

# Sources of variability of red heartwood in paper birch (*Betula papyrifera* Marsh.) wood and its impact on grade recovery and lumber value.

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## Abstract

Paper birch (*Betula papyrifera* Marsh.) as is an interesting alternative to the high-value species traditionally used by the Québec hardwood sawmilling industry. Its pale and homogeneous sapwood is appreciated for many indoor uses. However, paper birches grow a false heartwood, also called discolored wood or red heartwood, contrasting in coloration with the surrounding sapwood. The objective of this study was firstly to analyse the distribution of discolored wood at the stem and at the log levels. Tree age, tree dimension (DBH), tree vigor, log height class and log quality class were examined as explicative variables affecting the proportion of discolored wood in paper birch boards. Secondly, the impact of this color variability on grade recovery and lumber value was assessed. Results show that tree diameter and tree vigor were statistically found to influence the proportion of discolored wood; larger and less vigorous trees presented more discoloration on their boards. Tree age influence was not strong enough to impact directly the proportion of discolored wood; its influence was indirect through tree diameter. Neither log height class nor log quality class had a significant impact on red heartwood presence in boards. Results showed that tree diameter was the most important variable affecting board quality; larger trees were associated with higher board quality. Concerning board value, once again tree diameter was an important variable but also tree vigor. It was found that most vigorous trees produced higher board values with an average of 316.62 \$/m<sup>3</sup>, middle vigor classes showed averages of 218.28\$/m<sup>3</sup> and 251.84 \$/m<sup>3</sup> while the less vigorous trees had the lowest average with 165.94\$/m<sup>3</sup>. When selected for color, the majority of the board surface area fell under the sap category (50%), while 28 % were classified as regular presenting simultaneously both colorations and finally only 4% of the board area was classified as red. It was found that the most important variable affecting this board color distribution was mostly tree diameter whereas tree vigor and tree age had also a significant but lesser impact. In general, older, larger and less vigorous trees tend to present higher proportions of boards classified in the red category and less boards in the sap category. Finally the results obtained in this study are favoring longer harvesting rotations in order to produce large trees that can be transformed in higher value and quality boards but at the same time these same trees will also produce higher proportions of discolored wood in their boards.

## Introduction

The availability of high quality hardwood timber has become critical for furniture and other appearance products industries over the past years in Québec, Canada. The broad distribution of paper birch (*Betula papyrifera* Marsh.), as well as the good aesthetic and physical characteristics of its wood, makes it an interesting alternative to the high-value species traditionally used by the hardwood sawmilling industry. Its pale and homogeneous sapwood is appreciated for many indoor uses. However, paper birches grow a false heartwood (i.e. not induced by normal aging

processes), also called discolored wood or red heartwood, contrasting in coloration with the surrounding sapwood (Figure 1). This difference in shade is not appreciated by the appearance product industry where in general homogeneous color products are desired.

The importance of discolored wood in paper birch stems was underlined in many studies. Giroud and al. (2008) reported that discolored wood corresponded to 13.3% of the tree merchantable volume; a proportion obtained measuring 18 paper birch trees. In a study where 12 paper birch stems were dissected into more than 200 smaller stem sections, Belleville

et al. (2008) found that 98 % of those stem sections presented some discolored wood. Basham (1991) found that discoloration represented 70% of the white birch volume of defects, sampling 936 trees in a province wide survey in Ontario, Canada. Campbell and Davidson (1941) reported that most of paper birch trees older than 50 years presented some discoloration while they qualified this presence as considerable in trees older than 70 years. Finally, Brière (1992) mentioned red heartwood as the most important defect in paper birch for appearance products, small knots and bark inclusions being second and third in importance.

Discolored wood or redheart is considered as a traumatic coloration by many authors (Shigo 1967, 1986, Shigo and Larson 1969, Shigo and Hillis 1973, Hallaksela and Niemisto 1998, Campbell and Davidson 1941, Allen 1996, Boulet 2005, Siegle 1967 and Basham 1991). Most of them believe discolored wood would be a result of processes associated with tree injuries involving tree internal reactions and the action of micro-organisms. Broken branches, and to a lesser extent stem wounds, would be the triggering event for discolored wood formation. According to Shigo and collaborators, the sequence of events can be divided in three steps. Firstly the injured area exposes wood cells to the external conditions and constitutes a way of entrance in the tree for air and micro-organisms. At that time an initial discoloration appears in these injured cells; a chemical barrier is formed to create a protective zone to prevent infection in the tree. A second stage of the process might happen when bacteria and non-decay fungi invade this wounded area which may induce more

discolorations. Finally the process might reach a third stage if decay fungi enter the wounded area and lead to wood deterioration. Different stages of discoloration may be present in a paper birch tree through time and in different locations of the tree.

