A Tree Classification System for New Brunswick

Northern Hardwoods Research Institute

Notes about the Second Edition

The Tree Classification System for New Brunswick has been in place since 2012. It has since been gradually implemented in many jurisdictions for different purposes such as in forest sample plot inventory (FDS and PSP) by the New Brunswick Energy and Resource Development and in a variety of research projects by organisations in New Brunswick, Quebec and Maine, USA. Throughout its implementation, comments and suggestions provided by different users have been collected. This prompted a process to prepare a second edition of the Tree Classification System for New Brunswick.

To accomplish this task, valuable inputs were obtained from Bruno Boulet (forest engineer, pathologist and entomologist from Ministère des ressources naturelles et de la faune du Québec). During a workshop he facilitated, the discussion lead to improvements of the Risk key by observing external defects . Additionally, some fine adjustments were made to the Form determination.

The improvements to the Second edition are therefore, mainly with regards to the two determination keys (Form and Risk). The document was edited by HNRI staff: Sharad Baral, Emmanuelle Fréchette, Pamela Hurley-Poitras and Monique Girouard.   Field validation of the current version of the two determination keys was done by Pamela Hurley-Poitras.

Foreword

The Northern Hardwoods Research Institute (NHRI), located at the Edmundston campus of Université de Moncton, is a research center supported by a partnership among four forest companies, the Université de Moncton, the Government of New Brunswick, and the Government of Canada. Its mission is to encourage the sustainable development of hardwood resources and to support, through applied research activities, the optimal development of our hardwood forests for the benefit of businesses and organizations working in the forestry sector.

This document introduces a classification system that is both practical and innovative, to assist forestry professionals, managers and researchers to make silviculture decisions, predict product distribution, and determine harvesting costs, etc.

Acknowledgements

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Introduction

For many forest management activities, the knowledge of single-tree external stem attributes is critical to the decision-making process. As an example, it is important to take into account tree **vigor** and health when choosing a silvicultural system and prescriptions. Tree **form** and crown shape are in turn useful information in determining product potential, as well as predicting harvesting and processing costs.

Currently, there is no known tree classification system in New Brunswick that provides the necessary information to make silvicultural decisions, predict product distribution, and determine harvesting and processing costs. Tree classification systems used in other jurisdictions were investigated, but we could not find one that meets all of our requirements. While most of the existing systems only provide information for a single purpose such as product determination or overall health, others provide a general subjective rating that limits usefulness at later times and for purposes that are different than that of the original intent.

To be useful for making forest management decisions, a tree-level classification system should not only consider the current state of the tree but also allow the assessor to predict the long-term potential of the whole tree by looking at tree form and vigor (health). This information is used not only to estimate the product value of a tree at the present time but is also used to predict future growth and the evolution of its quality.

Given these needs, it was decided to create a new classification system that would have the following attributes:

- Able to assist in silvicultural decisions, determine product potential and harvesting implications;

- Applicable at the tree level but integrated in inventory and forest management planning activities at all scales;

- Easy to implement, flexible and adaptable;

- Focused on key variables rather than determining "grades";

- Linkable with existing systems from other jurisdictions;

- Predictions such as product breakdowns for tree classes are outputs determined through ad-hoc studies.

Despite its many features, the tree classification system presented in this guide is a simple tool for objectively classifying hardwood trees as well as softwoods. It is intended to become a reference system for forestry professionals, managers and researchers creating a common language to describe trees.

In addition to improve the manager's ability to characterize trees, the new tree classification system will enhance the overall picture of the forest inventory and will also be used in forest development surveys (FDS), permanent sample plots (PSP), research sites, and in other forest inventory programs. This system should also be integrated with the growth & yield processes already in place in New Brunswick. It will also provide data to generate management information from remote sensing tools, linking the observed characteristics with the key tree attributes.

Note that log grading is not covered by this system or in this guide. This type of classification represents a different activity, usually presented in scaling guidelines of the relevant jurisdiction.

Structure of the guide

This guide is divided into three main sections: a first section presents an overview of the concepts of tree form and vigor, a second section presents the components of the classification system and finally, a third section proposes links with other existing classification systems.

Throughout the guide, pictures and diagrams have been included to provide examples in order to help the reader understand the material. Additional images are presented in the appendices.

Field tool!

Once familiar with the tree classification system presented in this guide, print the determination keys on pages 17 and 34 on waterproof paper and bring them in the forest as a handy reminder.

1. ELEMENTS OF TREE FORM AND VIGOR

There are several methods of classifying trees, but most consider form, vigor or other criteria separately. Before presenting the details of the tree classification model developed for New Brunswick, here is an overview of some important concepts about the tree form and vigor.

1.1 Importance and impact of tree form

Along with species and tree diameter, tree form is a key element to consider when characterizing trees. It is a metric describing the geometry of a tree (ideotype) used to describe current and potential value (type and quality of product).

First, tree form can help **predict current and future product distribution**[1] within the tree. Indeed, tree form affects product potential according to their location on the tree. For example, defects present on the first 5 meters of the trunk greatly affect the volume of lumber available since this section usually represents nearly 60 % of the total usable volume (Boulet 2005). In addition, given that the goal is to generate the greatest value for products now or in the future, tree form analysis can enable the planner to evaluate the consequences of silviculture decisions such as harvesting valuable timber (e.g. veneer log potential).

Tree form also helps us understand the factors that must be considered in operations planning and in **determining harvesting costs** by providing clues to the operability challenges that are caused by tree form. For example, certain tree shapes cause difficulties during de-limbing and processing that result in lower productivity and higher wood costs or, in extreme cases, could limit the choice among harvesting systems.

Trees may present forks that can compromise survival, by making them more vulnerable to disturbances or by creating entry points for pathogens or exposing injured sections to micro-organisms that can eventually damage the tree (Boulet 2005). Consequently, some forms of trees could become **priorities for removal** (e.g. a tree with significant lean) **or trigger a particular silvicultural regime.**

In the following section, we review common tree malformations and some examples of their impact on product potential, harvesting costs, and implications for silvicultural alternatives when the goal is to maximize sawlog production.

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[1] Veneer, lumber, pulp or chip.

Multiple trees

For timber production, a tree should ideally have a single stem; however, it is common to see tree clusters with two or more trees from the same point of origin and fused at the base when trees are regenerated from stump sprouts or root suckers (Boulet 2005). The presence of tree cluster can affect:

- ### Product distribution

  The potential for high value products is limited. Tree clusters are usually smaller than if they grew as a single tree. Also, it is commonly observed that trees in a clump have a heart that is displaced from the geometric center of the stem (off-center pith).

- ### Harvesting costs

  Usually, the cycle time to process all of the trees in a group is greater than processing them if they were individual trees. The ability to position harvesting heads is compromised and more time is required to handle trees in a cluster than single trees of the same size.

- ### Silvicultural decisions

  While tree distribution metrics for a stand with a high incidence of multiple trees may be identical (on paper) to one with single trees only, the implications for silviculture choices are very different in practice.

Forks and crowns containing large branches

Some trees have large forks or crowns with large branches. These can affect:

- ### Product distribution

  The presence of significant forks on trees limits trunk length. When it occurs in the section of a tree that would normally contain a sawlog (i.e. in the first 5 meters), the impact on overall value is very important. Also, large branches may or may not contain certain product types as they have a tendency to curve as a result of competition for light.

- ### Harvesting costs

  It usually takes more time to de-limb or process trees with large limbs and forks. It may increase production costs and often causes mechanical damage to the stem that can downgrade products. A high frequency of trees with large limbs and forks may influence the type of equipment used during forest operations.

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- **Silvicultural decisions**

    V-shaped forks are more vulnerable to cracks, making them more likely to be colonized by pathogens that cause decay (Boulet 2005) and deterioration of economic value. Trees with large limbs and forks should be prioritized for removal as they are considered unacceptable growing stock (UGS). When the proportion of these types of trees is high in a stand, the silvicultural options may become limited.

Curvature of the tree (sweep)

It is common for trees to have light sweeps, but some trees have one or multiple significant curves in the first 5 meters of the trunk. This can affect:

- **Product distribution**

    A significant curve on a tree considerably reduces the amount of usable wood for lumber and thus downgrades the log (GQ 2012, Boulet 2005, OMNR 2004).

