Wood Degradation after Windthrow in a Northern Environment

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Abstract

Severe windthrows often require salvage operations that can lead to increased costs. Given these extra costs, it is of paramount importance to make sure that wood degradation does not become so advanced that significant value loss is incurred. The rate at which wood deteriorates is a function of many factors, including species and climate.

The study was conducted in a northern area affected by two partial windthrows. Logs from the damaged area were collected for two species, balsam fir (*Abies balsamea*) and black spruce (*Picea mariana*). Logs were classified into one of three degradation classes based on visual assessments. A sample of logs from standing trees was also collected. In total, 167 logs were sampled. Each log was sawn and one piece of lumber was selected from each to determine the bending strength and stiffness and the visual grade.

The time since tree death, as determined from dendrochronology, ranged from 1 to 31 years. The visual grade of the lumber was not affected after 1 year but severe downgrades were observed after 4 years. Moisture content decreased rapidly for both species during the first year and continued to decrease until 4 years after mortality. No clear decrease in bending stiffness was identified even though such a tendency was noticed for older black spruce windthrows. Bending strength became variable after 4 years for balsam fir and was reduced after 4 years for black spruce. Windthrows older than 7 years will produce low visual grade timber of reduced bending strength and possibly of lower bending stiffness.

Windthrow is an important disturbance in many forests of the world (Bergonzini and Laroussinie 2000). Windthrow, which can either be partial, with some trees left standing, or complete, has important economic impacts. Direct loss in value can occur when the bole breaks or splits, especially if this occurs in the bottom log. Furthermore, unless the timber is treated or stored under special conditions, it becomes subject to staining, decay, and insect attacks (Grayson 1987). Even though stain does not affect timber strength, it can nevertheless lead to value losses (Graham and Knight 1965). By contrast, decay involves a loss in wood quality through the degradation of cellulose and often also of lignin (Grayson 1987). The rate of infestation by decay fungi will be a function of tree species, water content, and temperature (Pischedda 2004). Trees that are only partially uprooted will degrade more slowly (Grayson 1987). Most wood-boring insects prefer dying or recently felled trees. After more than 1 year, changes in moisture condition or in physical and chemical conditions render the wood unattractive to insects. However, some insects require more than 1 year to complete their life cycle (Graham and Knight 1965). These insects create entry courts for decay fungi and can lead to significant lumber downgrade (Graham and Knight 1965).

Severe and extensive windthrows often require special responses that include salvage plans and log storing strategies. Volumes salvaged after windthrow have only been surpassed by those salvaged after fire in recent years in Quebec. Moreover, they have reached record values in 2006 to 2007 (Vaillancourt 2008). Salvage operations lead to increased costs related to operational harvesting difficulties and can require additional road access in some regions. In extreme cases, markets can become saturated by the influx of salvaged wood leading to lower timber prices (Grayson 1987, Bouchard et al. 2009).

In northern parts of the Canadian boreal forests, logging still takes place in virgin areas where important windthrows can occur. These forests often have no road access before they are scheduled for harvesting. Hence, when a severe

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windthrow occurs, new access roads need to be built, delaying the salvage operation. In addition, stand volumes are low and tree size is small, meaning that revenues are low, either for standing or downed timber. Given that harvesting costs are higher in windthrown areas, the profitability can be much reduced, especially if timber degradation has taken place. However, given the cold climate, wood degradation could be slower than in other regions (e.g., Wickman 1965, Touliatos and Roth 1971, Flot and Vautherin 2002, Jonsson 2008), which could extend the period under which wood of proper quality can be salvaged. In these conditions, a good knowledge of the rate of wood degradation becomes crucial.

In order to guide the planning of salvage operations, it becomes important to document the rate of wood degradation for specific conditions of species and climate. In this study, we document the effect of time since death on visual grade and mechanical wood properties for two major species typical of the boreal forest of eastern Canada.

