Juvenile response to conifer release alternatives on aspen-white spruce boreal mixedwood sites.

Part II: Quality of aspen regeneration

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ABSTRACT

This study, a component of the Fallingsnow Ecosystem Project, was designed to investigate the effects of conifer release alternatives on the quality of regenerating trembling aspen (*Populus tremuloides* Michx.). A randomized block design was used to compare untreated aspen with aspen growing in areas treated with two broadcast cutting treatments (brushsaw and Silvana Selective) and two broadcast herbicide treatments (glyphosate and triclopyr). The glyphosate treatment virtually eliminated aspen, whereas triclopyr tended to top-kill aspen, resulting in lateral dominance. Both fall cutting treatments generated prolific aspen root suckering and stump sprouting. Stain was common in aspen across the study site in damaged, untreated, and post-treatment stems, indicating that stain develops rapidly in young aspen suckers. Stems damaged by the treatments had higher incidences of decay (33% of cut stems and 10% of herbicide-damaged stems) than untreated aspen (8% of stems); however, decay volume was low for all treatments (1–4% of total stem volume affected). The location of decay (e.g., near ground level in cut stems) and presence of stem crooks in herbicide-treated aspen are important effects of the treatments on aspen quality. Armillaria root disease, which was found throughout the study site, was more prevalent in roots of treatment-damaged and untreated aspen than in suckers that originated post-treatment. These differences can be attributed to proximity to parent stumps, prevalence of root wounds, and older age of damaged and untreated stems.

Key words: aspen quality, decay, conifer release, vegetation management, fibre production

RÉSUMÉ

Cette étude, un élément du Fallingsnow Ecosystem Project, a été conçue pour analyser les effets des traitements de dégagement des résineux sur la qualité du peuplier faux-tremble (*Populus tremuloides* Michx.) en régénération. Un dispositif par blocs aléatoires a été utilisé pour comparer les trembles non traités aux trembles croissant sur des superficies traitées par coupe extensive (débroussailleuse et Silvana Selective) et par deux traitements de pulvérisation d'herbicide (glyphosate et triclopyr). Le traitement au glyphosate a virtuellement éliminé le tremble, alors que le triclopyr a eu tendance à détruire la pousse apicale entraînant une dominance latérale. Les deux traitements automnaux ont provoqué un drageonnement prolifique à partir des racines de tremble ainsi que des rejets de taillis. La coloration du bois était présente chez tous les trembles du site de l'étude dans le cas des tiges résiduelles blessées et non traitées, indiquant que la coloration s'installe rapidement parmi les jeunes drageons de tremble. Les tiges blessées lors des traitements démontraient une plus forte incidence de carie (33 % des tiges coupées et 10 % des tiges endommagées par les herbicides) que parmi les tiges non traitées de tremble (8 % des tiges); cependant, le volume de carie était faible dans le cas de tous les traitements (1 à 4 % du volume total des tiges). La localisation de la carie (par ex., près du niveau du sol dans le cas des tiges coupées) était plus évidente parmi les racines des trembles blessés par les traitements et les trembles non traités que chez les drageons issus à la suite des traitements. Ces différences peuvent être attribuées à la proximité des souches mères, la fréquence des blessures aux racines et l'âge avancé des tiges blessées et non traitées.

Mots clés : qualité du tremble, carie, dégagement des résineux, contrôle de la végétation, production de fibre

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Introduction

Trembling aspen (*Populus tremuloides* Michx.) is one of Ontario's major commercial forest species (OMNR 1997). Aspen currently represents 25% of Ontario's stumpage volume, of which one half is used to manufacture oriented strand board (OSB) (L. Colpitts, OMNR, personal communication, 2004). A sustainable supply of quality aspen is needed for the manufacture of OSB and other products including chip board, flakeboard and veneer. However, wood supply forecasts for Ontario's boreal forest zone indicate that supply will fall below demand in the near future—for poplar, this is predicted to occur within 15 years (OMNR 2004). The Provincial Wood Supply Strategy (OMNR 2004) identifies the pending "wood supply gap" as the most critical issue facing forest industry in the northeast and northwest regions of Ontario.