    The presence of curves on a stem also leads to the formation of tension and compression wood fibers.

- **Harvesting costs**

    Trees that have significant sweeps are more difficult to process and de-limb. Operators will often need to slowdown the processing in order to adjust their bucking decisions to account for the defect.

- **Silvicultural decisions**

    Because sweeps affect the economic value of a tree, which trees to keep or remove becomes a significant silviculture decision for a stand. In stands where there is a large number of crooked trees it can affect the eligibility of silviculture regimes.

Inclination of the tree (lean)

Trees with significant lean are considered in a precarious situation because they are more vulnerable to falling due to strong winds or injury under the weight of snow or ice. The condition normally exists where competition surrounding a tree is uneven.

These trees are likely to die standing or get up-rooted before the next cutting cycle (Boulet 2005). Quebec considers that the maximum acceptable level of inclination is 30° deviation from the vertical axis (Boulet 2005), while Ontario considers the maximum acceptable level of inclination to be 10° (OMNR 2004).

▪ *Product distribution*

Excessive lean in trees can produce wood property issues such as the growth of tension and compression wood. Furthermore, the heart of the tree is generally displaced geometrically when compared to trees that grow under normal conditions.

▪ *Harvesting costs*

Leaning trees may be difficult to fell because the direction is already pre-determined. Feller-bunchers, harvesters and chain saw operators' productivity will be reduced in order to override the natural felling direction when it is not appropriate. Also, damage to crop trees and the felled tree may occur because of mitigation measures used during felling. Re-directing a tree is a difficult task and is compounded when on slopes.

▪ *Silvicultural decisions*

Trees with excessive lean should be prioritized for cutting. If the presence of leaning trees is disproportionally high in a stand, it can affect tree selection and the choice of a silviculture regime.

1.2 Importance and impacts of tree vigor

Tree vigor can be defined as its ability and potential to grow (OMNR 1990 *in* OMNR 2004) and is a function of competitive status and health. It is a component of risk which indicates the likelihood of deterioration that will cause a reduction in value, or of mortality.
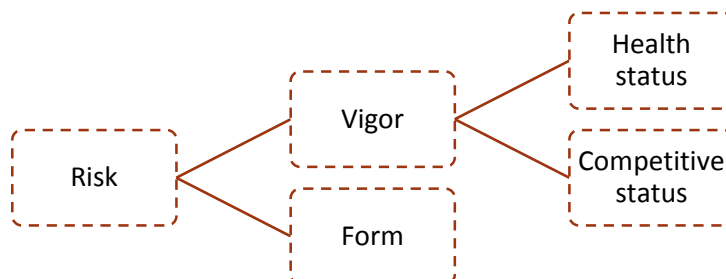
Measuring vigor must therefore assess the overall tree health and predict its evolution over time. It can be evaluated by observing various parameters of a tree's external appearance, such as crown shape and bark appearance. Other environmental factors such tree position within the cohort and competition level may, in turn, indicate the risk that a tree may lose vigor over time. In addition to these parameters, it is important to evaluate tree defects causing loss of vigor (e.g. injury and decay) and the conditions

that contribute to increase the risk of vigor loss such as the presence of major defects (e.g. significant fork) and vulnerability to natural disturbances (e.g. tree inclination) (OMNR 2004, Boulet 2005).

Traditionally, the identification of defects[2] affecting tree vigor is the first step in tree classification (Calvert and Petro 1993). Since partial cutting aims at releasing crop trees and promoting regeneration of desirable species, it is important to carefully choose trees to harvest. A poor choice may reduce overall stand vigor and increase mortality in the residual stand, thereby resulting in a significant drop in productivity. To counter this, it is essential to develop the ability to recognize trees that may die first (as a gradient of probability through time) by identifying defects that are present (Boulet 2006). It is important to remember however that this may not apply in the same manner to species that compartmentalize well, depending on the type of defect.

According to their impacts on tree vigor, the OMNR (2004) classifies defects into three broad categories:

- minor defects (trees with these defects should not lose vigor during the next cutting cycle);

- moderate defects (trees with these defects will slowly lose vigor during the next cutting cycle);

- major defects (trees with these defects will quickly lose vigor before the next cutting cycle).

Thus, the combination of species, diameter, tree form (section 1.1) and vigor (health status and competitive status) are the key elements to guide forestry professionals in their decision making.

Tree vigor is a key driver to **predict current and future product distribution** within the tree. Indeed, depending on the severity and location of defects, the potential for high-value forest products can be severely limited (OMNR 2004).

Tree vigor also helps understand factors that should be considered in operations planning and **determining harvesting costs** by providing clues as to the operational limits imposed by the current and future value of the tree. For example, a less vigorous tree is likely to continue losing value over time and reduce operation profitability. But, as stated below, it may not always be the case.

Tree vigor will inform removal prioritization (e.g. those losing vigor) **and is a key input in the selection of a silvicultural system (regime)** to use. The OMNR (2004) also points out that a successful single-tree selection treatment is characterized by residual trees that are vigorous, or potentially vigorous, and will increase in value. But, it also points out that even trees with low vigor can increase in value if they have the chance to gain and maintain their maximum vigor for a sufficiently long period after the intervention. In this context, the Quebec Government prioritizes the harvest of trees that may tip over, break, perish

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[2]Note that Section 1.2.1 presents the identification concepts of tree defects.

or deteriorate over time while healthy trees or trees with no serious defects (that will still be healthy in 25 years) represent acceptable growing stock (Boulet 2005).

Here is an overview of visible signs that may indicate poor tree vigor and some examples of their potential impacts on product distribution, harvesting costs, and silvicultural options when the goal is to maximize sawlog production.

Presence of fruiting bodies (Fungus)

Fruiting bodies are the visible part of fungi present within a tree. These structures carry the spores (the reproductive units of the fungus) and their presence on a tree indicates that the inside of the tree suffers from a decay that is likely very significant (OIFQ 2003, GQ 2012). Although there are many different types of decay-associated fungi that can affect trees in various ways (Boulet 2005), their presence is usually an indicator of a serious loss of tree vigor.

For example, the presence of fungus can affect:

- *Product distribution*

   The presence of fruiting bodies on a tree indicates that the quality of the wood can be greatly compromised. In various stages of decomposition, it is not usable and represents a significant loss in volume.

- *Harvesting costs*

   The presence of decayed tree sections may require further processing to work around affected areas.

- *Silvicultural decisions*

   Since tree decay reduces net merchantable volume to a point where it may even result in negative long-term growth (Boulet 2005), its presence is a key input in determining removal priority and the choice of a silviculture regime.

Holes and injuries on the main stem

Cavities on the main stem, such as holes and injuries caused by animals, insects or humans are defects that have different impacts on products, but are also entry points for pathogens and insects that may affect tree vigor.

- **Product distribution**

  Cavities or holes affect product potential in two ways; by limiting the length of usable wood and by extending internal decay into the trunk.

- **Harvesting costs**

  Notable decreases in machine productivity are associated with the extra time required to merchandize trunks.

- **Silvicultural decisions**

  An injured tree has an increased likelihood of mechanical failure, and a greater probability of being colonized by various pests; the potential impacts of these openings on a tree are similar to those of trees with fruiting bodies and indicates a high priority for removal.

Forks and splits

Some stems have large forks or crowns with large branches. These forms can affect:

- **Product distribution**

  Defects such as large branches reduce the length of the usable trunk and impact current and future potential products (product basket). Their presence also contributes to the likelihood of splits that in turn affect the proportion of discolored wood (Boulet 2005). These features also increase the proportion of knots and, eventually, rot.

- **Harvesting costs**

  The presence of forks and splits decreases the productivity of machines such as processors and delimber, and therefore increases cost.

- **Silvicultural decisions**

  Silviculture options are limited when the proportion of trees with large limbs and splits is high or un-evenly distributed.