Methods

Study region

The study was conducted in the eastern section of the black spruce–moss bioclimatic domain (50°18′15″N, 68°15′55″W), approximately 150 km north of Baie-Comeau, Québec, Canada. This domain covers 412,400 km^2 in the northern part of the commercial forest of Québec. The cold and humid climate (annual mean temperature, –2.5°C to 0°C; mean annual precipitation, 1,300 mm; Robitaille and Saucier 1998) is responsible for a low occurrence of forest fires. In these conditions, secondary disturbances tend to shape the ecosystem. Even if total windthrows do not occur at a very high rate at the regional scale (Bouchard et al. 2009), this region is still the most windthrow prone region in Quebec (M. Huot, personal communication, September 2007). The area is dominated by black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) growing in pure or mixed stands. Stands in the study area had generally reached or exceeded maturity (84% of the area >90 years), which is typical of virgin stands in the region.

From 2003 to 2006, the area was strongly affected by windthrow. A first partial windthrow occurred in 2003, followed by a major windthrow event in 2006. Over this period, a total area of 88,000 ha was affected by different levels of wind damage. The 2006 event led to a significant salvage plan that affected more than 20,000 ha.

Sampling protocol

Field sampling was conducted in 2007. All sampling sites were located within 20 km of each other. We took advantage of the fact that trees that had died at different times could be sampled together in the main sampling site. Since a proportion of stems had not been windthrown, living trees could also be sampled on the main sampling site.

A total of 167 trees, including both living and dead trees, were sampled with the aim of having approximately 20 to 30 trees per species and time of death (Table 1). The sample was based on a time of death for each tree in the field, estimated by external appearance. Windthrown trees that still had green foliage were assumed to have been blown down in the 2006 event. Trees with no green foliage but with the bark still attached solidly to the stem were assumed to have been damaged in 2003. Trees from which the bark could be easily peeled were put in an ‘‘older windthrow’’ category. Additional balsam fir trees, which presumably died in 2003, were sampled on a second site since balsam fir was not abundant enough on the main sampling site. In addition, black spruce was sampled at an older windthrow site of unknown exact age. This was not attempted for balsam fir since this species is known to be very prone to decay (Burns and Honkala 1990).

The bottom 8-foot log from each stem was collected and marked with paint, according to its estimated time of death and species. Log diameters (large end) ranged from 9 to 28 cm for black spruce and from 11 to 30 cm for balsam fir. Logs were transported to Laval University's ‘‘Centre de recherche sur le bois’’ where they were processed.

Dendrochronology-based mortality determination

The exact year of death was determined from dendrochronological analyses made on a disk collected at the large end of the log. After being dried, the disk samples from living and windthrown trees were sanded using successively finer grades of sandpaper until growth rings were clearly visible (Schweingruber 1987). Tree rings counts were made under a binocular microscope. Pointer years (narrow, wide, and incomplete rings) were detected visually and used for cross-dating (Schweingruber 1990). Growth reduction in the tree-ring width (e.g., 1978 to 1979) due to the spruce budworm (*Choristoneura fumiferana*) outbreak in the area was the principal event that helped for cross-dating. Tree-ring widths were measured to the nearest 0.002 mm along two opposite radii using a Velmex micrometer, avoiding wood anomalies (reaction wood, wood decay).

Each tree-ring series for both species was standardized using polynomial adjustments of degrees 2 to 4 (Fritts 1976). The yearly standardized indices from the living trees collected on the sites were averaged to produce an indexed master tree-ring chronology for each species. Two ring-width series were built with one consisting of 18 black spruce and the other of 17 balsam fir logs.

The individual series of dead trees were visually compared and cross-dated to the master chronologies. Subsequently, the Cofecha software (Grissino-Mayer 2001) was used to verify the accuracy of dating. Thus, the year of the outermost ring of every sample could be determined accurately; this exact dating forms the basis for comparisons of lumber properties.

Quality assessment procedures

Each log was processed with a portable sawmill. A 50-mm-thick by 100-mm-wide (2 by 4-in.) piece of lumber was sawn as close to the bark as possible. This was done in order to minimize the size of the slabs (which end up as a lower value chip product) as is the practice in a sawmill that performs sawing optimization. We located the position of the board in order to avoid wane, which would reduce visual grade. By positioning the board in such a way, we also made sure that all the boards came from a similar position relative to the pith, excluding this source of variability from the analysis. Three evenly distributed samples were taken from each slab to determine wood moisture content (MC) by the oven-drying method. The lumber obtained from each species was dried separately following a species-adapted

Table 1.—Correspondence between field estimates of year of death and results from dendrochronology.