In Ontario, conifer release treatments (both chemical and mechanical) are viewed as a means to reduce competitive vegetation, including aspen, from regenerating stands of conifers (Campbell 1990, Buse *et al.* 1995, Wagner *et al.* 1998). Depending on the conifer release treatment used, however, aspen often remains a component of the stand because it regenerates from root suckers and stem sprouts (Stoeckeler 1947, Perala 1971, Basham 1982, Mallik *et al.* 1997, Bell *et al.* 1999, Pitt *et al.* 2004a). As Ontario's aspen supply becomes fully utilized, industries that produce aspen-derived products will become more dependent on these mixedwood stands for their wood supply (F. Johnson, Grant Forest Products, personal communication, 2004). Indeed, increased utilization of available wood fibre is one of the strategies recommended to address the pending wood supply gap (OMNR 2004). Concerns about the potential quality of this resource must be addressed.

Wood decay commonly found in aspen stems and roots can greatly reduce timber quality (Basham 1993). Fungi that cause decay in aspen can enter trees in many ways, including through large branch stubs, dead leaders, stem and root wounds, and parent roots of suckers (i.e., those originating from the harvested "parent" aspen) (Anderson *et al.* 1977, Gross and Basham 1981, Basham 1993). Current chemical and mechanical conifer release treatments can cause similar damage (i.e., cut stems, dead leaders). The physical results of these treatments (e.g., stem crooks, multi-leadered crowns) and the effects of the fungi that colonize cut stems and dead leaders will affect future tree and fibre quality in the resulting mixedwood stands. Previous studies have reported decreased quality in young aspen stands following scarification treatments

and application of the herbicide 2,4-D (Basham 1982, 1988). However, information on the effects of other currently used conifer release treatments on aspen quality is limited. For example, in Canada 54 000 ha of forest area undergo manual tending annually (13-year average, 1990–2002) (CCFM 2004), yet little information exists on the effects of this treatment on aspen quality (Whaley and Johnson 1992).

The objective of this study, a component of the Falling-snow Ecosystem Project (Lautenschlager *et al.* 1997), is to quantify and compare the quality of aspen regeneration six growing seasons after five broadcast-type tending scenarios. Information gathered from this early survey of aspen quality, in conjunction with stand structure information (Pitt and Bell 2005), will help identify potential concerns regarding Ontario's future aspen resource and wood utilization issues on conifer regeneration areas.

Methods

Research site

The Fallingsnow Ecosystem Project is located 61 km southwest of Thunder Bay, Ontario (48°08'N, 89°49'W) in the Great Lakes–St. Lawrence forest region (Rowe 1972). The project has a randomized complete block design with three blocks planted to white spruce, each containing the following five silvicultural treatments: (1) brushsaw: a motor-manual cutting technique applied at 18 cm aboveground during mid to late October of 1993, (2) Silvana Selective/Ford Versatile Cleaning Machine: a tractor-mounted mechanical cutting tool used to remove woody vegetation at 33 cm aboveground during late October to early November 1993, (3) Release[®]: a selective herbicide applied by a Bell 206 helicopter at 1.9 kg acid equivalent (a.e.) triclopyr ester/ha in 31 L/ha solution during mid-August 1993, (4) Vision[®]: a broad-spectrum herbicide applied by a Bell 206 helicopter at 1.5 kg active ingredient (a.i.) glyphosate/ha in a 30 L/ha solution during mid-August 1993, and (5) Untreated: no treatment applied. Treatment plots of at least 4 ha were established on each of the three blocks. Site history and treatment details are available in Bell *et al.* (1997a, b).

Aspen stem sampling

In May 2000, a series of temporary stocking quadrats were installed in each of the 15 treatment plots at the Fallingsnow site. This sample was designed to quantify the stand structure (Pitt and Bell 2005) and quality of aspen stems six growing seasons after the conifer release treatments. The stocking quadrats were 2 m × 2 m and arranged in linear clusters of

Fig. 1. Effects of the cutting (brushsaw and Silvana Selective) and herbicide (glyphosate and triclopyr) treatments on surviving aspen stems at the Fallingsnow site: (a) New stem sprouts (white arrow) typically originated near the base of cut stems, (b) internal condition of cut stem and new sprout (evidence of insect tunnelling indicated with dark arrow), (c) top-killed leader from triclopyr treatment (white arrow), and (d) stain and minimal decay in the new leader.

five quadrats. A total of 30 clusters were randomly drawn for each treatment plot from a sampling frame consisting of all possible cluster starting points identified on a 60-m grid across the site. Cluster locations that overlapped missed or untreated sections within the plots, or that fell within 20 m of roads, exposed bedrock, or standing water, were not considered.