Competitive status

A tree's position in the cohort (crown class) and the relative amount of sunlit foliage will reflect, among other things, its competitive ability to acquire and process resources required for growth (photosynthesis). Indeed, the growth condition of a tree and the availability of resources greatly influence the tree's growth and development. The availability of light is the most limiting factor for its

growth and development (OIFQ 2009). Generally speaking, trees under significant competition (by other trees) or those with unhealthy crowns have limited ability for photosynthesis. Notwithstanding the impact of the species degree of shade tolerance, under those conditions, the risk of losing vigor is likely to be high (Boulet 2005).

- ▪ *Product distribution*

    Trees that have had poor vigor resulting from strong competition for long periods tend to be smaller in size. Trees that are older for a given diameter have a higher likelihood of being damaged with time. Eventually, older trees contain lower proportions of valuable wood products or exhibit signs of deterioration.

- ▪ *Harvesting costs*

    Processing time increases for trees showing signs of decay due to stress.

- ▪ *Silvicultural decisions*

    Trees under stress are more likely to be invaded by damaging insects and pathogens, and represent logical candidates for harvest. Signs of stressed trees include poorly healed branch stubs, large open and decayed stem wounds, and dead branches in the crown (Calvert and Petro 1993). When they represent a high proportion of the stand, then silvicultural options are limited.

In summary, to determine tree vigor we must consider the degree of competition and look for signs that indicate potential health issues such as the presence and severity of:

- Fruiting bodies on the main stem - indicating internal rot and wood discoloration (Kenefic 2012);

- Holes in the main stem - indicating a structural weakness that might lead to breakage (Kenefic 2012);

- Dead or dying main branches from the upper crown (Kenefic 2012);

- Points of weakness (forks, stilted roots from growing on a stump, significant lean; Nyland 2012);

- Evidence of decay or entry point for decay (bleeding, ants, sapsucker holes, trunk wounds or swelling, broken crown; Nyland 2012);

- Other indicators of poor health (thin or discolored crown, branch stripping by porcupines etc.; Nyland 2012).

1.2.1 Recognize defects, injuries and signs of decay

As showed in the previous section, defects, injuries and decay are factors that may significantly affect tree vigor. It is therefore important to be able to recognize signs of their

Reference guide

Défauts externes et indices de la carie des arbres.
Gouvernement du Québec, 2005.

presence on trees. Even experienced professionals may from time to time feel uncomfortable with the identification of pathological, entomological, and abiotic problems. While this guide is not intended to be a tool for identifying specific defects or decay, its purpose is to present some basic criteria to help recognize key signs and symptoms. It is advisable to acquire existing material on the subject such as the Québec guide *Défauts externes et indices de la carie des arbres*, which is a very complete tool.

The reference guides listed below also present different pictures of defects, injuries and signs of decay and may be useful in helping identify them when observing a tree:

- Ontario Ministry of Natural Resources. 2004.
  Ontario Tree Marking Guide, Version 1.1.
  Ont. Min. Nat. Resour. Queen's
  Printer for Ontario. Toronto. 252 p.
  http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@forests/documents/document/mnre000526.pdf

- Carpenter, R.D., Sonderman, D.L., Rast, E.D., Jones, M.J. 1989.
  Defects in hardwood timber.
  Agriculture Handbook No. 678.
  United States Department of Agriculture. Washington, DC. U.S. 88 p.
  http://www.nrs.fs.fed.us/pubs/aghandbk/AgHandbook678.pdf

- Nova Scotia Ministry of Natural Resources. 2005.
  Hardwood tree grading field guide.
  Nova Scotia Department of Natural Resources,
  Forest Inventory Division, 69 p.
  http://www.gov.ns.ca/natr/forestry/reports/sawlogguide.pdf

- Shigo, A.L. and Larson, E. 1969.
  A Photo guide to the patterns of discoloration and decay in living northern hardwood trees.
  U.S.D.A. Forest service research paper NE-127.
  Northeastern forest experiment station, Upper Darby, PA.
  Forest service, U.S. Department of agriculture, 100 p.
  http://www.nrs.fs.fed.us/pubs/rp/rp_ne127.pdf

- Shortle, W.C., Dudzik, K.R. 2012.
  Wood decay in living and dead trees: A pictorial overview.
  Gen. Tech. Rep. NRS-97. Newtown Square, PA: U.S.
  Department of Agriculture, Forest Service, Northern Research Station. 26 p.
  http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs97.pdf

Some defects that affect stem value are difficult to recognize; however, several methods of estimating defects from external signs were developed. They are usually categorized into two groups, biotic defects (caused by the action of living organisms such as fungus or insects) or abiotic defects (caused by the action of nonliving factors such as wind or freezing rain). These external indicators are important components in assessing tree vigor (OMNR 2004). Damage from previous harvesting activities are another major source of defects. They range from scrapes and wounds on the stems and roots to broken limbs and boles in severe cases. The Ontario Ministry of Natural Resources (2004) has prepared a methodology to classify defects (minor, moderate and major) depending on the magnitude of their impacts on tree vigor (Figure 1).

Figure 1. Observable defects (minor, moderate and major) (adapted from OMNR 2004)

Minor defects	Moderate defects	Major defects
- Crooks and sweep	- Mossy top	- Spine tooth fungus
- White-faced scar	- Sugar maple borer	- Punk knot
- Burl	- Spiral seam	- Coal fungus
	- Frost cracks and seams	- Yellow cap fungus
	- Small darkface scar < 900 cm^2	- Shoestring root rot
	- Sunscald	- False tinder fungus
	- Black knot	- Clinker (cinder) fungus
	- Epicormic branching	- Eutypella (cobra) canker
	- Pine engraver beetles	- Nectria (target) canker
	- Feeding damage	- Artist's conk
	- Mechanical damage	- Butt flare (barrelling)
	- Broken or dead top crown dieback	- Black bark
	- Lightning injury	- Large darkface scar > 900 cm^2
	- Root wounds	- Fire scar
	- Fire scar	- Fomes root rot
	- Lean > 10°	- Tomentosus root rot
		- White pine blister rust
		- Velvet-top fungus
		- Red ring rot
		- White pine weevil

According to the authors, there are three types of minor defects and their presence on a tree should not lead to a loss of health over the next cutting cycle. The 16 types of moderate defects have more impact on tree vigor since their presence causes a tree to degrade or slowly decay and lose vigor during the next cutting cycle. Finally, the 20 types of major defects, such as fungus and canker, have the greatest impact on tree vigor and their presence indicates that the tree may quickly lose vigor before the next cutting cycle.

As mentioned previously, tree form, species, and diameter are useful parameters for predicting current and future product potential from trees. Although some aspects of tree form influence the risk of losing vigor (e.g. significant fork that tends to create a split), it is mainly the assessment of health and competitive status that are key for predicting the risk of losing vigor.

This section has provided important information about tree form and vigor that constitute the basis of our new tree classification system of New Brunswick presented in Chapter 2.

In summary:

- Tree form is a stand-alone metric used to describe the geometry of a tree and is valuable to determine product distribution, harvesting equipment productivity and risk of mechanical failure or to lose value;

- Competitive status indicates the amount of stress a tree is under from the competition of other trees and plants;

- Health is assessed by verifying for the presence and severity of features that may limit the trees future growth;

- Vigor is function of health, competitive status and tree size;

- Risk is an index that considers vigor and tree form used to predict the likelihood of mechanical failure leading to tree mortality and can be used to infer potential losses in product value;

- All of those elements are critical to make silvicultural decisions.

2. Components of the Tree Classification System for New Brunswick

The tree classification system is a tool used to evaluate standing trees according to four variables, primarily their species and their diameter, but also their form and risk of mortality or of losing value. It was decided that it would not include the direct assessment of vigor (health and competitive status) but would focus on estimating risk (a composite indicator that consider many of these individual factors). As presented in the next sections, tree form ("F") can be classified according to eight different codes (section 2.1.1) and the risk of losing vigor ("R") can be classified according to four different codes (section 2.2.1). The other two elements, species and diameter, are straightforward and are not covered in this guide.

Our classification system was developed for merchantable trees having a DBH of 10 cm or more, although it could also be used for smaller diameter trees.