Different researches came with the same conclusion that fungi and microorganisms are involved in redheart formation. Siegle (1967) showed that discolored wood is the result of an enzymatic oxidation caused by fungi entering the tree after a mechanical injury. Campbell and Davidson (1941) established an association between discolored wood and a non-decay fungi *Torula ligniperda*. In Scandinavia, stem discolorations in planted silver birches (*Betula pendula* Roth.) were studied and non-decay fungi strains were isolated from 83% of the samples coming from 30 to 65 year old trees, while 65% of the discolored areas contained bacteria (Hallaksela and Niemisto 1998). However, only 6% of the sampled trees had a decay-fungi presence.

Red heart appears to be distributed either in a central column in the stem or in isolated areas mostly related to broken branches or other stem defects (Hallakseka and Niemisto 1998, Giroud and al. 2008, Belleville et al. 2008). Hallakseka and Niemisto (1998) found that the discolored column had a spindle shape, with or without branch discolorations connected to it, with a maximum cross-sectional area when approaching 1 meter in height. For Giroud and al. (2008) the vertical distribution of red heartwood in paper birch had a spindle shape for 14 trees and a conical shape for 4 trees. Belleville and al. (2008) found that the discoloration column increases in diameter



Figure 1: Red heartwood in birch material from the forest to the lumber (source I.Duchesne).

from the breast height (1.3m) to a maximum diameter at 3 to 4 meters of height.

Hallaksela and Niemistö (1998) results suggested that tree age had an effect on the proportion of discolored wood in the investigated planted silver birches (*Betula pendula* Roth) stems. As the trees got older the diameter of the discolored column around the pith increased. The average volume of discoloration in all sampled birches (18-65 years old) was 1.6 dm<sup>3</sup> while it was 3.2 dm<sup>3</sup> for the older trees (42-65 years old). Giroud and al. (2008) came with similar results; they noted that the presence of red heart was positively correlated with tree age at stump height.

Given the suggested relationship between tree defects (broken branches, stems wounds, etc.) and wood coloration in paper birch stems, it appears interesting to study the effect of tree vigor on the wood coloration of this species. In the province of Québec, selection system has become the main silvicultural strategy to manage uneven aged hardwood stands. Under this system, a recent classification system is used to determine tree vigor based on external tree defects, the MSCR classification (Boulet 2005). Trees classified as M (mourir), standing for non growing stock, and as S (survie), standing for poor growing stock, correspond to the less vigorous trees and should be harvested in priority. Trees classified as C (conserver), standing for acceptable growing stock, and R (réserve), standing for premium growing stock, are assigned to the most vigorous trees and correspond to the growing forest capital. The harvesting priorities of the industrial companies operating on crown lands are set following this classification, where less vigorous trees (M, S) have to be harvested first. The impact of this new classification system (MSCR) on board recovery was assessed (Duchesne 2006) and it was found that it takes twice the number of moribund (M) trees to produce 1000 board feet compared to the highest vigor trees, known as the reserve stock (R). The total average revenue per net cubic meter (m<sup>3</sup>) of stem was 90.99\$/m<sup>3</sup> for the less vigorous trees (M) and 163.08\$/m<sup>3</sup> for the most vigorous trees (R), when boards were unselected for color. When selected for color, these average values reached respectively 95.50 \$/m<sup>3</sup> and 194.90\$/m<sup>3</sup>. Consequently following these results revenues of sawmills

are expected to decrease in the future due to their obligation to harvest less vigorous trees in priorities, and this until hardwood stands recover some of their vitality.

The main objective of this study is to evaluate the importance of red heart in paper birch wood, to better understand its sources of variation, and to measure its impact on products quality and value. The specific objectives are to analyze the effects of tree age, diameter and vigor, as well as log height class and log quality on redheart distribution and to assess the impact of tree age, diameter and value on lumber grade recovery, lumber value as well as board selection for color (red-sap-reg).

