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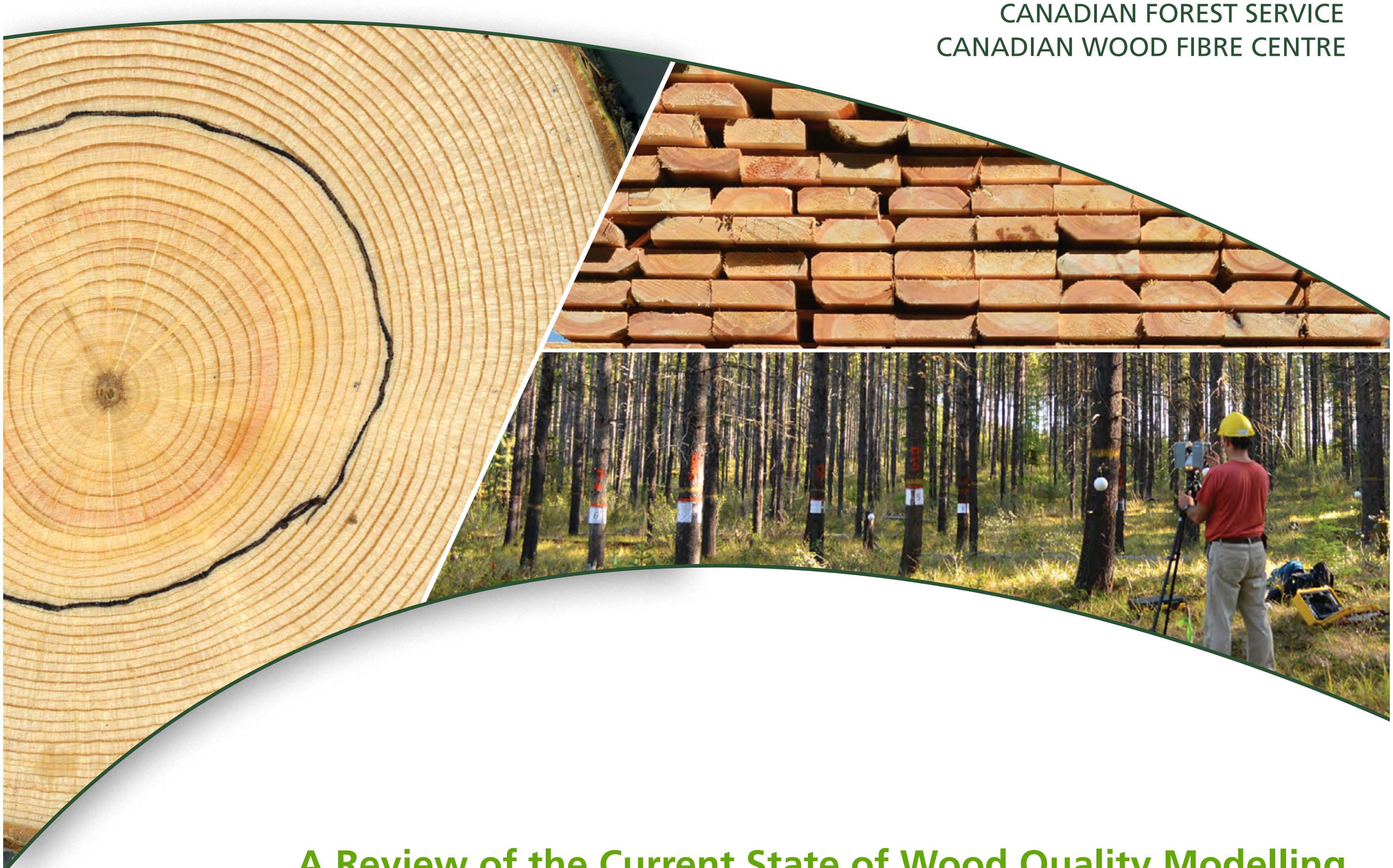

A Review of the Current State of Wood Quality Modelling and Decision Support Systems in Canada

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Canadian Wood Fibre Centre
Working together to optimize wood fibre value – creating forest sector solutions with FPInnovations

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The Canadian Wood Fibre Centre brings together forest sector researchers to develop solutions for the Canadian forest sector's wood fibre related industries in an environmentally responsible manner. Its mission is to create innovative knowledge to expand the economic opportunities for the forest sector to benefit from Canadian wood fibre. The Canadian

Wood Fibre Centre operates within the CFS, but under the umbrella of FPInnovations' Board of Directors. FPInnovations is the world's largest private, not-for-profit forest research institute. With over 500 employees spread across Canada, FPInnovations unites the individual strengths of each of these internationally recognized forest research and development institutes into a single, greater force. For more information, visit **FPInnovations.ca**.