2.1 Evaluating tree form

In our system, tree form is related to categories of crown ideotypes. Tree form is assessed for the first 5 meter section on merchantable trees greater than 10 meters in height or on the bottom half (50 % of total height) of shorter merchantable trees (< 10 m.).

> **Forest Inventories**
> Easily integrate the tree classification system to your regular forest inventories by adding two additional fields: code "F" and code "R".

Total height ≈12 meters

Total height ≈6.5 meters

5 m

3.25 m

To properly assess tree form, an observer determines the number of stems, the presence of curves or sweeps, the inclination or lean and the general shape of the crown. The eight form classes and their characteristics[3] are described in detail in Table 1 and summarized in Table 2.

Table 1. Description of the eight form classes

F1 Ideal tree form:

- ✓ A single stem in the first 5 meters
- ✓ Without curve or sweep on max. 1 axis
- ✓ Inclination of less than 15° from the vertical axis

F2 Acceptable tree form:

- ✓ A single stem in the first 5 meters
- ✓ Sweep on 2 axes or 1 significant curve on the stem
- ✓ Inclination of less than 15° from the vertical axis

F3 Poor tree form:

- ✓ A single stem with large branches in the first 5 meters
- ✓ Large branches potentially carrying roundwood products

F4 Unacceptable tree form:

- ✓ A single stem with large branches in the first 5 meters
- ✓ Large branches have no potential for roundwood products

F5 Poor tree form:

- ✓ A principal stem which is divided into a fork between 0.3 and 2.5 meters from the base of the tree

F6 Poor tree form:

- ✓ A single stem in the first 5 meters
- ✓ Sweep on max. 1 axis
- ✓ Significant inclination of more than 15° from the vertical axis

F7 Acceptable tree form:

- ✓ A principal stem which is divided into a fork between 2.5 and 5 meters from the base of the tree

F8 Poor tree form:

- ✓ A fork or multiple stems are present under 0.3 meters from the base of the tree
- ✓ Can represent a clump of trees of the same species or various tree species

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[3] Refer to Table 3 for definition of terms related to tree form determination.

Table 2. Summary of tree forms

Code	Silhouettes	Stem count	Stem curve	Stem inclination angle (°)	Comment
F1		Single stem below 5 m	Sweep on max. 1 axis	Less than 15°	N/A
F2		Single stem below 5 m	Sweep on 2 axes or 1 significant curve	Less than 15°	N/A
F3		Single stem, large branches below 5 m	N/A	N/A	Presence of large branches / Potentially carrying roundwood products
F4		Single stem, large branches below 5 m	N/A	N/A	Presence of large branches / No roundwood products
F5		Multiple stem, Fork between 0.3 m and 2.5 m	N/A	N/A	N/A
F6		Single stem below 5 m	Sweep on max. 1 axis	Significant lean more than 15°	N/A
F7		Multiple stem, Fork between 2.5 m and 5 m	N/A	N/A	N/A
F8		Multiple trees or fork below 0.3 m	N/A	N/A	N/A

The determination key (Figure 2) illustrates the logic followed to grade a tree for form. Details are further provided for each decision point in the key.

Figure 2. Determination key for determining form ("F" rating)
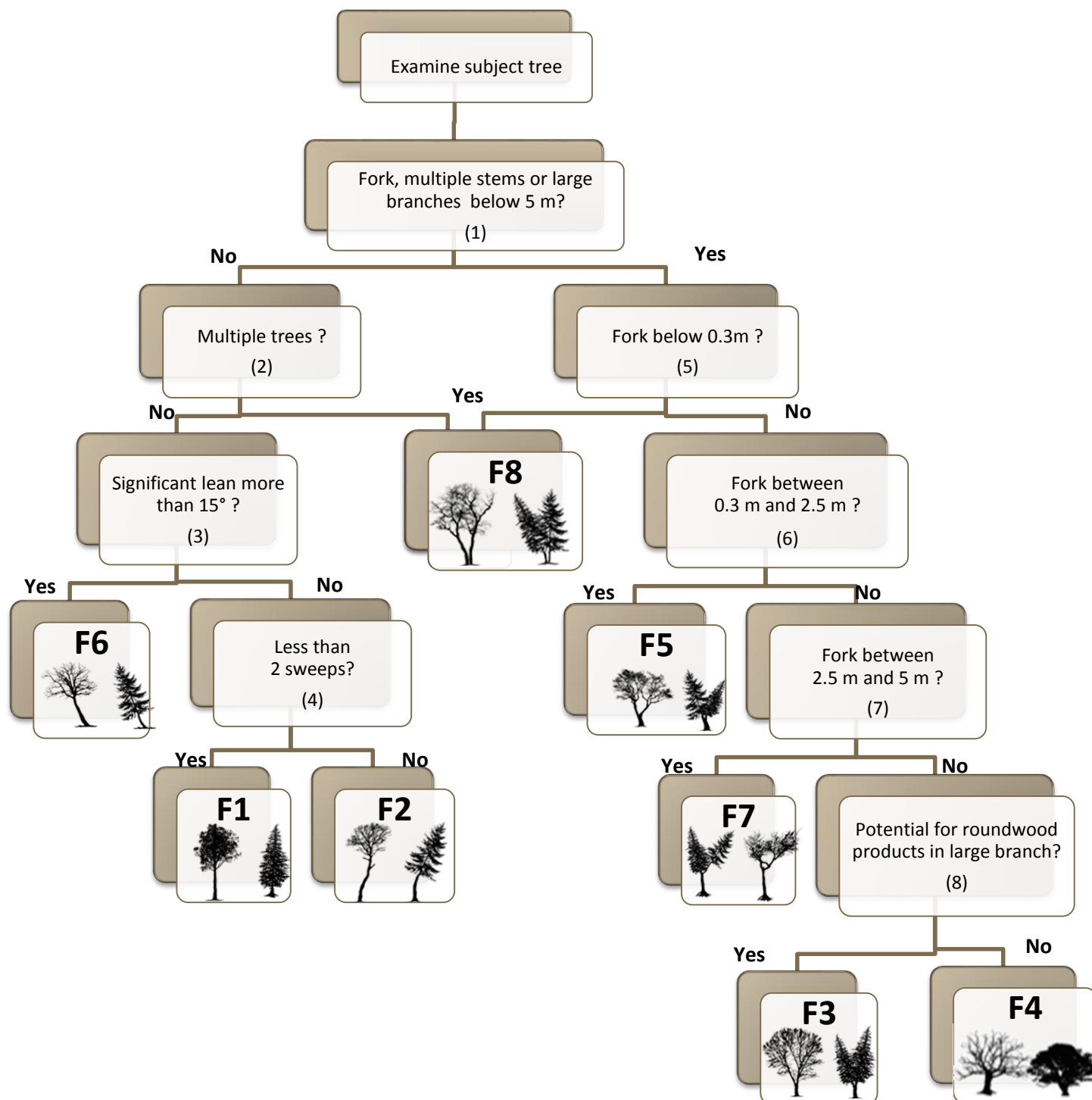
To reduce subjectivity, following is a brief description of the questions to answer at various decision points in the key found in Figure 2. For definitions of technical terms, refer to Table 3 below.

(1) Fork, multiple stems or large branches below 5 m?

Does the tree have a single stem (e.g. no forks, no multiple stems, no large branches) in the first 5 meters of the main stem?

(2) Multiple trees?

Is there more than one stem, coming from the same point of origin or growing very close (≤ 5cm) (stems will touch when they will get larger) from each other?

(3) Significant lean?

Does the tree have an inclination of 15° or more from the vertical axis?

(4) Less than 2 sweeps?

Does the stem have none or one sweep and no large branches within the first 5 meters?

(5) Fork below 0.3 m ?

Does the tree fork in the first 0.3 meters of the stem?

(6) Fork between 0.3 and 2.5 m ?

Does the tree fork between 0.3 and 2.5 meters of the stem?

(7) Fork between 2.5 and 5 m ?

Does the tree fork between 2.5 and 5 meters of the stem?

(8) Potential for roundwood products in large branches?

Is it possible to make roundwood products from this tree – do large branches contain, at least, a pulp product on a section of 2.44 meters without a significant curve and are at least 8 cm in diameter at the small end?