Species	Field estimated year of death	No. of sample trees for each measured year of death				
		2006	2005	2004	2003	Before 2003
Black spruce	2006	25	1			
	2003	1			21	4
	Before 2003				4	17
Balsam fir	2006	10	1	1	2	
	2003			2	15	1

schedule in a 2.5-m^3 capacity convection laboratory dry kiln. Black spruce was dried at a dry-bulb temperature varying between 76°C and 99°C and at a relative humidity varying between 36 and 89 percent. Balsam fir was dried in slightly milder conditions, at a dry-bulb temperature varying between 74°C and 95°C and at a relative humidity varying between 53 and 99 percent. The target MC was 12 percent in both cases. Each piece was visually graded before and after drying by a qualified grader according to the National Lumber Grades Authority (NLGA 2000) Standard Grading Rules for ''Structural Light Framing'' (NLGA article 124). The reasons for any lumber downgrade were recorded.

For each piece of lumber, the modulus of elasticity (MOE) and modulus of rupture (MOR) in static bending were determined. The lumber was tested edgewise according to ASTM D198-02 (ASTM International 2002a). Before the bending test, one determination of MC was made on each piece of lumber with an electrical resistance moisture meter. The bending MOE and MOR were adjusted to 12 percent MC following ASTM 2915-03 (ASTM International 2003) and ASTM D1990-00 (ASTM International 2002b).

Correlations between log characteristics (age, diameter) and wood properties (MC, MOE, MOR) were calculated to check for sources of variation that would not be related to year of death. To complete this step, an analysis of variance was conducted on log characteristics. Then, an analysis of variance was also performed on MC, MOE, and MOR (dependent variables) for each species. When a significant effect of year of death (explanatory variable) was detected, means were compared using the Duncan multiple range test. All analyses were performed using SAS (9.1) software with $\alpha = 0.05$.

Results

The numbers of trees sampled by estimated and measured year of death are presented in Table 1. The measured time of death was closely linked to field estimates. Of the 21 black spruce trees for which death was estimated to have occurred before 2003, 4 had died in 2003 (Table 1) and none had died in 2001 or 2002. Time of death was thus reclassified. Trees that died in 2005 or 2006 form the 2006 group, and trees that died in 2004 and 2003 are pooled in the 2003 class. Time of death ranged from 1976 to 2000 for old black spruce windthrows (Fig. 1); these trees are referred to as the ''2000'' category in this article. Figure 2 provides an example of the appearance of the different types of logs, from living trees (Log 107) to one of the oldest trees that had been dead for a very long time (Log 418).

For black spruce, age was not related to MOE or MC ($P = 0.19$ and $P = 0.25$, respectively). However, MOR decreased significantly with age ($r = -0.51$, $P < 0.0001$). The 17 trees that died in 2000 were older than the other groups (187 years old vs. 92 to 97 years old) that did not differ from each other ($F = 83.18$). Log diameter was positively correlated with MC ($r = 0.39$, $P = 0.0003$). Diameter of the 19 living stems was somewhat larger (19.94 cm vs. 15.84 to 17.27 cm) than the diameter in the other categories ($F = 5.27$, $P = 0.0023$). For balsam fir, MOE, MOR, and MC were not correlated with age or diameter ($P > 0.46$).

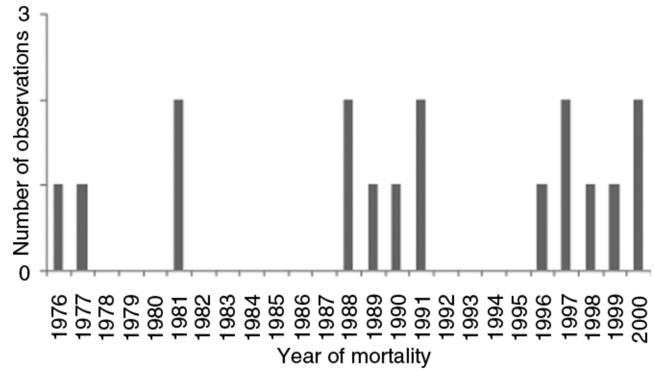

Figure 1.—Time of death of black spruce trees initially classified as old windthrows.