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Executive Summary

To match the right fibre to the right end-use and maximize product value, it is important to know the quantity and quality of the forest resource. It is also important to understand the effects of our forest management decisions on wood quality. Is the Canadian industry aware of, and prepared to face, a possible change in wood supply quality due to more intensive silviculture and shorter rotations, and to climate change? What properties are the most affected? To answer these questions requires knowledge of tree and wood quality attributes as well as value chain optimization tools to assist with forest management decisions across the country.

The objective of this project was to promote the integration of wood quality models developed by the Canadian Wood Fibre Centre (CWFC) and other institutions into growth and yield simulators or value chain optimization systems so that the forest and forest products sectors can derive maximum benefit from these models. The approach was threefold: to review the literature on existing wood quality models, growth and yield simulators and decision support systems to have a clear portrait of the situation in Canada, to send a questionnaire survey to model developers to estimate the level of integration of their model(s), and to hold a national workshop with experts to discuss challenges related to the integration of wood quality models into decision-support systems, and reflect on a strategy to address these challenges.

The literature review has shown that the CWFC and other institutions have produced over 350 models to predict a variety of wood quality attributes for some important commercial tree species. In brief, most of the effort so far has been directed towards lodgepole pine, Douglas-fir and western hemlock in the western provinces, and to black spruce, jack pine, white spruce and balsam fir in the eastern provinces. Less effort has been put toward hardwood species. In terms of attributes, taper, wood density, branchiness/knottiness and modulus of elasticity have received the most attention. From these findings and the workshop output synthesis, we have identified six major gaps with recommendations on how to address them.

1. There is a need for improved communication between wood quality modellers and the developers of growth and yield simulators and decision support tools. Current efforts are not coordinated, and models often use scales and data not compatible with other planning and projection tools.

2. Many wood quality models have been developed and published as standalone equations, with no further developments planned. To be effective for growth projection or decision making at the operational, tactical or strategic level, they need to be linked to growth and yield models or decision support systems.

3. Most of the domestic growth and yield simulators and decision support systems are mature and are flexible enough to accommodate wood quality models; however, some effort is still required to develop strong, accurate, transparent, and validated wood quality models that can provide robust decision support for forest management and that are compatible in scale and the types of variables used. There is a need for a nation-wide program involving scientists and professionals from various disciplines and industry sectors to coordinate research activity, and to help define standards or best practices for sampling, data acquisition, and information delivery systems.

4. Understanding wood quality variation across the landscape is very important for management and planning questions (e.g., to adapt manufacturing processes to incoming fibre supply). With the exception of the ForValueNet initiative and more recent projects such as the Newfoundland Fibre Inventory Project or Québec Wood Quality Index Project (IQB-Indices de qualité du bois), wood quality modelling research has tended to be small scale and piecemeal. New research would benefit from an integrated large-scale modelling approach involving partners for data acquisition and management.

5. The economic impact is well known for some wood quality attributes, not so for others. Further research and case studies are needed, along with a meta-analysis to develop more generic application of the results of the individual case studies. This would help prioritize attributes in current forests, more efficiently forecast attributes of future forests and allocate resources to produce trees with desirable attributes in the future, which altogether would likely increase the interest and engagement of stakeholders in wood quality assessment and modelling.

6. Inconsistency in sampling procedures, incompatibility between data due to use of different assessment techniques or methods, and the lack of standards means that comparison among studies is often difficult or impossible. Mapping of wood quality attributes on a regional or national basis to draw the big picture will rely on data from multiple sources. When data are derived from different methods or processes, there should be some means sought to provide robust conversion factors.

We recommend the following:

Recommendation 1
Setting up an "in-house" **Wood Quality Model Integration Team** for the Canadian Wood Fibre Centre (CWFC) and FPInnovations that will be a national advisory group, multidisciplinary in nature, including programmers, modellers, researchers, and managers from both organizations. They would attend to the above-mentioned issues, perhaps by striking sub-committees and bringing in outside subject experts. The team's objectives would be:

A1: To make recommendations to CWFC and FPInnovations on national modelling priorities.

A2: To survey the wood quality models and DSS available and choose which ones to integrate based on compatibility, importance to industry, and feasibility, and to integrate these as a demonstration project.

A3: To evaluate and set standards for wood quality measurement, and develop conversion factors when multiple methods are used. To publish these standards for other agencies to consider and adopt.

Recommendation 2
Improving the economic case for wood quality modelling and integration within the FPInnovations Modelling and Decision Support (MDS) program, by developing more case studies involving scientists, economists and market specialists for different supply chains covering the entire span of the forest value chain, to determine the economic value of selected wood attributes. The objective for MDS would be:

A4: To assess the range and representation of the wood quality supply chain studies that already exist, to evaluate the options for a generalization of case-study results through a meta-analysis, and to direct future work to the areas most in need of information (by location, species, processor).