Table 3 defines the various terms used in the determination of form. Please note that the red spot in the images indicates Diameter at Breast Height (DBH) of the sample tree (at 1.3 meter).

Table 3. Definition of terms used in the determination of form

Term	Definition	Example
Single main stem	Main axis of tree does not include significant fork(s) below 5 meters.	
Multiple stems	Trunk of tree divides into significant forks between 0.3 and 5 meters.	
Multiple trees	Cluster of trees stemming from the same point of origin or growing very near[4] to each other (OIFQ 2003). Multiple trees can be of different species.	

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[4] Stems that are ≤ 5 cm apart at the base.

Term	Definition	Example
Straight stem	Stem which presents no visible lean or curvature.	
Sweep	Stem presenting a visible, but not significant curve: i.e. the stem axis is diverted compared with its normal axis, but the loss of yield in sawtimber is decreased by less than 33 %. (See next definition).	
Significant curve	Deviation from the main axis resulting in a loss of sawtimber yield of more than 33 % (NBG 2012) For each DBH classes, the maximum deviation is indicated in the table below. | DBH Class (cm)	*Acceptable maximum deviation "X" (cm)
---	---
10-20	10
20-30	13
30-40	17
40-50	20
50 and over	28 | *If the deviation is longer than the value in the table, the curve is considered significant.	Evaluation of the deviation (X) : Determine the length of the curved section (e.g. 2 m in the above figure) on the first 5 meters. Measure the deviation (X) at the middle of the curve. Refer to the table (left) to compare against the maximum allowed.

Term	Definition	Example
Significant lean	Tree leans 15° or more from the vertical axis on the first 5 meters of the tree. In presence of leaning curved tree, measure the first 5 meters from the base of the tree.	
Large branches	Branch measuring ≥ 1/3 of the diameter of the main stem (measured below the fork).	
Significant fork	Fork where one of the branches measures ≥ 1/3 of the main stem diameter (measured below the fork). In presence of a significant fork, none of the branches can be identified as the main stem. The point where the fork is identified is where the wood fibers separate and take different directions.	

Term	Definition	Example
Roundwood products potential	Large branches that contain, at least, a pulp product: • 2.44 meter section without significant curve; • Diameter at the small end ≥ 8 cm.	

Example of tree form ratings (F1 to F8) are presented in Table 4 (see appendix A for more examples).

Table 4. Examples of tree form ratings

F1
Single main stem below 5 meters

Lean less than15°

Straight stem, fewer than 2 sweeps

Tamarack

Yellow birch

F2

Single main stem below 5 meters

Lean less than 15°

Sweeps on 2 axis or more, or 1 significant curve

Sweeps on 2 axis

White birch

Significant curve

Sugar maple

F3

Single stem below 5 meters

→ Large branches below 5 meters

No lean or sweeps

Potential for roundwood products

Roundwood product

Norway Spruce

Roundwood product

3.5   m

Sugar Maple

F4

Single stem below 5 meters

→ Large branches below 5 m

No lean or sweeps

No potential for roundwood products

Jack pine

Yellow birch

F5

Multiple stems below 5 meters

→ Fork between 0.3 and 2,5 meters
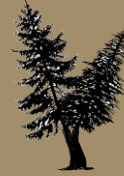
Red maple
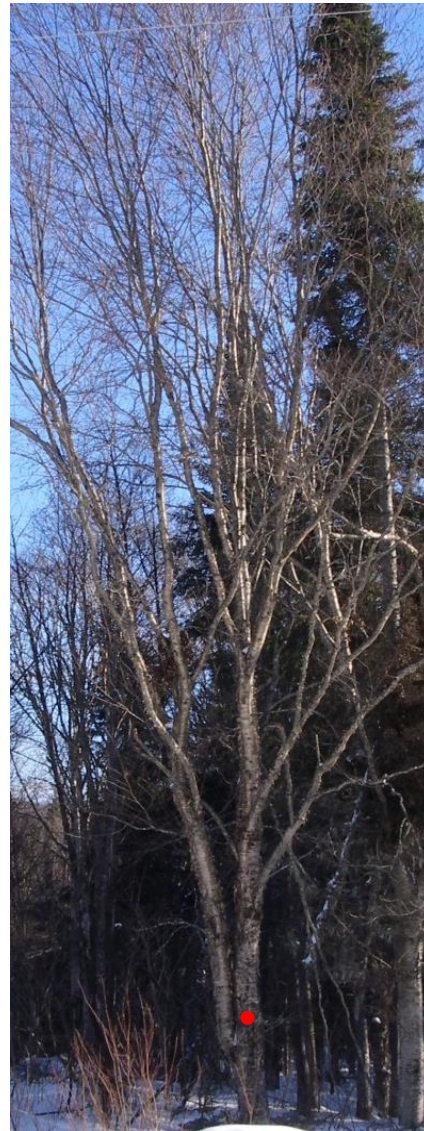
Yellow birch

F6

Single stem below 5 meters

Significant lean more than 15°

>15°

Sugar maple

5 m

>15°
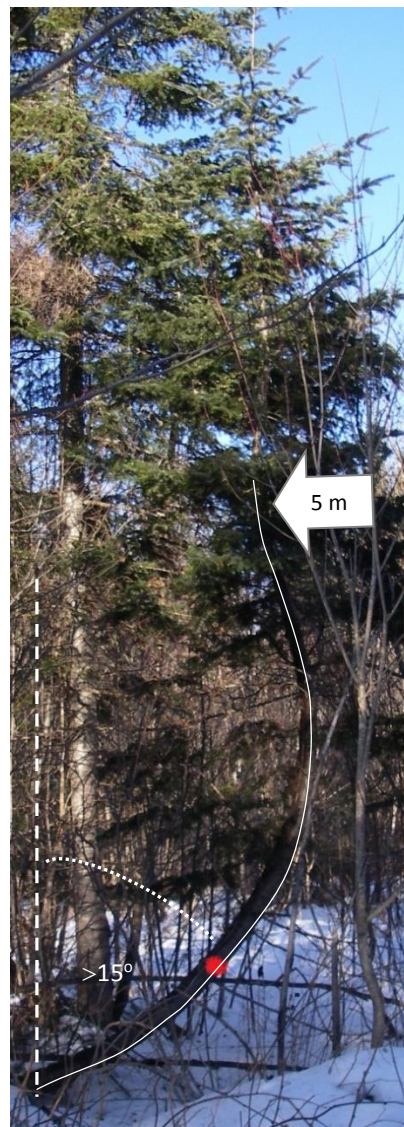
Balsam fir

F7

Multiple stems below 5 meters

→ Fork between 2.5 and 5 meters

No lean or sweeps

3.5 m

4 m

Tamarack

Sugar maple

F8

Multiple stems or multiple trees below 5 meters

→ Significant fork under 0.3 meter

→Trees stemming from the same point

White birch

Yellow birch

2.2 Evaluating risk (of deterioration and mortality)

We made the deliberate decision not to assess individual factors such as health class, competitive class and vigor in our system but rather record risk of losing vigor as a composite index. Risk rating is determined for the whole tree.

Rating for risk requires us to look for the presence of visible signs and symptoms that indicate a reduction of health status. The three broad categories of signs and symptoms are:

1. The presence of fruiting bodies (fungus) or large holes, open wounds or open splits on the main stem.

2. The presence of significant forks, splits, or injuries caused by animals, mechanical damage, small holes, healed wounds and other factors.

3. The presence of strong competition and/or a ratio of live crown to total height and the ratio of dead branches.

The process for assessing the risk of losing vigor is different than that of rating for form, since it is not only the presence of features on the tree that are indicative but also the severity and the anticipated trajectory of change. It is rather subjective but a high risk tree might exhibit:

- Poor vigor (small, thin crown);

- Overmaturity relative to pathological longevity;

- Structural weakness (stilt roots, lean > 15 degrees, fork, large low branch);

- Decay (fruiting bodies, ants);

- Damage (entry points for decay: broken top, split, or skidding/felling or other physical damage).

Below is a description of the four risk classes, along with some examples of signs or defects[5] that are useful in the assessment. Risk classes are also summarized in Table 6.