## Method

### *Material selection and preparation*

The research material used in the present study originated from paper birch stems collected in two stands located in the north of the Laurentian region in the province of Québec, Canada (N47°, W74°). The first overmature mixed stand was selected in the winter 2005 while the second stand which regrouped younger and smaller trees was selected in the autumn 2007. They were located less than a kilometer away from each other on the same ecological type (MJ22: Bétulaie jaune à sapin sur dépôt de texture moyenne mésique (Yellow birch-fir forest on loamy or mid texture and well drained soil)) (Gosselin 2002).

A total of 100 and 68 paper birch stems were selected in the first and the second stand respectively, based to the tree vigor which is determined by MSCR classification system. The aim of this selection was to obtain a fairly even distribution in each vigor classes.

The first stand was harvested in the winter of 2005. More precisely, trees were harvested at the end of March 2005, left in the forest with their branch intact until June 2005 when they were cut into logs following an optimized slashing based on Petro and Calvert (1976) rules for log quality. A total of 261 logs were produced out of which 130 were of sawlogs (F1, F2, F3 and short logs (F4)) and 131 logs were pulpwood. The sawlogs originated from sixty-height trees.

The second stand was harvested at the beginning of October 2007. Logs were produced following the same slashing optimisation two weeks after the harvesting operation. From this process, 84 sawlogs (F1, F2, F3, F4) and one veneer log were obtained (from 54 different birches) while the other 101 logs produced were pulpwood.

In total, 122 of the previously 168 selected stems gave sawlogs and only those logs were retained for the present study, including the only veneer log. For those trees which produce sawlogs, the diameter at breast height (DBH) ranged from 24 cm to 66 cm, with an average of 33 cm, both stands included. Tree age ranged from 46 to 154 years, with a mean of 101 years. While most of the trees coming from the first stand were older than 100 year with an average of 122 years, trees of the second stand were younger than 100 years with an average of 74 years. Concerning tree vigor, 32% of these trees were classified as M, 26% as S, 22 % as C and 20% as R.

Log quality was assessed and measured under the provincial grading system (MRNFQ 2007) for which logs are classified either as A for veneer logs, B and C for sawlogs, D for pulp wood and E for short logs, and under a similar system; the Petro and Calvert (1976) for which sawlogs are classified (F1, F2 and F3) and short logs (F4).

The 130 sawlogs of the first mill were sawn into boards at a hardwood sawmill, using a sawing around pattern, in June 2005. The central blocks were resawn into boards on a “WoodMizer” portable sawmill shortly after. From those operations, more than 1400 boards were produced. The 85 logs of the second stand were sawn at the beginning of November 2007 and this time more than 800 boards were produced. In total 2284 boards were retained for colorimetric analysis.

The produced boards had dimensions that ranged from 1.22 to 3.66 meters (4 to 12 feet) in length and from 7.62 to 33.02 cm (3 to 13 inches) in width. These boards were graded under the National Hardwood Lumber Association (NHLA) grading rules (Rules of the measurement and inspection of hardwood and cypress) (NHLA 2007) prior to drying. In addition, a selection for color was realized

meaning the red and sap categories were assigned to homogeneously colored boards. Board prices were determined using the Hardwood Market report price list of February 2008 (table 1) which assigns a price for each NHLA categories. The prices, in US dollars per 1000 pmp, were selected for birch in the Northern Hardwood table, and they are prices for 4/4 boards of random widths and lengths, green and rough. Prices for the #3B Common category (pallets) was obtain from this same report under the pallet lumber for the 4x4 random widths. Prices for color selection were used, meaning that additional values of 305\$/M’ and 280\$/M’ were added for boards classified as red and sap respectively. Lumber value in a broader perspective was determined on a tree basis. The lumber value per tree is the sum the total value of all boards of a tree over the volume of these boards and is expressed in US dollar per cubic meter (US\$/m<sup>3</sup>).

Table 1 Paper birch lumber prices

NHLA categories	REGULAR	RED	SAP
	US \$ / M <sup>3</sup> <sup>a</sup>		
FAS	1055	1360	1335
SEL	1035	1340	1315
#1C	650	955	930
#2A	415	720	695
#3A	285	590	565
#3B	225	–	–

Source : Hardwood Market Report, March 14 2009

a : 4/4, Green, rough, random widths and lengths

All boards were dried by conventional kiln drying in the following month of the sawing for both stands, according to a mild schedule that reached a maximal temperature of 140 F (Normand 2004). They were planed on both face using a moulder (Weinig Unimat 23 EL) to get a fresh and clean surface before scanning to study wood color.

