | | (1.2) | (0.5) | (0.9) | (0.6) |
| *Pine* | Control | 2.7 a | 4.8 a | 4.8 a | 3.9 a |
| | | (0.3) | (0.3) | (0.4) | (0.5) |
| | Above girdle | 2.9 a | 4.7 a | 4.9 a | 4.7 b |
| | | (0.5) | (0.7) | (0.2) | (0.4) |
| | Below girdle | 2.0 a | 3.0 b | 3.0 b | 2.2 c |
| | | (0.9) | (0.7) | (0.0) | (0.3) |

which gave a clear and consistent blue-black reaction. All the control and above-girdle samples of maple tested positive for starch. Starch clearly was reduced below the girdle in two of the three girdled maple trees. In pine, girdling reduced starch levels, especially below the girdle.

### *Susceptibility to sap-stain and mold fungi*

With the exception of *Gliocladium virens,* the mold and stain fungi grew well in the trial with tamarack (Table 5). The below-girdle wood was not as susceptible to the growth of *Aureobasidium pullulans* and *Aspergillis niger* as were the above-girdle and control samples.

The mold fungi did not grow as well on the maple as on the other species. The differences between the control and girdled trees were not as evident in maple as with the tamarack and pine. In the case of *Trichoderma*, the average growth rating for the below-girdle sections was less than the other groups, but only at the 10% confidence level.

The growth of sapstain and mold fungi was consistently reduced on the below-girdle sapwood pine samples.

## DISCUSSION

This study suggests that girdling influences the properties of the sapwood of the tree, especially below the girdle. Moisture content generally was lower in girdled trees, as was parenchyma viability. The effect of girdling on extractive contents was variable, according to species and extractive type. Reductions in starch by girdling observed here are in agreement with the work of Parkin (1938), who observed a similar effect in *Quercus*. The accumulation of energy storage compounds above the girdle (polysaccharides in maple and pine, and lipids in pine) is similar to the effect noted in other girdling experiments (Noel 1970). A build-up of heartwood-type extractives (phenolics) was observed below the girdle in maple.

The high levels of tamarack heartwood extractives observed here are similar to those levels found by others who have determined that the extractives are mostly arabinogalactan, a water-soluble polysaccharide (Adams and Douglas 1963).

Because heartwood is dead, it is generally thought to be inert once formed (Hillis 1987).

However, the heartwood of the girdled pines had a slightly lower sugar content than the heartwood of the control trees, both above and below the girdle. It may be that the movement of sugars is possible by diffusion. The presence of normal heartwood in a tree very often involves the maintenance of extreme gradients of moisture content and extractives over a very few number of cells. Presumably it is possible for changes in the sapwood to alter these gradients. It should be noted that the heartwood examined in this study came from relatively near the sapwood/heartwood boundary, and thus it would be more susceptible to such changes in the neighboring sapwood.

The lower mold and sapstain susceptibility of the below-girdle wood of all three species, but particularly evident in the pine, may be due to one of a number of factors. The girdling treatment reduced the moisture content of the treated softwoods. However, the reported optimum moisture content for stain and mold fungi development is 60–80% (Williams et al. 1998), well below the green moisture content of the sapwood of the controls. In fact, the reduction of moisture content associated with girdling brought the wood *closer* to the optimum levels for fungal growth. Furthermore, in the maple there was no appreciable difference in moisture content related to the girdling, and yet reduced growth of fungi was observed.

Others have reported that the physiological state of wood (parenchyma living or not) can influence which fungi—mold or sapstain—are better able to colonize a piece of wood (Strong et al. 1998). Sapstain fungi appear better able to attack living wood, while mold fungi outcompete sapstainers on dead wood (Williams et al. 1998). This is not a consideration in this case for a number of reasons: First, all wood was dead at the time of inoculation, having been autoclaved to ensure sterility. Second, all inoculations were done with single species of fungi; different species were not required to compete with one another. Third, reductions in fungal activity were noted for both mold (*Trichoderma*) and sapstain (*Aureobasidium*) species.

No one extractive component, of those examined, can be correlated to all the differences in fungi susceptibility observed here. Simple polysaccharide and chloroform/methanol soluble extractive contents were similar in the control and below-girdle sapwood of pine, and yet the growth of the fungi was not the same on these two groups. Below-girdle sapwood of maple and pine, which had reduced fungal growth, was higher in phenol-type compounds than the controls and above-girdle samples. However, in tamarack, phenol levels were lower in the analogous tissues and still fungal growth was reduced, or at least not increased, on those samples.

There was less indication of starch in the below-girdle samples than in the controls of the three species, and a corresponding reduction in the growth of some of the fungi. However, in the case of pine, the fungi grew as well, or better in the case of the *Trichoderma*, on the above-girdle samples compared with the controls, and yet starch was less evident in the above-girdle samples than in the controls.

Thus it seems that a combination of factors, or some factor not included in this study, must be responsible for the reduction of sapstain and mold fungi on below-girdle wood samples.

The samples in this study were evaluated at only one time after inoculation. It is possible that the differences observed were not so much differences in the *degree* of susceptibility, as differences in the rate. Perhaps the below-girdle samples were simply slower to develop sapstain, or slower to give outward signs of fungal growth. Williams et al. (1998) found that the development of sapstain and mold fungi, inoculated as separate species, was at its maximum in five to fifteen days. Thus it would seem likely that the two-week exposure period used in this case was sufficient to allow for the full development of the various fungi.

It should be noted that the sapstain trials were conducted some time after felling. As described above, the samples were cut fresh and

then wrapped in plastic and stored frozen. Inevitably, changes (e.g., moisture content and parenchyma viability) occurred over this time. However, all samples were handled in the same manner, so, while these results may not be reproduced in all girdled trees, the results obtained here still indicate differences due to girdling.

## Conclusions

The trees studied in this case were girdled for extended periods, ranging from one to two years. However, the trees were not dead when felled, so the results here only indicate possible trends for girdle-killing trees.

Girdling did influence the amounts of free sugar, starch, fats, and phenol in the sapwood; however, these changes were not always in the ways predicted. Results varied between the species, and the species were cut at different times of the year; thus general conclusions about the effect of girdling on extractive content are not possible.

Sapwood from girdled trees had lesser parenchyma activity and lower moisture content. This effect was most evident in the wood from below the girdle. Sapwood from below the girdle of treated trees was less susceptible to sapstain and mold fungi than sapwood above the girdle or sapwood from control trees.

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