For balsam fir, drying generally had little impact on visual lumber classification, except for the 2003 windthrows for which the yield of Grade 3 lumber increased from 28 to 47 percent at the expense of the better grades. After drying, most of the lumber from living balsam fir trees was classified as Grade 2 or better (Fig. 3). The same situation is also observed for trees that had been dead for 1 year. For the 20 trees that died in 2003, Grade 3 was the most frequent. In the 12 pieces from the 2003 and 2006 groups that were Grade 3 or lower, 10 were downgraded due to the presence of rot (insect holes and a split board explained the other

Figure 2.—Examples of the different types of logs included in the study: Log 107, living balsam fir tree, 104 years old; Log 208, balsam fir, dead for 1 year, 110 years old; Log 316, black spruce, dead for 5 years, 88 years old; Log 319, black spruce, dead for 5 years, 86 years old; Log 418, black spruce, dead for 30 years, 185 years old.

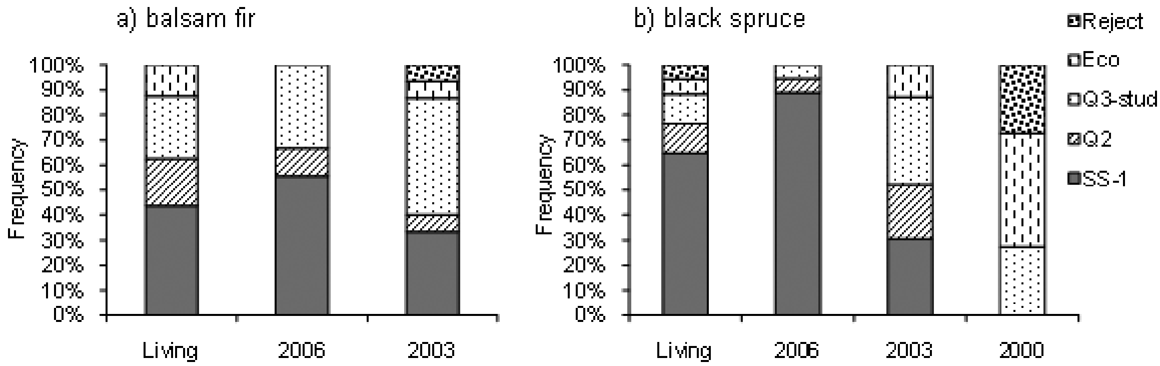

Figure 3.—Lumber visual grades by year of mortality (after drying). NLGA grades: SS-1, Select Structural and Grade 1; Q2, Grade 2; Q3, Grade 3; Eco, Economy.

two). All living trees rated as Grade 3 were downgraded due to rot.

For black spruce, the majority of the 19 living and 27 recently dead trees qualified for Grades 1 and Select Structural, both before and after drying (Fig. 3). Inferior grades (lower than Grade 2) were more frequent for trees that died in 2003, and drying increased their frequency from 33 to 48 percent. In the 2000 and 2003 groups, all boards degraded to Grade 3 or less were downgraded due to rot. No lumber from the oldest windthrows qualified for Grade 2 or better, either before or after drying.

Insect holes were present in several pieces from both species (7 of 20 windthrown firs and 20 of 52 windthrown spruces, none in living trees). The NLGA Select Structural grade allows for some insect holes. For example, 16 of the 22 pieces of lumber from the 2003 spruce sample contained insect holes. Among those, six still qualified for the Select Structural grade. Since specific markets do not accept insect holes, a premium ''no insect holes'' class is often segregated to serve these more stringent market requirements. About half of the living or recently dead (2006) black spruces qualified for this premium class. Unlike the 2006 category in which four of seven degrades were due to insect holes, the grade reductions in the live trees category were related to other defects. Almost no trees that died in 2003 (3%) met the premium standards.

The MC of the slabs sawn from green logs is presented in Figure 4. For both species, there was a significant decrease in MC of slabs from living trees to trees that died in 2006 and to trees that died in 2003 (balsam fir: $F = 43.78$, $P < 0.0001$; black spruce: $F = 36.31$, $P < 0.0001$). An increase in water content was observed for old black spruce windthrows (2000) compared with trees that died in 2003. Although MC remains above the fiber saturation point for all groups, the mean MC for black spruce trees that died in 2003 was only slightly above it (Fig. 4).