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[5] Refer to Figure 1 in Section 1.2.1 for a complete list of minor, moderate and major defects.

Table 5. Description of the four classes of risk

R1 Healthy and vigorous tree	R2 Unhealthy tree
✓ Unlikely to lose vigor during the next cutting cycle ✓ Very low (or zero) probability of dying during the next 25 years ✓ Monetary value of the tree likely to increase over time ✓ Low probability of product value loss ✓ No defects or only the presence of minor defects, such as: *Crook and sweep, white face scar or burl*	✓ Will slowly lose vigor ✓ Low probability of dying during the next 15 to 25 years ✓ Monetary value of the tree probably stable over time ✓ Moderate probability of product downgrade ✓ Presence of moderate defects, such as: *Frost cracks, small dark face scar, lean, fire scar, insect or wildlife feeding damage*
R3 Unhealthy tree	**R4 Dying tree**
✓ Likely to lose vigor fairly quickly ✓ Moderate probability of dying during the next 10 to 15 years ✓ Monetary value of the tree likely to decrease over time ✓ High probability of product value loss ✓ Presence of fungus on the tree or the presence of moderate defects such as: *Frost cracks, small dark face scar, lean, insect or wildlife feeding damage*	✓ Likely to continue to quickly lose vigor ✓ High probability of mortality during the next 10 years ✓ Monetary value of the tree will probably reduce significantly over time or has already reached a minimum ✓ Very high probability of product value loss ✓ Presence of major defects, such as: *Spine tooth fungus, punk knot, black bark, velvet-top fungus*

To assess a tree according to risk of losing vigor, we recommend you follow the steps listed below:

1. Follow the determination key shown in Figure 3.
2. Refer to the summary of risk classes if necessary (Table 6).
3. Adjust the rating if necessary.

The determination key in Figure 3 illustrates the logic of classifying a tree according to the risk of losing vigor. Follow the key as you answer questions about the subject tree. Note that the number listed under each question of the key refers to helpful information presented in Table 8, aimed to help rating the risk.

Table 6. Summary of risk classes

Rating	Probability of mortality	Value ($) projected in time	Probability of product downgrade
R1	Nil, > 25 years	Improve	Low
R2	Low, 15-25 years	Stable	Moderate
R3	Medium, 5-15 years	Deteriorate	High
R4	High < 5 years	Substantial loss	Very high

The effect of tree size is an additional factor affecting tree vigor and product potential. Studies have found that larger diameter hardwood trees that are associated with moderate or major defects (injuries) have higher probability of product downgrade as such trees are not vigorous enough to compartmentalize the damages efficiently. Therefore, it is suggested to consider interactive (joint) effects of defects (of different size and severity) and the tree size (DBH) on probability of product downgrade (Table 7) while making silvicultural decisions.

Table 7. Joint effects of tree size and vigor on tree mortality and probability of product downgrade

Rating	Presence of damages	DBH (cm)	Probability of mortality	Value ($) projected in time	Probability of product downgrade
R1	No or minor defects	< 40	Nil	Improve	Very Low
		> 40	Nil	Stable	Low
R2	Moderate defects	< 40	Low	Stable	Low
		> 40	Low	Deteriorate	Moderate
R3	Moderate or major defects	< 40	Medium	Deteriorate	Moderate
		> 40	High	Substantial loss	High
R4	Major defects	< 40	High	Substantial loss	High
		> 40	High	Substantial loss	Very high

Figure 3. Determination key for determining risk of losing vigor ("R" rating)

```
                          ┌─────────────────────┐
                          │  Examine subject tree│
                          └──────────┬──────────┘
                                     │
                ┌────────────────────┴────────────────────┐
                │ Presence of fruiting bodies or ob-       │
                │ vious signs of decay or open splits,     │
                │ or big holes or canker on at least 3     │
                │ faces of main stem?                      │
                │ (1)                                      │
                └────────────────────┬────────────────────┘
       Yes                                          No
        │                                            │
      ┌────┐                        ┌────────────────────────────┐
      │ R4 │                        │   Significant fork or        │
      └────┘                        │   multiple stems?            │
                                    │   (2)                        │
                                    └──────────────┬──────────────┘
```

Yes   No

High competition or	High competition or
Live crown ratio less than 30% or	Live crown ratio less than 30% or
Dead branches more than 30% (tolerant spp.)	Dead branches more than 30% (tolerant spp.)
or more than 10% (intolerant spp.)?	or more than 10% (intolerant spp.)?
(3)	(3)

Yes   No   Yes   No

Canker or small holes,	Canker or small holes,	Canker or small holes,	Canker or small holes,
or healed splits or wounds,	or healed splits or wounds,	or healed splits or wounds,	or healed splits or wounds,
or animal or mechanical	or animal or mechanical	or animal or mechanical	or animal or mechanical
damage on at least 2 faces	damage on at least 2 faces	damage on at least 2 faces	damage on at least 2 faces
of main stem?	of main stem?	of main stem?	of main stem?
(4)	(4)	(4)	(4)

Yes   No   Yes   No

R4   **R3**   **R3**   **R2**

Yes   No   Yes   No

R3   **R2**   **R2**   **R1**

Below is additional information for determination of risk of lowing vigor (from Figure 3). For technical term definitions, refer to Table 8.

(1) Presence of fruiting bodies, obvious signs of decay, deep splits, big holes or canker on at least 3 faces of main stem?

Does the main stem have fruiting bodies (visible fungus), obvious signs of decay, deep splits, large visible holes (> 8 cm²), or canker on more than 3 faces of the main stem?

(2) Significant forks or tree cluster?

Does the tree have a significant fork, or is it part of a cluster of trees stemming from the same point of origin or growing very near to each other?

(3) High competition? Live crown ratio less than 30 %? Dead branches more than 30% (tolerant spp.) or more than 10% (intolerant spp.)?

Is the tree under significant competition from neighboring trees?
and/or
Does the tree have a live crown ratio of less than 30 %
and/or
Does the tree have more than 30 % of dead branches in the case of a tolerant species or more than 10% in the case of an intolerant species?

(4) Canker, small holes, healed splits or wounds, animal damage, mechanical damage on at least 2 faces of main stem?

Does the tree have canker, small holes, healed splits or wounds, animal damage, mechanical damage on 2 or more than 2 sides of the main stem?
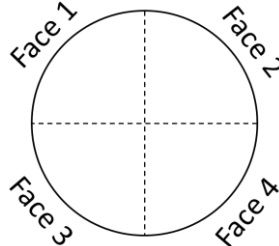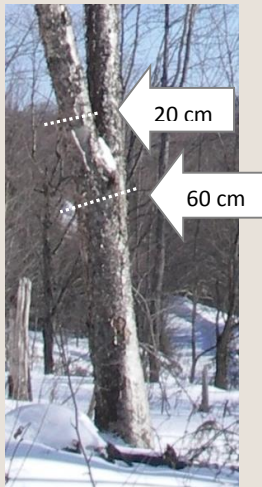
Table 8. Definitions of terms used when rating the risk of losing vigor

Term	Definition	Examples
Fruiting body	Visible part of a fungus that produces or carries spores. Its presence indicates that the interior of the tree is affected by decay, which can already be in an advanced state. Fruiting bodies may be present anywhere at the base, stem or at the junction of branches and the trunk (OIFQ 2003, GQ 2012).	
Obvious signs of decay	Decay is the decomposition of wood by fungi or other micro-organisms, resulting in softening, progressive loss of strength and weight and often changes of texture and color (OIFQ 2003). It originates from a wound (branch death) that didn't heal for a long period of time.	Presence of fungi sporophores Swelling at the base of the tree

Term	Definition	Examples
Split	Open split: unhealed split (length ≥ 1.5 m) present at any height on the stem or main branches, leaving an opening to pathogens, which may worsen mechanically over time. A severe seem that has affected the cambium may be treated as a significant split.	Open split Healed or healing split

Hole on main stem	Visible opening on the stem that reaches cambium. Caused by factors agents, such as:
	
	  ✓ Birds
	  ✓ Sap-sucking insects or insect larvae
	  ✓ Rotten nodes
	
	(Calvert and Petro 1993, GQ 2012).
	