Aspen in the sample quadrats were identified as either stems damaged by the treatments or post-treatment stems. Damaged aspen included stem sprouts originating from a stump following the motor-manual and mechanical cutting treatments, or stems in which the original terminal shoot was killed by one of the herbicide treatments (Fig. 1); post-treatment aspen suckers originated after the conifer release treatments. To evaluate the internal quality of the aspen growing stock, the dominant aspen representing each stem type (damaged and post-treatment) in each quadrat was severed at ground line; limbed; topped at 2.4 m; labelled with the quadrat, cluster, treatment plot, stem type, and block number; and transported by covered truck to the Ontario Forest Research Institute (OFRI), in Sault Ste. Marie, ON, where they were stored at 2°C until further analysis. Dominant aspen suckers were selected for sampling, as they are most likely to survive to maturity and form part of the future stand (Pollard 1971, Basham 1982, Perala 1984, Stanoz and Patton 1987b). Our sample length of 2.4 m corresponds with the first and most valuable log at harvest. Additionally, the root system of every 10th aspen harvested for each stem type was excavated within a 30- to 35-cm radius of the stem, labelled, and transported to OFRI as above. Roots were not collected in the glyphosate-treated areas because very few aspen survived this treatment.

In the brushsaw, Silvana, and triclopyr plots, our goal was to destructively sample 80 stems in both damaged and post-treatment categories (i.e., 160 stems per plot, 20 root systems per plot). In untreated plots, we destructively sampled 80 aspen root suckers that originated after harvest. Due to non-uniform stem distribution and the presence of conifers, the desired numbers of samples per treatment, stem type, and block were occasionally not collected in 30 clusters. In these cases, an east-west line was established through the plot, and one dominant aspen was collected every 10 m until the desired sample size was achieved. Since glyphosate killed almost all aspen in the treated area, and few new root suckers (i.e., post-treatment stems) developed after the triclopyr treatment, the target sample sizes were not always achieved for the herbicide-treated plots.

In the lab, each of the 2.4-m aspen stems was cut into 30-cm sections with a mitre saw. For each section, two measurements of inside-bark diameter (nearest mm) were made at right angles to one another on the lower cut surface. The diameters of stained and decayed wood were measured in the same way on the cut surfaces. Stain and decay were classified similarly to Basham (1982) and Basham and Navratil (1975). Stain was defined as discoloured but sound (i.e., hard) wood. Decay was defined as discoloured wood that is softer than sound wood (Basham 1993). The presence and location of insect galls, borer damage, wounds other than those directly caused by the treatments, and branch stubs were also recorded. In total, 1613 stems were examined. Because of logistical limitations, a sample of the most common stains and decays observed were selected for further analysis. Over 55 wood

samples per treatment containing typical stain and decay were cultured on selective media (Wiensczyk *et al.* 1996) for identification of decay fungi (only nine samples from the glyphosate treatment plots were cultured). For damaged stems, most samples were taken from the points where the new stem sprout or new leader initiated on the pre-treatment aspen sucker, as this was where treatment effects were expected to occur (Fig. 1). For untreated and post-treatment stems, representative samples of stain and decay were selected from all points along the stem. Fungi were identified using methods and keys described in Stalpers (1978), Malloch (1981), and Barnett and Hunter (1998). Eight isolates were sent to CBS (Centraalbureau voor Schimmelcultures, Utrecht, The Netherlands) for confirmation. Root systems were cleaned with a power washer, and presence of stain and decay on (1) the cut surface, (2) the root collar, (3) the parent root, and (4) distal roots greater than 10 mm in diameter was recorded (as in Basham 1988). Presence of externally visible wounds was also recorded, and decayed wood samples were cultured on the selective media. Armillaria isolates were further identified to species using haploid-diploid pairings (McLaughlin 2001). The resulting data were used to determine: (1) the occurrence of stain and decay in the first log length of aspen stems and the occurrence of decay in roots, by treatment and stem type, (2) the location of stain and decay in stems and roots, (3) the volume of stained and decayed wood in the first 2.4 m of stems by treatment and stem type, and (4) the species of decay fungi present in stems and roots.

Data analyses

In preparation for data analysis, each pair of diameter measurements for the stem, stain, and decay was averaged by taking the geometric mean of the two measures (Husch *et al.* 1972). The cross-sectional area of each of these measurements was then computed from the averaged diameters. The stem, stain, and decay volumes were calculated using Smalian's formula (Husch *et al.* 1972).