Recommendation 3

Establishing a broad-based national working group, network or community of practice for all researchers and stakeholders. The joint CWFC/FPInnovations Wood Quality Model Integration Team would be instrumental in establishing and supporting this collaboration with external partners (universities, governments and forest sectors). The objectives for this working group would be:

B1: To create a wood quality community of practice to facilitate information exchange and coordination of effort among the organizations engaged in wood quality research and development across Canada.

B2: To survey the wood quality models and decision support systems available outside the CWFC and FPInnovations and identify candidates for the integration process.

B3: To define a common vision, define standards and best practices, design a conceptual framework for modelling, and identify key variables to be used.

B4: To develop a national strategy for wood quality modelling and integration, developing the necessary partnerships, seeking appropriate funding, and carrying out the work.

1. Introduction

Understanding the development and variation of wood quality attributes (WQA) of commercial tree species in Canada is important in the context of forest value chain optimization (harvest, bucking, log allocations, product conversion) and for long-term forest management planning. "*Under a value-based forest management paradigm, the best economic strategy for achieving the goal of maximizing the net benefits (or the difference between the value creation and costs) is to obtain the best market opportunity by matching fibre attributes with end products that best utilize the quality of the available fibre*" (Li 2009). In order to do this, models are needed at each stage to predict relevant raw material properties directly from some measurable input variables. In long-term forest management planning, apart from selecting the genetic material at the time of planting, it is of particular interest to understand how wood quality can be influenced by silvicultural practices, and what impact these practices may have on the economic return from the forest (Mäkelä et al. 2010).

Over time, growth and yield (G&Y) models, G&Y simulators, and decision support systems (DSSs) have been developed to aid decision-making in long-term forest management planning or value chain optimization. However, volume was the only consideration in most of the cases. The Canadian Wood Fibre Centre (CWFC) was created in 2006 with the mission of creating innovative knowledge to expand the economic opportunities for the forest sector to benefit from Canadian wood fibre. In recent years, under the paradigm of value-based forest management, efforts have been directed toward the development of new tools for wood quality and value assessment and modelling, either by the CWFC or other institutions.

A wood quality model can be defined as an equation or system of equations relating a wood property or quality attribute to some combination of measurable variables, either internal (e.g., ring number, ring width) or external (e.g., tree dimension, location, climate). It can be translated into a programming code with or without a user-interface. While it is simple to define a wood quality model, it is sometimes difficult to distinguish among a G&Y model, a G&Y simulator and a DSS. For the sake of clarity, we adopted the definitions of growth model, growth simulator and DSS proposed by Garcia-Gonzalo et al. (2012):

- **Growth and yield model:** a dynamic representation of the forest and its behaviour; a group of equations that describe diameter increase, height increase, recruitment, mortality, etc., are therefore growth models.
- **Growth and yield simulator (forest simulator):** an integrated computer tool that, based on a set of forest models, makes long-term predictions of the status of a forest under a certain scenario of climate, forest policy or management, e.g., CAPSIS (Computer-Aided Projection Strategies In Silviculture, Dufour-Kowalski et al. 2012), AMSIMOD (Application for the Management of Simulation MODels, Larocque et al. 2014), FVS (Forest Vegetation Simulation, Hoover and Rebain 2010) and TASS (Tree and Stand Simulation, BC's Ministry of Forests, Lands and Natural Resource Operations, Di Lucca et al. 2009).
- **Decision support system:** a software platform that provides support for decision-making for complex systems by integrating user interface, simulation tools, expert rules, stakeholder preferences, database management, and optimization algorithms. Some DSSs do not include optimization, but rather enable analysis of different scenarios. In this sense, a G&Y simulator is itself a DSS; however, in this report we considered G&Y simulators separately from DSS.

As substantial efforts have been dedicated to developing wood quality models, and as there is an increasing number of models being produced, it is increasingly important to assess the usefulness and efficiency of these models. This project was initiated to promote the incorporation of wood quality models developed by the CWFC and other institutions into G&Y simulators or value chain optimization systems so that the forest and forest products sectors can derive maximum benefits from these models.

The project objectives are:

1) to review existing wood property models developed for Canadian species;
2) to review existing G&Y simulators currently used for Canadian species;
3) to review DSSs currently used along the forest value chain in Canada;
4) to identify knowledge and development gaps and opportunities to create and link models, and improve decision support and optimization systems; and
5) to provide information and a conceptual framework to support CWFC researchers in incorporating their wood quality models into tools and optimization systems developed by other organizations.

2. Methodology

The research questions to be addressed in this project were:

1) How many studies have been dedicated to wood quality modelling for Canadian species?
2) What G&Y simulators are currently being used in forest management planning in Canada?
3) What DSSs are currently being used along the forest value chain in Canada?
4) What are the challenges in linking wood quality models into G&Y simulators or DSSs?
5) What could be done to address these challenges?