	- Small hole : 2 to 8 cm diameter
	- Large hole : > 8 cm diameter	

Canker	Swelling with necrosis of the underlying bark and cambium, resulting in exfoliated bark and distorted main stem. Canker provides openings for organisms responsible for discoloration and decay.	
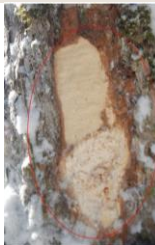
Term	Definition	Examples
Face of main stem	The stem is divided vertically into 4 faces of equal dimensions, from the bottom to the top of the stem.	
Significant fork	Fork where one of the branches measures ≥ 1/3 of the main stem diameter (measured below the fork). Can be located at any height on the tree. In presence of a significant fork, none of the branches can be identified as the main stem. A significant fork, in addition to being a key feature to determine form, is an important indicator of the risk of losing vigor. In fact, even on a healthy tree, a fork is likely to suffer damage and split during significant weather events (e.g. wind, freezing rain). It will likely become a gateway for pathogens or insects, and will increase the risk of the tree losing vigor.	
Multiple trees	Cluster of trees stemming from the same point of origin or growing very near to each other (OIFQ 2003).	
High competition	An established tree whose crown is not free to grow and might not develop in the future.	

Term	Definition	Examples
	For shade-tolerant species, a tree is considered under high competition when at least 3 faces of its crown are shaded by neighboring trees. For shade-intolerant species, a tree is considered under high competition when at least 2 faces of its crown are shaded by neighboring trees.	
Live crown ratio (LCR)	Ratio indicating the length of live crown available for photosynthesis. Length of live crown x 100 Total tree height (OMNR 2004, GQ 2005)	 $$LCR = \frac{3\ m}{20\ m} \text{ x } 100 = 15\ \%$$
Dead branches	Extent of dead, dying, or missing crown foliage expressed as a percentage (Boulet 2005).[6]	White birch with 70% dead branches

[6] Excludes natural pruning

Term	Definition	Examples
Shade-tolerant species	A species capable of growing and successfully reproducing beneath the shading canopy of other species. In New Brunswick, shade-tolerant tree species include: balsam fir, sugar maple, American beech, white ash, white spruce, black spruce, red spruce, eastern white cedar red maple and yellow birch.	
Shade-intolerant species	A species not capable of growing successfully in shade. In New-Brunswick, shade-intolerant tree species include: white birch, pines and aspen/poplars.	
Animal damage	Unhealed injury present on the stem or main branches, leaving an opening to pathogens, which may worsen over time. Includes injuries caused by: ✓ Birds (woodpecker holes) ✓ Insects (worm holes, maple borer, larvae) ✓ Mammals (cervids, rodents, etc.).	Injury from a woodpecker Injury caused by a moose
Mechanical damage	Damage occurred to the tree by another tree falling on it or injury caused by machinery.	

Term	Definition	Examples
Wound	Open wound : no callus tissue has been formed Healed wound: callus tissue has been formed to compartmentalize the wound.	
Dead branches	Extent of dead, dying, or missing crown foliage expressed as a percentage (Boulet 2005).[7]	 White birch with 70 % dead branches

Table 8 contains a summary of the section on rating trees for risk of losing vigor. Sample images are included to help in the interpretation (see Appendix B for more examples).

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[7] Excludes natural pruning

Table 9. Summary of risk ratings including images

R1	Very low probability of mortality
	Value ($) of the tree should increase over time
	Low probability of product downgrade
	Absence of defects or presence of minor defects

Burl
(red maple)

Live Crown > 30 %,
dead branches < 25 %
(White Birch)

R2	Low probability of mortality
	Value ($) of the tree should be stable over time
	Moderate probability of product downgrade
	Presence of moderate defects

Hole on main
stem
(sugar maple)

Healing split
(sugar maple)

R3
Moderate probability of mortality

Value ($) of the tree should decrease over time

High probability of product downgrade

Presence of moderate defects significantly affecting the vigor

Fruiting bodies on main stem
(Sugar Maple)

Significant fork & split
(Yellow Birch)

R4
High probability of mortality

Value ($) of the tree should decrease over time

High probability of product downgrade

Presence of major defects

Significant fork & live crown < 30 %
(red maple)

Fruiting bodies on main stem
(red maple)

3. Links with other systems

To relate tree classes from this system with existing classification systems from other jurisdictions, conversion matrices were prepared. They are introduced only as a quick way to compare classification schemes and are no substitute for grading trees in their original systems.

3.1 The AGS / UGS and Six class systems (USA and Ontario)

The Ontario Tree Marking guide refers to indicators such as vigor, potential risk and tree quality potential. It consists of two scales: the first one has two classes: AGS (Acceptable Growing Stock) and UGS (Unacceptable Growing Stock). The second classification is more detailed and has six classes. The latter is recommended for pre-cut cruising and for stand analysis (OMNR 2004).

Table 10. Links between the New Brunswick tree classification system and the AGS/UGS system

Species	Good form (F1, F2, F7)				Poor form with log potential (F5, F6, F8)				Poor form with no log potential (F3, F4)			
	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
Beech	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Poplar	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Red maple	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Red oak	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Sugar maple	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
White ash	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
White birch	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Yellow birch	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Black spruce	AGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Cedar	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Fir	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Hemlock	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Jack pine	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS

Red pine	AGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Red spruce	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
Eastern white pine	AGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS
White spruce	AGS	AGS	UGS	UGS	AGS	UGS	UGS	UGS	UGS	UGS	UGS	UGS

Table 11. Links between the New Brunswick tree classification system and the Six class system

Good form (F1, F2, F7)				Poor form with log potential (F5, F6, F8)				Poor form with no log potential (F3, F4)			
R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4
A1	A	A	-	B1	B	B/C	C	-	-	D	D

3.2 The MSCR Classification system (Québec)

The MSCR guide is used to identify principle tree defects and to evaluate their effects on the tree's change in vigor, and is used primarily to assign a harvest priority. There are four classes[8]: M (Non-growing stock), S (Poor growing stock), C (Acceptable growing stock) and R (Premium growing stock) (Boulet 2005).

Table 12. Links between the New Brunswick tree classification system and the MSCR classification system

R1	R2	R3	R4
R	C	S	M

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[8] Forms are not included in the matrix because not all the forms had an equivalent in the classification system.

3.3 The ABCD classification system (Québec)

The ABCD classification system is designed to grade stems from the perspective of sawtimber production, by evaluating the best 3.7 meters section within the first 5 meter butt log. The section to evaluate is then separated into 4 faces to assess clear cuttings and percentage (%) of volume reduction. A minimum diameter is required for each class: A: 40+ cm, B: 34+ cm, C: 24+ cm, D: 24+ cm stems that don't meet the criteria of class C (GQ 2012).

Table 13. Links between the New Brunswick tree classification system and the ABCD classification system

Good form (F1, F2, F7)			Poor form with log potential (F5, F6, F8)			Poor form with no log potential (F3, F4)
3.1 m	2.5 m	1.8 m	3.1 m	2.5 m	1.8 m	-
A	B	C	A	B	C	-

3.4 The Petro classification system (Nova Scotia)

The Petro classification system is used to evaluate all visible defects and characteristics that could affect the quality of the end product. The system includes three grades for standing trees: G1, G2, and G3. These classes are determined for the best 3.66 meter (12') section within the first 4.88 meter (16') butt log, which is divided into four faces. Cutting sizes and percent yield of cuttings (including rot, sweep, and crook) result into the specific grades. A minimum diameter is assigned to each class: 40.64 cm or 16" (G1), 33.02 cm or 13" (G2), G3: 25.4 cm or 10" (G3) (Calvert and Petro 1993).