For each 2.4-m log, the percentages of total volume that were stained and decayed were calculated. Similarly, the largest cross-sectional area of stain and decay measured within the stem and the total cross-sectional area measured at ground level were used to calculate the maximum percentage of defective sectional area for each log. Within each stem type (damaged and post-treatment), these variables, plus the percentage of the samples found with stain and decay, were subjected to analysis of variance (ANOVA) to compare treatments. The procedure Proc Mixed of the SAS[®] system (Littell *et al.* 1996) was used to accommodate the frequent unbalanced sample sizes of the response variables and to compute the correct least squares means and standard errors for the treatments. In analyses for the undamaged stems, the following orthogonal contrasts were used to test null hypotheses stemming from the Fallingsnow treatment structure:

- Overall treated and untreated responses do not differ
- Brushsaw and Silvana responses do not differ
- Triclopyr and glyphosate responses do not differ
- Cutting (brushsaw and Silvana) and herbicide (triclopyr and glyphosate) responses do not differ.

In analyses for damaged stems, the treated vs. untreated contrast was omitted, since the untreated plots had no damaged trees.

Table 1. Incidence and volume of stain and decay in the first 2.4-m log of aspen stems six growing seasons following conifer release treatments on the Fallingsnow Ecosystem site. Values shown are least squares means from ANOVA.

Treatment	Number of stems sampled	Percent of stems sampled:			Percent of volume:			Percent of area: ¹	
		With stain	With decay	Stem volume (cm ³)	Stained	Decayed	Stem cross-sectional area (cm ²)	Stained	Decayed
Undamaged stems ² :									
Untreated	240	98	12	4578	8	< 1	34	15	< 1
Brushsaw	242	75	2	393	9	< 1	4	17	< 1
Silvana	240	84	1	748 ⁵	9	< 1	7	17	< 1
Triclopyr	120	78	2	590	7	< 1	6	14	< 1
Glyphosate	7	70	< 1	651	7	< 1	5	14	< 1
Contrasts ³ :									
	Untreated vs. treated:	0.08	< 0.01	< 0.01	0.84	0.15	< 0.01	0.96	0.08
	Brushsaw vs. Silvana:	0.51	0.44	0.47	0.81	0.55	0.34	0.92	0.88
	Triclopyr vs. glyphosate:	0.63	0.35	0.95	0.93	0.72	0.95	0.97	0.81
	Cutting vs. herbicide:	0.57	0.39	0.93	0.38	0.61	0.94	0.38	0.63
Damaged stems ⁴ :									
Untreated	0	—	—	—	—	—	—	—	—
Brushsaw	252	97	32	755	18	3	11	41	8
Silvana	247	96	35	756	21	4	13	44	10
Triclopyr	240	95	9	1345	14	1	12	24	1
Glyphosate	25	82	15	1681	23	1	16	34	4
Contrasts ³ :									
	Brushsaw vs. Silvana:	0.90	0.68	0.99	0.08	0.32	0.68	0.20	0.22
	Triclopyr vs. glyphosate:	0.09	0.45	0.52	0.03	0.70	0.47	0.08	0.50
	Cutting vs. herbicide:	0.12	< 0.01	0.06	0.51	0.04	0.45	< 0.01	0.01

¹Calculated using point of maximum stain and decay in the stem.

²Stems from untreated (control) plots and those that originated post-treatment in the treatment plots.

³Orthogonal contrasts of treatments. Values shown are probabilities of a greater F value, under the null hypothesis of no difference between treatments.

⁴Stems affected by treatment, i.e., sprouting from a cut stump following cutting, or initiating a new leader after herbicide-caused top kill.

⁵The relatively large volume indicates that stems that were missed by the treatment were included in this sample.

Results

Most aspen stems sampled contained stain, regardless of whether or not stems were damaged by the release treatments (Table 1). Stain tended to be more prevalent in untreated stems than in post-treatment stems from treated blocks (98% vs. 79%; $p = 0.08$), likely because the latter were younger aspen. In damaged stems, the incidence of staining was similar across treatments, averaging 96%. Staining appears to be less prevalent in glyphosate-damaged stems ($p = 0.09$), although the small sample size for these stems lends reduced weight to this result.

In post-treatment stems, staining averaged about 8% of total stem volume and 15% of cross-sectional area, regardless of treatment (Fig. 2; $p > 0.84$). In contrast, an average of 19% of the total volume of older, damaged stems was stained. Differences between aspen in cut and herbicide-treated plots were small ($p = 0.51$); Silvana-damaged aspen tended to contain more stain volume than brushsaw-damaged aspen, and aspen in glyphosate-treated plots contained more stain than those in triclopyr-treated plots ($p < 0.08$). Expressed in terms of defective sectional area, trees damaged by cutting averaged nearly twice as much stained wood as the trees damaged by herbicide (42 vs. 25%; $p < 0.01$). This result reflects the location of the two types of injuries. The cutting wounds occurred low on the stem, where cross-sectional area is greatest, while the herbicide damage occurred on the crown/upper

stem, where cross-sectional area is smaller (Fig. 1 and 3). Consistent with the trends observed with stain volume, Silvana- and glyphosate-damaged trees contained more stained area than their counterpart treatments, although differences were statistically significant only for the herbicide-treated aspen ($p = 0.08$). Insect damage (galls and tunnels) was observed in 23–38% of aspen stems from all treatments and stem types. Stain was always (but not only) associated with insect damage.