#### *Colorimetric analysis*

The colorimetric analysis was performed on board images acquired by an industrial scanner developed by the CRIQ (Centre de recherche industrielle du Québec) for a wood furniture industry application, the BorealScan (Caron 2005). For each board two digital images were recorded, i.e. one on each face. Defects have been automatically identified by the scanner. An image processing software developed for

the scanner, CRIQTraitement, was used to view these images, to process them and to collect colorimetric information. The software allowed for the segmentation of the board images into two different zones representing the sapwood and the discolored wood, based on the pixel color intensity (Figure 2).

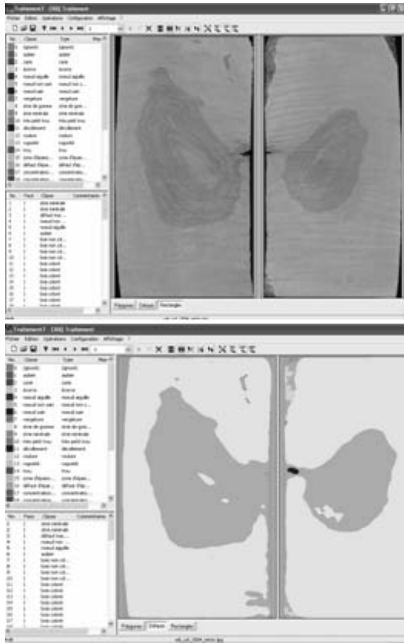


Figure 2 Example of an image segmentation achieved by the software CRIQTreatment where sapwood and discolored areas were created.

### *Statistical analysis*

Results were validated using the SAS software version 9.1 for Windows (SAS Institute 2003). Multiple regressions were used to test and model simultaneously the effects of three tree variables (tree age, diameter and vigor) on the proportion of discolored wood in boards. A mixed model procedure was used to take into consideration the random effects associated with the hierarchical model i.e. board, log, tree and stand associations. The significance threshold used to determine the significant variables was  $\alpha = 0.05$ . A same kind of analysis were done to measure the impact of the log variables (log height class and log quality) on the proportion of discolored wood in boards and to measure to impact of tree age, diameter and vigor on the lumber value per tree.

In the case of the NHLA and board selection for color distributions, logistic regressions were used due to the categorical nature of these dependant variables. Again the effect of tree

age, diameter and vigor were assessed. Random effects were also added in these models, to consider this time the associations between the boards belonging to the same logs, trees and stands. The fact that these random effects were included in the model did not allow using polynomial (or polychotomous) logistic regressions. Therefore, many binary (or individual) logistic regressions were used to compare separately each level of the variation of the dependant variables. According to Begg and Gray (1984), using numerous binary logistic regressions do not take away too much efficiency from the model and results are comparable to a polynomial logistic regressions including the same comparisons. The Bonferroni correction (Abdi 2007) was applied on the probability values when assessing the tree vigor effect because of the multiple comparisons done between each of the MSCR classes.

## **Results**

### *Proportion of discolored wood*

Discolored wood was present in almost every tree analyzed in this study, but the sapwood's proportion was higher on board surfaces. When considering all boards, an average percentage area of 32.4 % of discolored wood was obtained. Tree diameter and tree vigor significantly influenced the proportion of discolored wood in boards whereas the effect of tree age was not strong enough to have a significant influence in the model. Tree age effect was considered as indirect through tree diameter. Larger trees presented more discoloration on their boards (Figure 3), as well as less vigorous trees, which showed a mean percentage area of 45.32 % compared to middle vigor classes and most vigorous trees which obtained a mean percentage area of 30.78% and 15.47 %, respectively (Figure 4). Neither the log quality nor the log height class had a significant effect on the proportion of discolored wood. In consequence, this part of the study suggests shorter rotations to limit the presence of discolored wood in boards. Moreover, according to these results log selection based on quality classes should not influence too much the presence of discoloration in paper birch boards, which means that the probability to get discoloration

is about the same regardless of log quality classes.