Question 1: Wood quality models

The first question encompasses many issues, for example, the species and attributes modelled, the modelling trends, the scale of modelling, the maturity of the models (i.e. whether they are in operational use or integrated into a G&Y simulator or DSS). The information regarding these issues could not all be found in the literature; therefore, we used two approaches: 1) literature research; and 2) questionnaire survey.

A literature review was conducted to find articles published in academic journals by searching in several relevant databases (CAB Abstracts, Agricola, AGRIS, Biological Abstracts, Scopus, etc.) for the terms "tree", or "stem" or "log" or "wood" associated with "property" or "characteristic" or "attribute" or "quality", combined with the terms "model*", "equation", or "regression". To narrow down the number of studies, we then limited the research by region (i.e. Canada). At this step there were still too many articles with most of them unrelated to wood quality modelling. Therefore, the titles and abstracts of the selected articles were scanned to remove irrelevant ones. This automated search was complemented by a manual search through the Literature Cited sections of the articles found in the automated search, as well as in selected review papers and books (Zhang and Koubaa 2008, Middleton and Zhang 2009, Burgess et al. 2011). At the end of this step, there were 158 papers related to wood quality modelling. We believe that most of the wood quality modelling studies (excluding genetics/genomics studies which were not searched in detail) were covered. After gathering all the publications, they were explored in detail to collect information on the affiliation of the first author, the publication year, the species and attributes modelled, the region covered by the model(s), the modelling approach, etc. The models that dealt with genetics/genomics studies were kept in our database for preliminary analysis; however, they were not considered in our final analysis.

To acquire information not available in the literature, we prepared and disseminated a questionnaire survey (Appendix A1) to selected scientists and experts working in the area of wood quality modelling, as identified from the literature research and personal contacts. The questionnaire survey responses on wood quality models were analyzed separately from the literature research.

Questions 2 and 3: Existing G&Y simulators and DSSs

For G&Y simulators and DSSs, a preliminary search was conducted to identify scientists and experts working in these areas. Some of them had previously been identified by CWFC and FPInnovations scientists. Two questionnaire surveys, one for G&Y simulators (Appendix A2) and another for DSSs (Appendix A3) were then prepared and sent out. The final versions of the questionnaire were developed based on a draft document summing up inputs from CWFC and FPInnovations scientists regarding issues and challenges in linking wood attribute models to a G&Y simulator or DSS. Responses to the questionnaire surveys were analyzed and summarized.

Questions 4 and 5: Gap analysis and proposed solutions

Some observations and recommendations could be made from analysis of the literature review and of questionnaire survey responses. To complete this preliminary study, a workshop was organized in March 2015 to address in more depth the challenges of incorporating WQA into G&Y models or DSSs. Located in Victoria and Quebec City, 24 experts from BC, AB, ON, QC, and NL participated in the presentations and brainstorming sessions. The workshop allowed the group to compile ideas and propose some solutions, which are reported in "Workshop BrainLab output synthesis" (Section 8). The Workshop Agenda is provided in Appendix A7.

3. Wood quality models

3.1. Literature review results

3.1.1. Overview of models

We first looked at the number of publications over time by plotting the number of articles against year (Fig. 1). Most of the modelling work has been accomplished in the past two decades, with a renewed interest in recent years. Before 1995, there were few studies related to wood quality modelling, for example, Heger (1974), Singh (1984, 1986), Yang et al. (1986), Kozak (1988), Di Lucca (1989), Mitchell et al. (1989), Hazenberg and Yang (1991a,b), and Hatton and Cook (1992). The continuous increase in the number of studies since 2001 may be explained by the increase in awareness of the importance of wood quality for value chain optimization, the development of new technologies for rapid wood quality assessment (aerial and terrestrial LiDAR, SilviScan, sonic tools, etc.), and the availability of funds. This awareness has been translated into major initiatives such as the creation of the CWFC, the ForValueNet program, and the upcoming AWARE program. It is expected that the number of publications will continue to increase in the coming years.