Advanced decay was found in 12% of untreated trees. Although observed most frequently at stump level in these trees (8%), decay also occurred higher in the stems, and was usually associated with mechanical wounds, insect galls, or branch stubs. In comparison, only 1–2% of post-treatment suckers growing in treated plots ($p < 0.01$) had visually detectable advanced decay. Again, stem age provides a likely explanation for the differences in decay incidence between these two groups. Decay found in post-treatment suckers was associated with mechanical wounds or insect galls. The volume of decay in these two groups was low (< 1%). In contrast, treatment-damaged trees had much higher incidences of decay, with 33% of cut stems and 10% of herbicide-damaged stems containing visible decay ($p < 0.01$). Regardless, the overall extent of decay was low, with 3–4% of the total volume of cut-damaged trees affected and only 1% of the total volume of herbicide-damaged trees affected ($p = 0.04$).

Fig. 2. Average volume of first 2.4-m logs sampled in each treatment. Plotted values are least squares means from ANOVA.

Expressed as cross-sectional area, decay extent averaged 9% in cut-damaged trees and 1% in herbicide-damaged trees ($p = 0.01$). Decay incidence differed little between the cutting treatments ($p > 0.22$) or herbicide treatments ($p > 0.50$).

When the portion of the sample containing decay was analyzed separately, the extent of decay shifted from 3–4% of total volume to 6–8% (13–23% of cross-sectional area) for cut-damaged stems and from 1–10% of total volume (27% of cross-sectional area) for herbicide-damaged stems. Fig. 3 presents the average area of clear wood, stain, and decay at location of maximum defect for untreated and treatment-damaged stems.

Decay fungi (class Hymenomycetes) isolated from decayed and stained wood samples are listed in Table 2. Except for the *Trametes* species, these fungi occurred rarely in stems from all treatment plots. The selective media was chosen specifically to isolate wood decay fungi; its properties, however, can limit or completely restrict the growth of many non-hymenomycetous fungi that may cause staining in aspen suckers. The non-basidiomycetes listed in Table 2 are only those that managed to grow on the selective media and are not intended to be a representative sampling of the stain fungi in the aspen stems.

Because of the small sample size, root decay assessments were not subjected to rigorous statistical analysis. The following are general observations. Root wounds were observed on more damaged and untreated stems (average = 4.5%) than the younger, post-treatment stems (average = 1.3%). Decay incidence was also higher on the damaged and untreated stems (25–50% vs. 0–17%). *Armillaria sinapina* Bérubé & Dessureault was the most common fungus isolated (Table 2). *A. ostoyae* (Romagnesi) Herink was isolated once from the roots of an untreated aspen. Location of *Armillaria* on the roots was as follows: parent roots (38%), stump surface (21%), root collar (19%), root wounds (13%), other roots (8%).

Discussion

In this study, the high percentage of aspen in untreated (control) areas with stain (98%) indicates that most cutover-

origin aspen stems develop this condition at an early age. This conclusion is supported by previous studies of cutover-origin aspen in which 57–84% of young aspen stems contained stained wood (Kemperman *et al.* 1976, Gross and Basham 1981, Crouch 1983). Stain in these young suckers is attributed to shoot blights or insects that kill leaders or branches, and is often physiological rather than fungal or bacterial (Perala 1984, Basham 1993). A portion of the stain observed in our study was associated with the high levels of insect damage observed in all stem types; however, the selective nature of the media used limits our knowledge of the nature of the stain in these stems. The incidence and extent of advanced decay was very low in untreated aspen (12%, or 29 trees affected), and was associated with mechanical wounds, insect galls, and branch stubs. In a similar survey of aspen suckers in Colorado, advanced decay occurred in only 6% of the 591 suckers surveyed (Hinds and Shepperd 1987). The fungi identified from decayed wood samples from untreated plots (Table 2) are usually classed as decayers of dead wood; however, both *Punctularia strigoso-zonata* (Schwein) Talbot and some species of *Trechispora* P. Karst are associated with stem and butt decay in aspen suckers as well as in mature aspen (Basham 1958, Laflamme and Lortie 1973, Kemperman *et al.* 1976, Anderson *et al.* 1977).