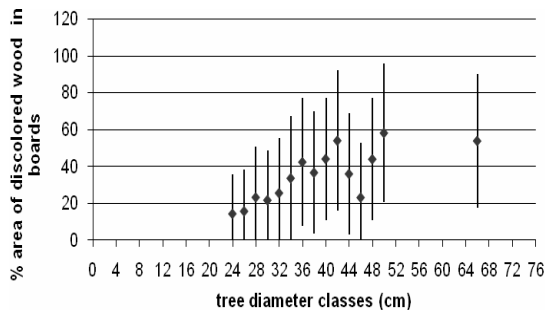


Figure 3 Percentage areas of discolored wood in boards in relation to tree diameter (average and standard deviation).

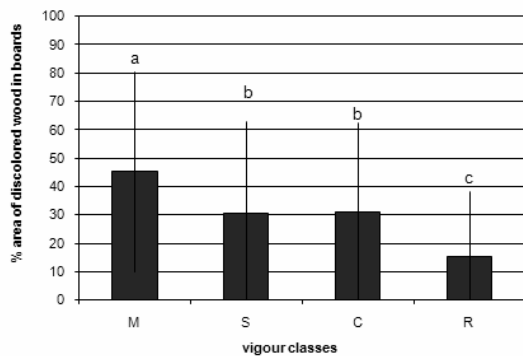


Figure 4 Percentage areas of discolored wood in boards in relation to tree vigor classes (average and standard deviation). Different letters indicate significant differences between vigor classes.

### Board quality and value

Regarding board quality, paper birches stems assessed in this study yielded a high proportion of low-grade lumber according to the NHLA rules; only 19% of the total board surface area belonged to Select and none of them reached the higher grades FAS and FAS-1-Face (Table 2 and Figure 5). Results showed that tree diameter was the most important variable affecting board quality; larger trees were associated with higher board quality. Board quality was partly influenced by tree age and tree vigor, but not as strongly as tree diameter.

When boards were selected for color, 50 % of the boards surface area belonged to the sap category, 28% to the regular category on which a mix of sapwood and discolored wood is present and only 4% were classified in the red category (Figure 5). It was found that the most

important variables affecting this board color distribution were mostly tree diameter (Figures 6) whereas tree vigor (Figure 7) and tree age had also a significant but lesser impact. In general, older, larger and less vigorous trees tend to present higher proportions of boards classified in the red and regular categories. Thus, these same trees tend to produce less sap classified boards.

Table 2 Lumber grade distribution

NHLA grades	% of total number of boards	% of board surface
FAS	0	0
F1F	0	0
Select	14.8	19
#1 Common	17.6	21
#2A Common	21.7	20
#3A Common	24.8	22
#3B Common	21.2	18

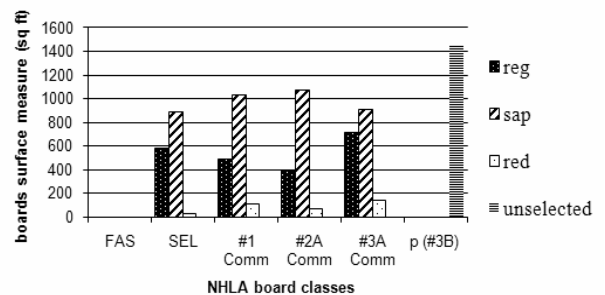


Figure 5 NHLA distribution when boards are selected for color.

Using market value (table 1), the average lumber value per tree was calculated. When all of the 122 trees are considered, a mean value of 230.76 \$/m<sup>3</sup> was obtained. The range of values was fairly large, from a minimum value of 99.38 \$/m<sup>3</sup> to a maximum value of 412.62\$/m<sup>3</sup>, with a standard deviation of 58.49 \$/m<sup>3</sup>. Tree diameter had a significant impact on lumber value; larger trees were associated with higher lumber values per tree (Figure 8). Lumber value per tree was as well influenced by tree vigor but not by tree age. Most vigorous trees produced higher board values with an average of 316.62 \$/m<sup>3</sup>, middle vigor classes showed averages of 218.28\$/m<sup>3</sup> and 251.84 \$/m<sup>3</sup> while the less vigorous trees had the lowest average with 165.94\$/m<sup>3</sup> (Figure 9).