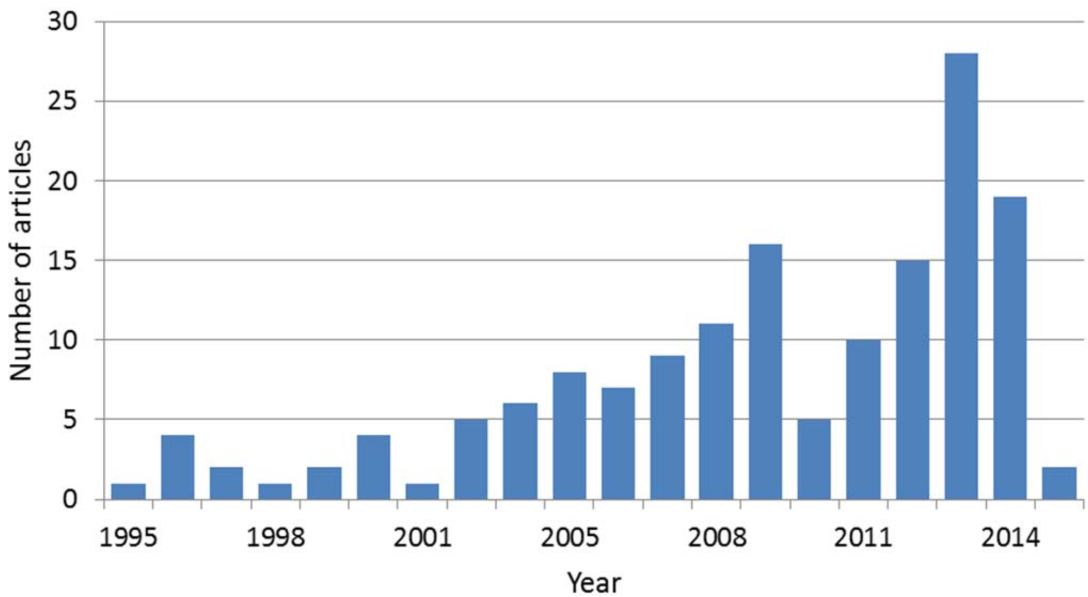


Figure 1. Number of publications relevant to wood quality modelling over time as of March 2015.

We also wanted to determine the key areas of research focussing on wood quality modelling. To answer this question, we used VOSviewer version 1.6.0 (Van Eck and Waltman 2010, 2015) to map out the occurrence of words in the titles and abstracts of the selected publications and the links between items. The network obtained is shown in Figure 2. For each item, the font size of the item's label and the size of the item's bubble depend on the weight of the item. Items are also organized by clusters.

It appears that the research activities were centered on three main axes, according to main clusters (Fig. 2): fibre or clearwood quality attributes, external tree, stem or log quality attributes and genetics/genomics. In the fibre attributes cluster, items such as wood density, modulus of elasticity (MOE), ring, and transition have greater weight, meaning many studies dealt with them. In the external attributes cluster, value, tree height, spruce, taper, knot and lumber have greater weight while in the genetics/genomics cluster, the most frequent topics were growth, provenance and family. This first analysis gives an indication of what has been done in different laboratories through the country.

When looking at the links between items (Fig. 2), it appears that there are fewer links between genetics/genomics items and fibre attribute items than between external wood quality items and fibre attribute items. Most of the research in the genetics/genomics area was dedicated to volume productivity, with little or no consideration of the fibre properties. This can be explained by the fact that genetics/genomics studies usually require analysis of a large number of samples, which was too expensive and cumbersome to characterize manually in the past. It is only recently, with the development of rapid and economical fibre quality assessment technologies such as SilviScan or non-destructive testing technology, that it has been possible to consider fibre properties in genetics/genomics studies. The number of publications in this area is also expected to increase in the near future.

As mentioned earlier, a detailed review of all the publications led to a final number of 158 articles and reports dealing with wood quality modelling, including genetics/genomics studies. They are presented in Appendix A4 with the species and attribute(s) modelled, the scale and the study area. A separate list is shown in Table 5 (Section 7), highlighting publications in which a CWFC scientist was involved as a coauthor.

Among the 158 papers, 30 dealt with genetics/genomics studies and are indicated in the list (Appendix A4) by a star. These 30 publications were not included in further analysis. From the remaining 128 publications dealing with wood quality modelling, 379 models were counted, with a model being defined as an equation or a system of equations describing a given attribute for a given species for a given region. This means that an article can contain more than one model. The following analysis is based on these 379 models.