The bending properties of balsam fir lumber did not vary significantly based on year of death (Fig. 5; MOE: $F = 1.22$, $P = 0.3073$; MOR: $F = 0.37$, $P = 0.6906$). However, variability becomes high in trees that died in 2003 (coefficients of variation for living trees: MOE 9%, MOR 21%; for trees dead in 2003: MOE 25%, MOR 39%). For black spruce lumber, there was a tendency for a reduction of the bending MOE in old windthrows only (Fig. 6; $F = 2.58$, $P = 0.0622$). A reduction in bending MOR occurred earlier since trees that died in 2003 had significantly lower MOR values compared with living trees ($F = 11.42$, $P < 0.0001$).

Discussion

The first impact of windthrow on wood characteristics was a reduction of the green MC. According to Pischedda (2004), the high MC of freshly dead wood makes it a poor

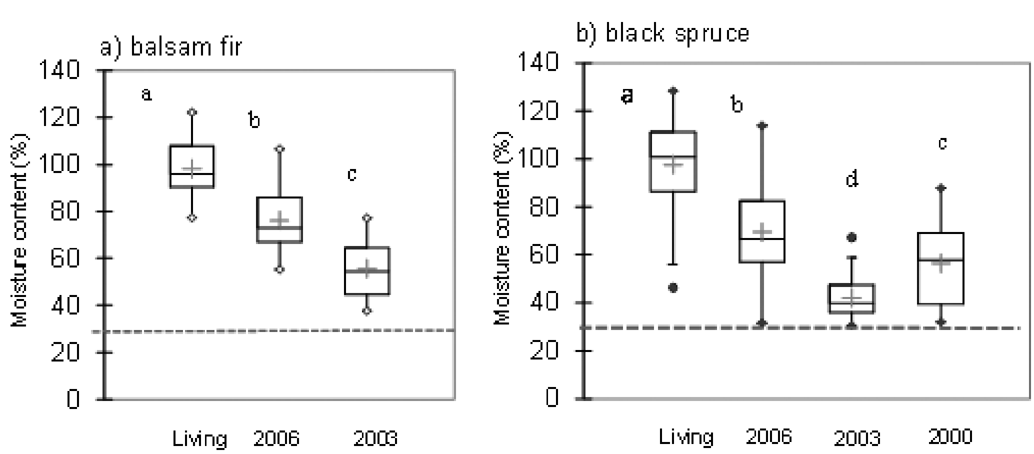

Figure 4.—Moisture content of slabs obtained from green logs by year of mortality: (a) balsam fir; (b) black spruce. Dots, minimum and maximum values; bars, first quartile, median, and third quartile; cross, mean; dotted line, fiber saturation point. Values with similar letters are not significantly different based on a Duncan multiple range test (α = 0.05).

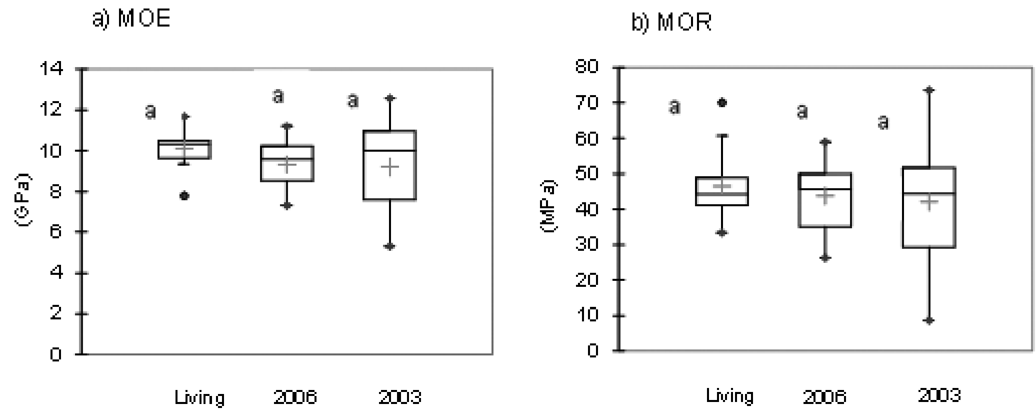

Figure 5.—Bending properties of balsam fir lumber according to time of death. Dots, minimum and maximum values; bars, first quartile, median, and third quartile; cross, mean. Values with similar letters are not significantly different based on a Duncan multiple range test (α = 0.05).