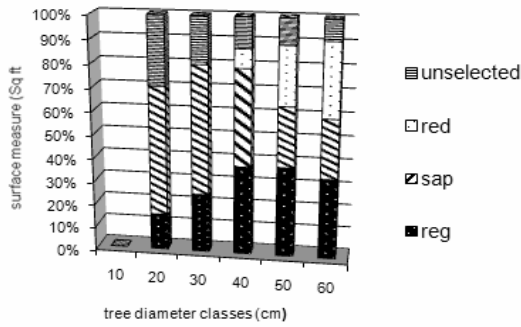


Figure 6 Board color classification in relation to tree diameter

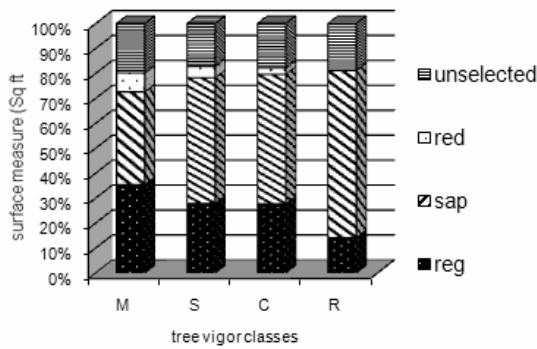


Figure 7 Board color classification in relation to tree vigor

Finally from a product perspective, longer harvesting rotations should be favored in order to produce large trees that can be transformed in higher value and quality boards. However, these same trees will produce lumber with higher proportions of discolored wood, which will increase the challenge of producing homogeneously colored final products. The impact of tree vigor seems to be mostly on wood color and not on surface defect since it did not influence too much board quality but did influence board color and the percentage of discolored wood in board. Finally, in current North American markets, boards classified as red have the highest prices; therefore it should be considered as an asset in an economic perspective, but as a niche market product considering its limited presence (4% of board surface).

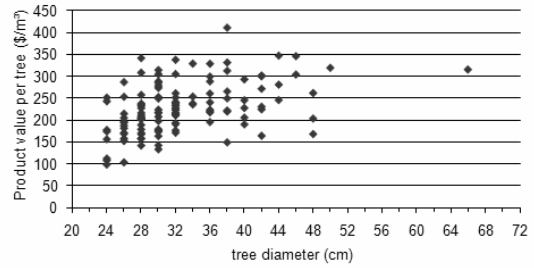


Figure 85 Lumber value per tree in relation to tree diameter (DBH)

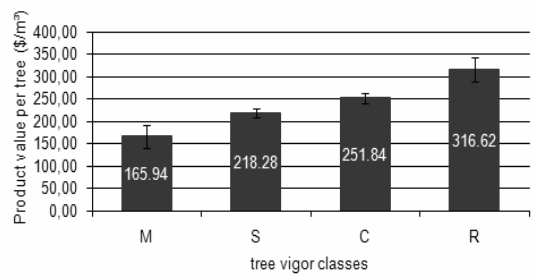


Figure 9 Lumber value per tree in relation to tree vigor (MSCR) (average and standard error).

### Random effect

The analysis of the random effects throughout the study demonstrated that most of the total random variance of the dependent variables came mostly from the between board variation, but also from the between tree variation and to a lesser extent from the between log variations. These results suggest that the fact that boards are coming from a same tree or a same log does not influence excessively the variables assessed in this study compared to the random variability that exists between boards. Site effect never induced any significant impact on the observed variables; the fact that only two stands were considered induced a too high incertitude to draw any conclusion.

### Conclusion

This study allowed developing knowledge on the distribution of red heartwood in paper birch stems, on the explicative variables affecting its presence as well as on its impact on lumber quality and economic value. It was found that tree diameter was an important variable impacting discolored wood proportions, lumber quality, lumber color selection and

lumber value. In general larger trees produced higher quality and value lumber, but also induced a higher proportion of red heartwood on lumber surface. The impact of tree age was most of the time in the same direction than tree diameter but not as strong and not always significant. Tree vigor classes (MSCR) seemed to influence mostly the proportion of discolored wood on board surface and product value. Most vigorous trees produced lumber with higher proportions of sapwood and higher values. The log characteristics evaluated in this study, i.e. log height class and log quality, did not influence significantly the proportion of discolored wood in boards.

Better knowledge on the relationships between tree characteristics and final hardwood product attributes will help improve silvicultural decisions and raw material allocation for specific end-uses. This study contributed to assess the sources of variability of paper birch wood color, which is a prerequisite to predict its presence and further develop the utilization of this species in value-added hardwood products.

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