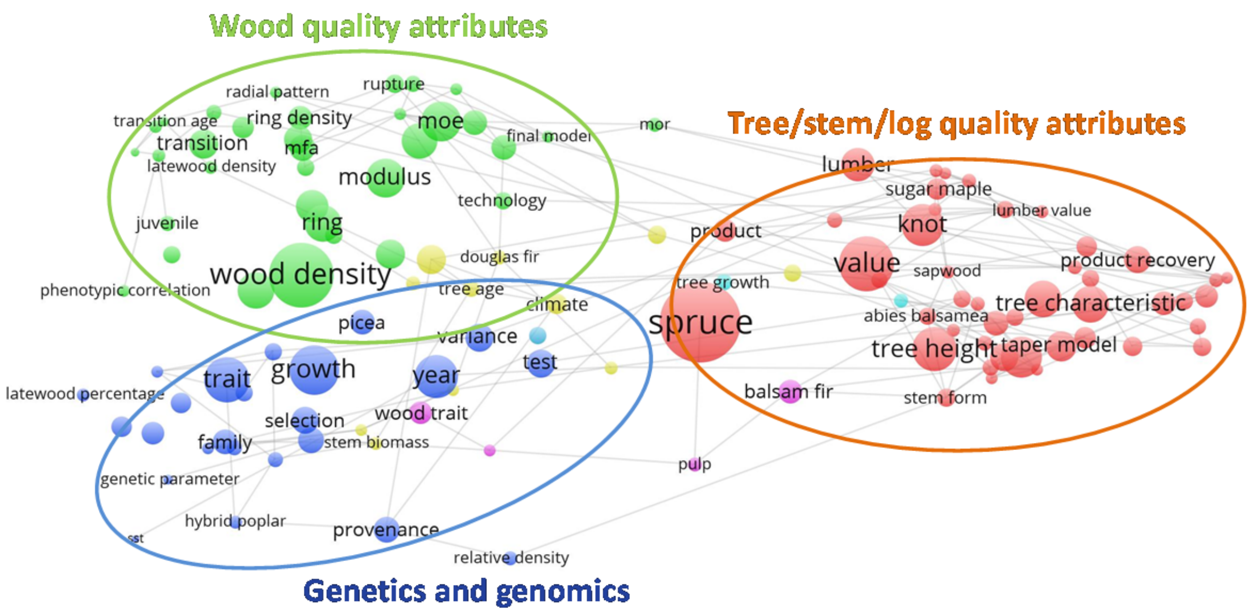


Figure 2. Areas of research focussing on wood quality modelling.

3.1.2. Models by institution

Figure 3 presents the number of models produced by institution. Only the affiliation of the first author was considered. Canadian Forest Service (CFS) and CWFC researchers have been very active, with a total number of 129 models published, 50 and 79 respectively. When considering the affiliation of all the authors, it appears that CWFC scientists have been involved in the development of 148 models in total since 2006 (see Section 7 for more detail).

There have been some notable models that address wood quality issues developed by other institutions. In decreasing number of models, we have Université Laval (42), University of British Columbia (UBC, 35), FPInnovations[1] (31), and Université du Québec à Montréal (UQAM, 22). The remaining institutions shown in Fig. 3, as well as the ones not shown, produced fewer than 20 models in total. Some institutions outside Canada also appear in Fig. 3 (University of Maine and NASA), because we considered only the affiliation of the first author. However, the studies were on Canadian species and involved other institutions located in Canada.

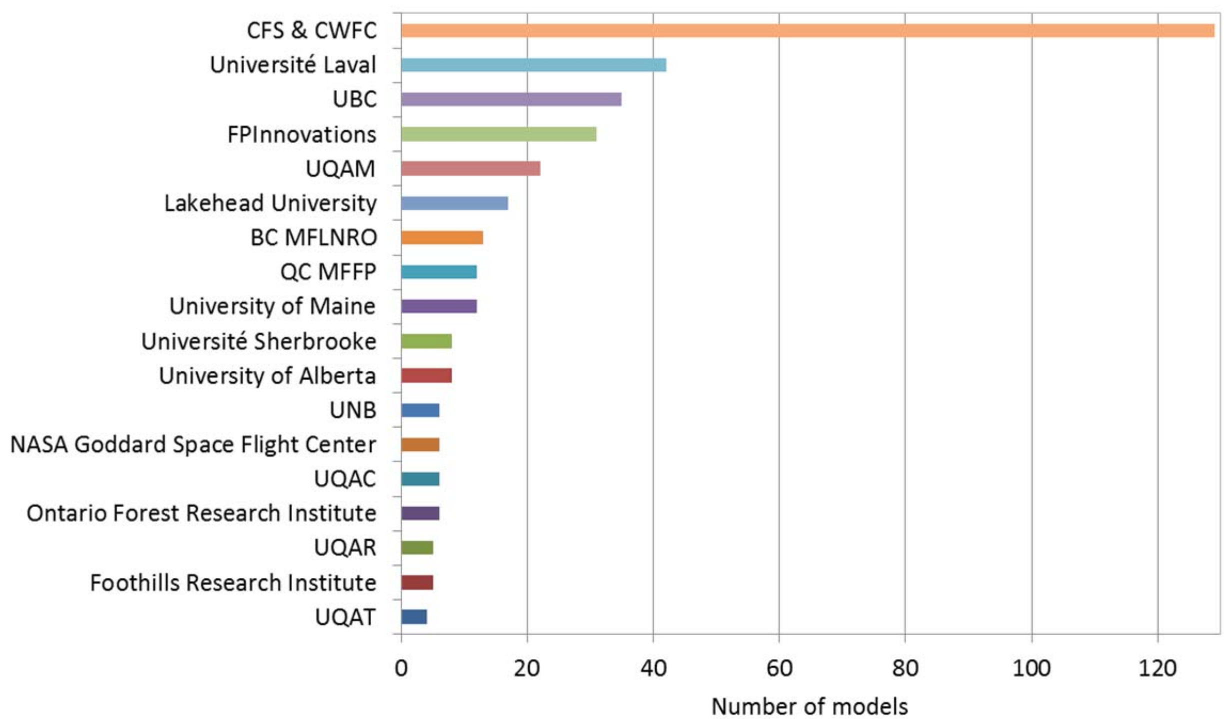


Figure 3. Available wood quality attribute models by institution. Only institutions having developed more than three models are shown.