substrate for fungal development. Soon after death, however, the MC starts to drop and significant decreases are observed after 1 year. The fact that the crown is still attached to the uprooted tree hastens the decrease in MC (Pischedda 2004). The relationship between MC and log diameter for black spruce was simply due to the larger diameter of living stems. For balsam fir, a decrease in MC was also seen after 1 year, without any effect due to log diameter. MCs after 1 year were in a range (20% to 80%) favorable for decay fungi development. Studies in Europe have shown that in situ storage of trees that are only partially uprooted could preserve lumber quality for 6 to 12 months in *Picea abies* (Pischedda 2004, Jonsson 2008). Both studies reported losses in wood quality after the second growing season. However, the rate of degradation is related to the local climate and degradation could be slower in a cold climate such as that of the current study area.

Lumber from the 40 trees that had been dead for 1 year showed few signs of degradation. After 1 year, the visual grade after drying was not seriously affected for either species, considering that the Select Structural and Grades 1 and 2 are generally sold at the same price. The yield of Grade 3 lumber from these trees probably reflects the amount of rot that was already present in the living trees. Hence the product value after 1 year should not be affected, as long as the recovery rates from a given log are not reduced. An additional study would be required to look at the impact of windthrow age on recovery rates, but it is likely that these would be reduced in the older windthrows, adding to the problem of reduced quality.

The bending properties (MOE and MOR) of both species were also unaffected after 1 year. According to Wilcox (1978), toughness, or the ability to withstand shock loading, is generally the property most sensitive to decay. Bending properties would be the next most sensitive to decay; however, the relative sensitivity of MOE and MOR seems to differ between studies. In the milder climate of Scotland, Mochan (2002) also noticed that the yield of machine stress rated (MSR) lumber was not affected up to 18 months after windthrow for Sitka spruce (*Picea sitchensis*). It must also be mentioned that growth of Sitka spruce in plantations is much faster than growth of natural virgin stands of black spruce in a cold climate. Even though their properties will necessarily differ, it remains interesting to compare their rates of degradation in the absence of more comparable studies.

Insect holes in black spruce did not cause additional reduction in premium lumber yield after 1 year. According to Graham and Knight (1965), freshly dead trees would be the most attractive for wood-boring insects, suggesting that most of the infestation would occur during the first year

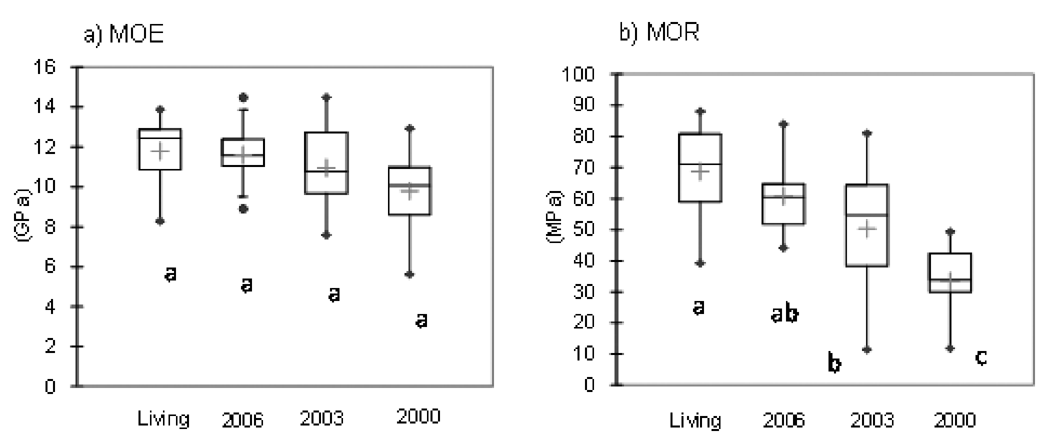

Figure 6.—Bending properties of black spruce lumber according to time of death. Dots, minimum and maximum values; bars, first quartile, median, and third quartile; cross: mean. Values with similar letters are not significantly different based on a Duncan multiple range test (α = 0.05).

after windthrow. However, the main species present, *Monochamus scutellatus,* requires 2 years to complete its life cycle in the climatic zone where the study was conducted (Natural Resources Canada 2010). Because eggs are laid in the summer and the 2006 windthrow occurred in late fall, there was a delay before the trees were attacked. This could explain why decreases in premium lumber yield were not observed after 1 year but became important thereafter.