Most cutover-origin aspen develop as root suckers; few originate as stem or stump sprouts (Baker 1918). However, if these young stands are cut again to promote conifer growth (e.g., via motor-manual cutting), they will regenerate as a combination of stem sprouts and root suckers (Stoeckeler 1947, Mallik *et al.* 1997, Bell *et al.* 1999). In our study, stem sprouts in the brushsaw and Silvana Selective treatment plots had developed the most decay, both in occurrence and in volume affected. Most of this decay entered through the cut stump of the original, pre-treatment sucker; stain and decay then progressed into the new stem sprout (Fig. 1). Insect damage was common in cut stems and at the base of new stem sprouts.

The fungi isolated from stain and decay samples from the cut treatments are commonly found in aspen wood (Morawski *et al.* 1958, Basham and Navratil 1975, Hinds and Shepperd 1987, Basham 1988), and most are classified as saprobes, found in dead branches and stems and sometimes on wounds (Chamuris and Falk 1987, Gilbertson and Ryvarden 1987, Farr *et al.* 1989, Callan and Ring 1994). However, both *Peniophora cinerea* (Pers.:Fr.) Cooke and *Trametes versicolor* (L:Fr) Pilát can cause decay in mature living aspen (Basham 1958, Breitenbach and Kranzlin 1986, BC Min. For. 2003). The decay fungi most commonly found at the cut sites (Table 2) were isolated from both stained and decayed wood; thus, at these wound sites, much of the defect classified as stain may contain incipient decay. It is therefore likely that advanced decay incidence and volume will increase in the future. However, because of the largely saprophytic nature of the fungi invading the stumps of the cut aspen suckers, it is unlikely that they will progress to any substantial level in the new stem sprout. Species of *Phialophora* (Table 2) are often found in stained wood surrounding advanced decay in mature aspen. These non-hymenomycetes may play a role in preparing wood for infection by decay fungi such as *Phellinus tremulae* (Bond.) Bond. & Borisov (Basham 1958, Etheridge 1961, Shigo 1963, Hiratsuka *et al.* 1990).

Fig. 3. Schematic and pictorial views of average cross-sectional area containing stain and decay for the subset of treatment-damaged trees found with decay. Cross-sectional area was measured at point of maximum defect on each stem and related to stump area. Untreated stems with decay are shown for comparison. Diameters shown are for the stems of mean cross-sectional area, as calculated from the least squares means from ANOVA.

Table 2. Occurrence of decay fungi in stained and decayed stems and roots on the Fallingsnow site. Samples cultured on selective media (Wiensczyk *et al.* 1996)¹.

A. Stems						
Organism	Untreated	Brushsaw	Silvana	Triclopyr	Glyphosate	
<i>n</i> = number of wood samples tested	(<i>n</i> = 61)	(<i>n</i> = 56)	(<i>n</i> = 73)	(<i>n</i> = 65)	(<i>n</i> = 9)	
(% of samples)						
Basidiomycetes ²						
<i>Trametes versicolor</i> or <i>zonatus</i> ³	0	25	26	0	0	
<i>Punctularia strigoso-zonata</i> ³	2	4	8	3	0	
<i>Peniophora rufa</i>	0	0	0	2	0	
<i>Peniophora cinerea</i> or <i>violaeceolivida</i> ³	0	2	1	2	0	
<i>Trechispora</i> sp.	3	0	0	2	11	
Unidentified	0	2	3	2	11	
Non-basidiomycetes ⁴						
<i>Phialophora</i> sp.	7	9	1	5	0	
<i>Trichoderma</i> sp.	0	5	1	0	0	
<i>Aureobasidium</i> sp.	0	7	4	6	0	
<i>Fusarium</i> sp.	0	4	0	2	0	
<i>Alternaria</i> sp.	2	4	4	0	0	
<i>Aspergillus</i> sp.	2	0	0	0	0	
<i>Cladosporium</i> sp.	0	0	1	0	0	
<i>Penicillium</i> sp.	0	2	1	0	0	
<i>Cytosporina</i> sp.	0	0	1	2	0	
Unidentified	6	5	11	12	0	
No growth ⁵	79	32	37	66	78	