It is worth mentioning that many of the models developed so far have been on a small geographic scale or the sampling has been very limited, and therefore they may be of limited practical application. This may have been due to budget and time constraints. Some exceptions to this limitation in applicability are models developed for stem taper (Kozak 1988, Ung et al. 2013, Schneider et al. 2013), wood quality models developed for deployment in TASS/SYLVER (Mitchell et al. 1989, Goudie and Di Lucca 2002, Goudie and Parish 2010, Nemec et al. 2010, 2012), and wood quality models of black spruce and balsam fir in Newfoundland (Luther at al. 2013, Lessard et al. 2014).

3.1.3. Wood species modelled

All commercial species have not been studied to the same degree. Emphasis has been put on some species, sometimes with some duplication. Study species were chosen based on their relative commercial importance. Figure 4 shows that black spruce, jack pine, balsam fir, white spruce, lodgepole pine, Douglas-fir and trembling aspen are the species most modelled. Other species have also received

[1] Papers from Forintek Canada Corp., FERIC, Paprican and FPInnovations were counted as FPInnovations.

some attention, but to a lesser extent. When considering jurisdiction, as shown in Fig. 5, efforts have been directed in the western provinces toward lodgepole pine, Douglas-fir and western hemlock and in the eastern provinces toward black spruce, jack pine, white spruce and balsam fir. Figure 5 shows also that less effort has been devoted to hardwood species, although there is increasing interest in the east for hardwood species, and especially in Québec concerning trembling aspen, sugar maple and yellow birch.

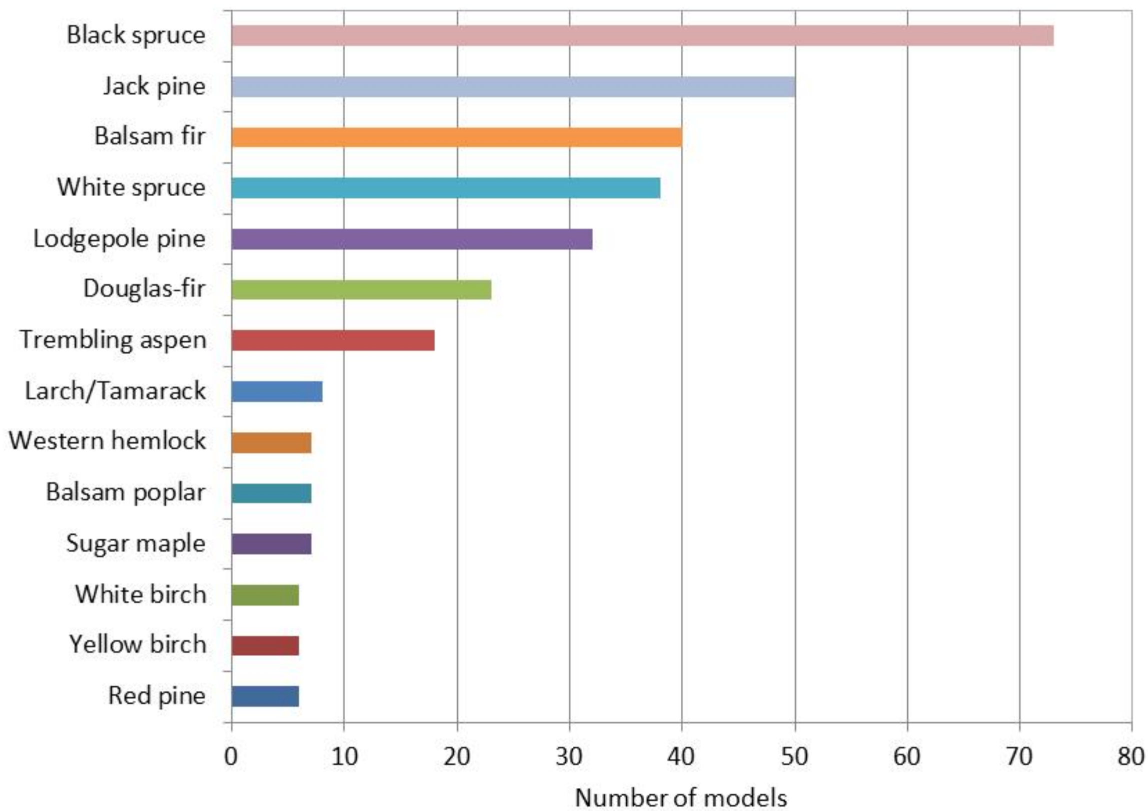


Figure 4. Number of wood quality models produced, by species. Only species for which more than five models have been developed are shown.