For the 50 trees dead for 4 years, important signs of degradation were seen for both species. For both dried balsam fir and black spruce lumber, Grade 3 became dominant and the proportion of Grade 1 was strongly reduced (Fig. 4). The bending properties of balsam fir were not significantly reduced but became extremely variable (Fig. 5). For black spruce, bending MOE was not affected, but MOR was reduced (Fig. 6). The lack of MOE reduction contrasts with observations from Mochan (2002) who found a significant decrease in MSR lumber yield for Sitka spruce, 3 years after windthrow. The milder climate of Scotland where the Mochan study was conducted or species differences in wood properties and resistance to rot could lead to this difference. However, this study provides no information on the impact of rot. Strong reductions in MC in slabs were also observed for both species.

Wood mechanical properties are strongly determined by cellulose organized in microfibrils in the cell wall. Brown rot, which is typical of softwoods, metabolizes cellulose and hemicelluloses of the cell wall, leaving lignin relatively intact (Schmidt 2008). The speed of degradation would be a function of both the resource quality and the environment, namely temperature and humidity (Swift et al. 1979). Significant decreases in strength and dimensional stability can occur at relatively low mass loss (Schmidt 2008).

For the 17 black spruce trees dead for 7 years or more, wood degradation was evident. This category included a wide range of time since death, from 7 to 31 years. The best grades (Select Structural, Grades 1 and 2) were nonexistent in our sample and several rejects were found. Reductions of product value are to be expected, even without changes in recovery rates. Mean MC was lower than in living trees but higher than in trees dead for 4 years. Such increases in MC when decay progresses are typical in the process of organic matter decomposition (Swift et al. 1979). Bending MOE values were not significantly reduced although a clear tendency was noted. Bending MOR showed important reductions in comparison with living trees. Even though a relationship between MOR and age was noted for black spruce, the decrease in MOR with time since death could not be attributed to age because the decrease was significant for trees that died in 2003, without differences in age. To try to account for the wide range of year of windthrow in that category, an attempt was made to subdivide it into trees that had been dead for 7 to 11 years and those that had been dead for longer periods. These two groups did not differ from each other in terms of MC, MOE, or MOR. Trees that had been dead for 7 to 11 years differed from trees that had been dead for 4 years in terms of MC but not in terms of MOE and MOR. Thus, the general conclusions are not affected by the 2000 group having a wide range in time since death.

In this study, drying schedules were designed to take into consideration the variability of the material. They were generally successful in avoiding further downgrades of sawn timber. One exception was for the 2003 windthrow in which additional downgrades were observed postdrying for both species. Even though we used a species-adapted drying schedule, it remains possible that some of this timber was over-dried due to its lower initial MC. This material was also shown to be more variable in terms of MOE and MOR. It is likely that local field conditions affect the rate of wood degradation and that after 4 years conditions reach a critical threshold. In salvage operations involving a complex windthrow pattern such as the present one, the material that would be sent to the sawmill would include trees of both species that were still living, trees that were recently windthrown, as well as trees that may have died 4 years before. MC, as well as other properties, will be extremely variable, making it difficult to design an optimal drying schedule, unless the logs are initially sorted or in line MC determination is used to sort the lumber.

Conclusion

The rate of degradation varies with the properties examined. Visual grade is generally not affected after 1 year. Important downgrades were seen for both balsam fir and black spruce after 4 years. MC diminished rapidly and this continued up to 4 years after windthrow for both species. Bending MOE was not significantly reduced during the first 4 years after windthrow, although it tended to become more variable. There are some indications that it could be reduced in older black spruce windthrows. Bending MOR became highly variable after 4 years for balsam fir and a reduction in MOR was observed for black spruce.

Given these results, salvage operations in windthrown balsam fir and black spruce stands in northern Quebec in which the damage occurred less than 1 year prior would probably have a minor impact in the sawing process and product value, except maybe for the drying process. After 4 years, the situation becomes complex and value losses are to be expected. It may also be necessary to sort the logs to avoid problems at the drying phase. The fact that a reliable estimation of time since death can be made in the field would offer an opportunity to conduct this operation. Given the important changes in wood properties in windthrown timber older than 7 years, salvage operations in such stands should be avoided.

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