B. Roots							
Organism	Untreated	Brushsaw		Silvana		Triclopyr	
<i>n</i> =number of root systems sampled	(<i>n</i> = 24)	Damaged	Post-ttmt ⁶	Damaged	Post-ttmt ⁶	Damaged	Post-ttmt ⁶
		(<i>n</i> = 25)	(<i>n</i> = 24)	(<i>n</i> = 22)	(<i>n</i> = 24)	(<i>n</i> = 24)	(<i>n</i> = 14)
(% of root systems)							
Basidiomycetes ²							
<i>Armillaria</i> sp.	46	25	8	50	17	25	0
<i>Trametes versicolor</i> or <i>zonatus</i> ^{3,7}	0	32	0	27	0	0	0
<i>Stereum hirsutum</i>	4	0	0	0	0	0	0
Non-basidiomycetes ⁴							
<i>Alternaria</i> sp.	0	8	0	4	4	0	0
<i>Fusarium</i> sp.	0	4	0	0	0	0	0
<i>Penicillium</i> sp.	0	4	0	4	0	8	0
Unknown	0	8	4	8	17	8	14
No growth ⁵	4	8	0	4	0	0	0

¹The non-basidiomycetes listed in Table 2 are those that grew on this media, and are not a representative sampling of non-hymenomycetes in the aspen stems.

²Most fungi that cause advanced decay in wood are basidiomycetes.

³Cultures identified by Karen Nakasone, Forest Products Lab, USDA Forest Service.

⁴These fungi do not cause advanced decay in living aspen.

⁵No fungi isolated from these samples, probably due to the selective nature of the media used.

⁶These aspen originated post-treatment.

⁷Found on the stump surface of root systems.

The location of most of the decay and insect damage in cut stems is perhaps of most concern at present. Concentration at the base of at least 32% of the dominant stem sprouts will likely increase the probability of early mortality due to windthrow, snow press, or insufficient conductive tissue between roots and stem (Fig. 3). Thus, many of the stem sprouts in the brushsaw and Silvana Selective treatment plots are unlikely to become a valuable future resource. Very little decay was found in the new root suckers that were initiated after the cutting treatment, possibly because of their young age (six years). These post-treatment stems may not develop any more stem decay than untreated stems; however, there is little evidence to

suggest that they will outgrow the defective stem sprouts. Pollard (1971) noted that aspen with larger original diameters are more likely to continue to grow, whereas small-diameter suckers (under 1 cm) usually died from suppression.

Both the general public and forestry professionals consider motor-manual cutting to be an acceptable forest management tool (Buse *et al.* 1994, 1995; Wagner *et al.* 1998). In Ontario, 3000 ha of forest land are tended manually each year (13-year average, 1999–2002) (CCFM 2004). Since cutting is currently the only practical alternative to the use of herbicides, these treatments will likely continue to be used. The presence of defect in the treated aspen stems, both as present-

day decay and as potential sites for future decay, coupled with the decreased growth of these stems (Pitt and Bell 2005) should raise concerns about the quality and utility of this future resource. Modifying broadcast cutting treatments (for example, removing only those aspen growing near conifers) could benefit the quality of both the conifer and hardwood components of the future stand (Pitt *et al.* 2004b). Properly timing such selective treatments, combined with using an appropriate cut height, may increase their effectiveness (Harvey *et al.* 1998).

In Ontario, broadcast application of herbicides is the most common treatment for controlling aspen when conifer is the preferred future crop. Very few aspen suckers survive broadcast applications of the non-selective herbicide glyphosate (Bell 1989, Mallik *et al.* 1997, Pitt *et al.* 2000). In our study, only 32 aspen suckers were found in glyphosate-treated areas. The treated areas, therefore, do not have the potential to produce merchantable aspen of any quality (Pitt and Bell 2005). Selective herbicide application methods that remove only part of the aspen crop may be better suited for mixedwood management.

Unlike glyphosate, the triclopyr treatment killed only aspen leaders. Six years after treatment, a side branch had developed into a new leader on most top-killed suckers (Fig. 1). This top kill did not lead to substantial decay; only 8% of triclopyr-treated aspen had advanced decay at the top-kill site. Similarly, young aspen leaders are often killed by shoot blights, insects, or frost, which results in staining but little decay (Basham 1982, Perala 1984). In our study, stain originating at the top-kill site often progressed down into the stem and up into the new leader; however, decay was rare (Fig. 1). Similar to the cutting treatments, decay fungi were isolated from stained wood as well as from decayed wood at the top kill sites; therefore, future increases in occurrence of advanced decay may occur. However, these fungi are generally classed as saprobes, which are able to colonize dead wood—in this case, wood killed by the herbicide treatment. In a few cases, they were able to move into the newly developing leader, causing localized pockets of decay, but substantial advance into the new leader is not predicted. Antimicrobial defences and internal compartmentalization within the trees should create barriers that protect new wood from invasion by these fungi (Shigo 1984, Basham and Haig 1991, Pearce 1996).