Table 14. Links between the New Brunswick tree classification system and the Petro classification system

Good form (F1, F2, F7)			Poor form with log potential (F5, F6, F8)			Poor form with no log potential (F3, F4)
3.05 m (10')	2.44 m (8')	1.83 m (6')	3.05 m (10')	2.44 m (8')	1.83 m (6')	-
G1	G2	G3	G1	G2	G3	-

4. Future work

The system we have created allows characterizing trees in terms of their form and the risk to deteriorate over time. Those two factors are useful in determining product distributions, understanding impacts on harvesting costs and making silvicultural decisions. In the future, specific projects will be initiated to increase knowledge of the impacts of risk and tree form on key forest management activities. They will primarily aim at :

- Increasing knowledge of tree form on stem volume and **product distribution**

The current approach to predict merchantable volume in stems relies on volume equations that are independent of tree form and the geometry of the tree. There are known biases and errors associated with this simplification in particular for hardwoods. The derivation of new taper equations that take into account tree form will reduce variation significantly.

Very little information exists to predict product potential as a function of species, size, form and risk. Product potential in hardwood trees is highly variable and dependant on several factors other than gross merchantable volume. Tree bucking studies considering those factors will improve our capability of understanding product distributions within a tree.

- Understanding the impacts of tree characteristics on **harvesting cost**

Forest stands have high variability (species composition, tree characteristics, stand structure, etc.) and using average machine productivity and associated harvesting costs could be misleading. It is recognized that certain tree forms can significantly increase processing time. However, the effect of tree form has not yet been quantified. This lack of knowledge limits our ability to forecast machine productivity, and improve harvesting prescriptions to increase profitability. Furthermore, this knowledge is a key missing piece of the foundation for a financially driven decision support system. Depending on the harvesting system, felling and processing costs can represent up to 50% of the total costs of mill wood supply. We are currently limited to average productivity and cost functions that tend to overlook the influence of tree form. The understanding of those relationships will allow to develop machine productivity functions that are specific to changes in tree characteristics (form and risk classes), and to suggest BMP's to improve machine productivity and lower operating costs.

- Enabling **silviculture decision-making** by increasing knowledge of the resource

Silviculture guides will be prepared in order to leverage the additional information provided by implementating our tree classification system. Determination keys for prescribing silviculture treatments will be improved by discouraging treatments where the potential to increase value is low as a consequence of high occurances of trees at high risk and poor form. We intend to test this classification system and to improve our ability to assess risk and form and to validate it on the scientific grounds.

Finally, we hope that growth and yield modelers will adopt the system in order to predict, with accuracy, the optimal development of our forests so that it will be used broadly by practitioners and regulators.

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Appendices

Appendix A - Sample images of form ratings
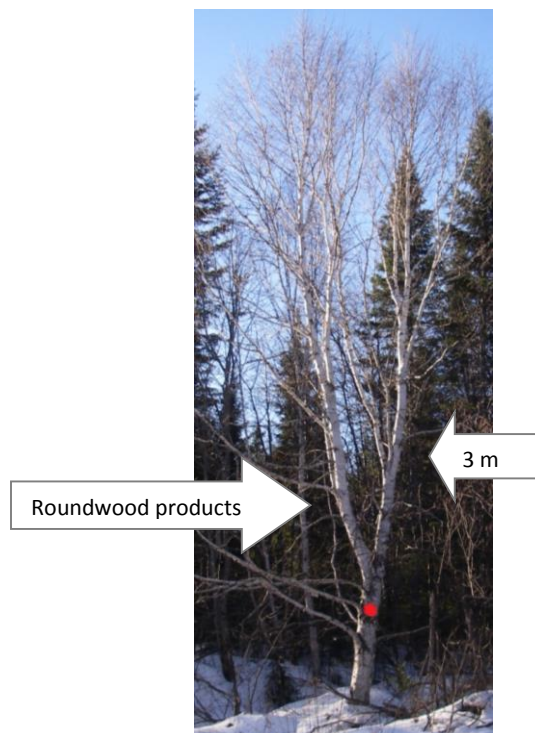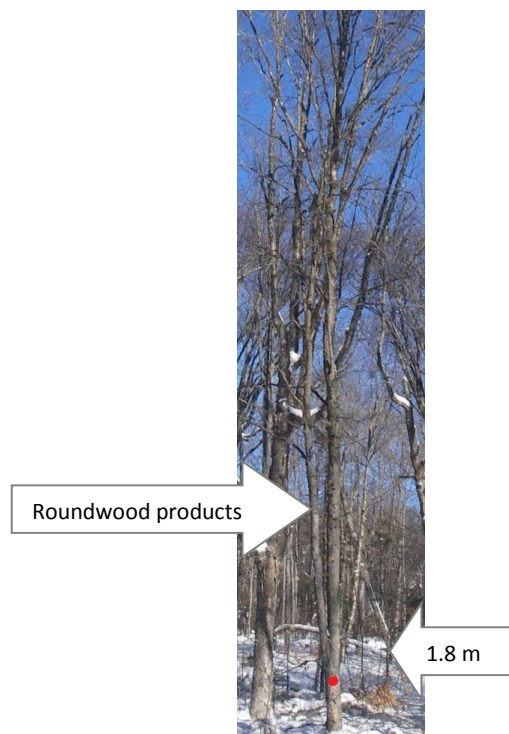
F1 - White spruce

5.5 m

F1 - Red maple

Significant curve

F2 - Yellow birch

Significant curve

F2 - White birch

3 m

Roundwood products

F3 - White birch

Roundwood products

1.8 m

F3 - Beech

F4 - Jack pine

F4 - Yellow birch

F5 - Red maple
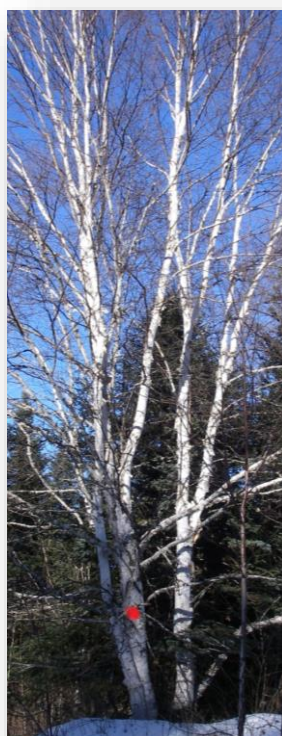
F5 - White birch

F6 - Red maple
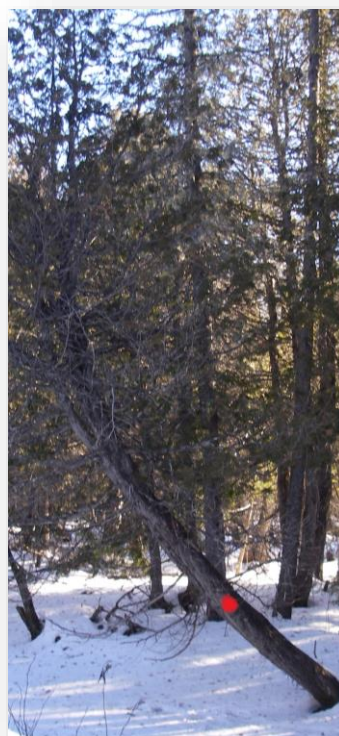
F6 - Eastern white cedar

F7 - Sugar maple

2.7 m

F7 - Norway spruce

3 m
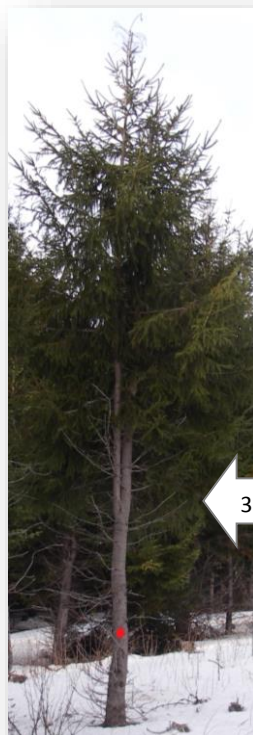
F8 - White birch

F8 - Red maple

Appendix B - Sample images of risk of losing vigor ratings

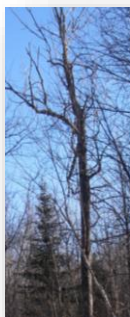**R1 - White face scar**

R1 - Burl

R2 - Hole (≤ 5 cm)

R2 - Fork and split

R3 - Over 25 % of dead branches

R3 - Hole (≥ 5 cm)

**R4 - Hole on main stem
& significant split**

R4 - Fruiting bodies on main stem