The triclopyr treatment resulted in aspen stems with substantial stem crooks where the new leaders began (Fig. 1). In previous studies, pronounced crooks in aspen stems disappeared in as few as 12 years after top kill (Perala 1971, Basham 1993). However, observations at the Fallingsnow site in 2004 showed that substantial stem crook was still evident 11 years after treatment. Sucker age at treatment time may affect the development of lasting stem crooks. Suckers treated at or below age 5 may recover completely (Perala 1971, Basham 1993), but those that are treated later may retain this defect. We observed similar conditions in a 30-year-old white spruce plantation treated with 2,4-D at about age 15; top kill of the aspen and stem crooks were still evident but no advanced decay was detected at the point of top kill (S. Greifenhagen, unpublished data). The triclopyr-damaged aspen at Fallingsnow may develop into crop trees with poor stem form, limiting their use to composite products. Further monitoring is necessary to determine how long the stem crooks persist.

Aspen root systems are generally described as more defective than stems (Gross and Basham 1981). Although our sample size was small (only four to eight root systems collected per block, treatment, and stem type combination), *Armillaria* root disease appears to be common across the Fallingsnow site, infecting regenerating aspen through parent roots and root wounds. In addition to causing root and butt decay, *Armillaria* root disease can reduce height and diameter growth and eventually kill both small suckers and large trees (Wargo and Shaw 1985, Morrison *et al.* 1991).

Compared to the untreated control, the four conifer release treatments did not directly increase the levels of root disease. Similarly, Perala (1971) did not find increased damage to aspen roots after 2,4-D and 2,4,5-T were applied. However, Stanoz and Patton (1987b) found that aspen stumps and root collar sprouts resulting from repeated short-rotation harvesting were more frequently colonized than suckers. Scarification treatments also increase stain and decay in aspen suckers, mainly due to associated root wounding (Basham 1988, Pankuch *et al.* 2003). In our study, differences in the occurrence of *Armillaria* root disease among treatments can be attributed largely to tree age differences: The younger root suckers that developed after the conifer release treatments had less root decay than the older stem sprouts, top-killed stems, and untreated trees. Similarly, Stanoz and Patton (1987a) observed lower root disease incidence in 3- and 9-year-old than in 15-year-old sucker-origin stands. After harvest, root decay fungi spread from decaying stumps into the parent roots of suckers (Wargo and Shaw 1985, Basham 1988). The new suckers that developed after the release treatments are not as likely to be infected by this method, because they are not as closely linked to the old stumps (Stanoz and Patton 1987b). The Fallingsnow trial area was site prepared using Young's teeth and a disc trencher, both treatments that wound roots, creating entry points for decay fungi (Basham 1988, Wargo and Harrington 1991). In our study, aspen suckers that existed prior to site preparation had more root wounds than the younger suckers that originated after release. Consistent with findings by Pankuch *et al.* (2003), *Armillaria sinapina* was often isolated from root wounds. *Armillaria* species were not isolated from the surface of the cut stems in the mechanical or manual cutting treatments, probably due to their relatively high cut heights. *Armillaria* is the most important root disease in Ontario (Whitney and Myren 1978). Its presence in such a high percentage of young aspen roots suggests that root disease may significantly affect future growth, survival, and quality of the aspen at Fallingsnow.

In Ontario, demand for aspen products is increasing; at the same time, we are rapidly approaching a wood deficit that is predicted to last for 70 years (OMNR 2004). The "unintentional mixedwoods," created by a variety of harvesting and silvicultural treatments, will be viewed as potential sources of aspen fibre in the near future. Observations from the Fallingsnow study site indicate that much of the aspen regenerating from current broadcast conifer release approaches may have reduced potential to develop into a valuable resource, both in terms of quality and growth (Pitt and Bell 2005). The quality of those stems that survive conifer release treatments will continue to decrease with age as other fungi, including *Phellinus tremulae* (the most important decayer of aspen in Ontario) enter the stems through branch stubs and other wounds, regardless of past silvicultural treatments

(Thomas *et al.* 1960, Anderson *et al.* 1977, Basham 1991). If aspen are to become an additional resource on upland sites planted to conifers, then more targeted, individual-tree conifer release approaches may serve to protect the quality of this resource.

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