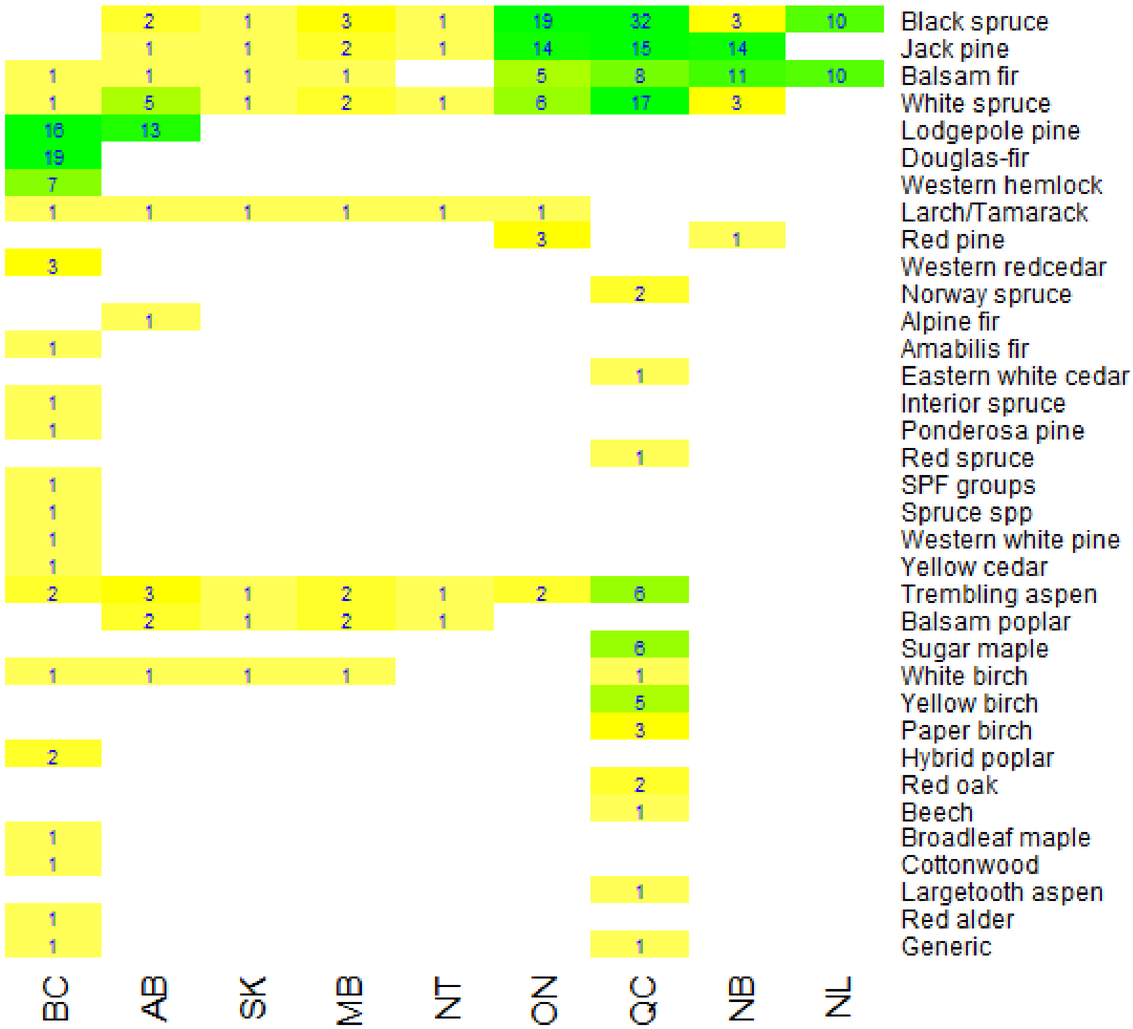


Figure 5. Species (hardwoods/softwoods) most modelled by province.

3.1.4. Wood quality modelled

Taper, wood density, branchiness/knottiness, MOE, and product value recovery (stem value, lumber grade or dollar value, chip quality, etc.) are the attributes most modelled (Fig. 6). By combining species and attributes as shown in Fig. 7, it is evident that most of the attention has been on modelling properties that affect lumber volume recovery (stem form) and lumber grade/value (branch/knots, wood density, MOE, MOR), or directly the product value recovery for the important species (black spruce, jack pine, white spruce, balsam fir, lodgepole pine, and Douglas-fir). Taper has been modelled for almost all commercial species; however, taper models are only included in Fig. 7 where there is at least one other attribute model, to avoid inflating the figure with a large number of species for which there is only one model.

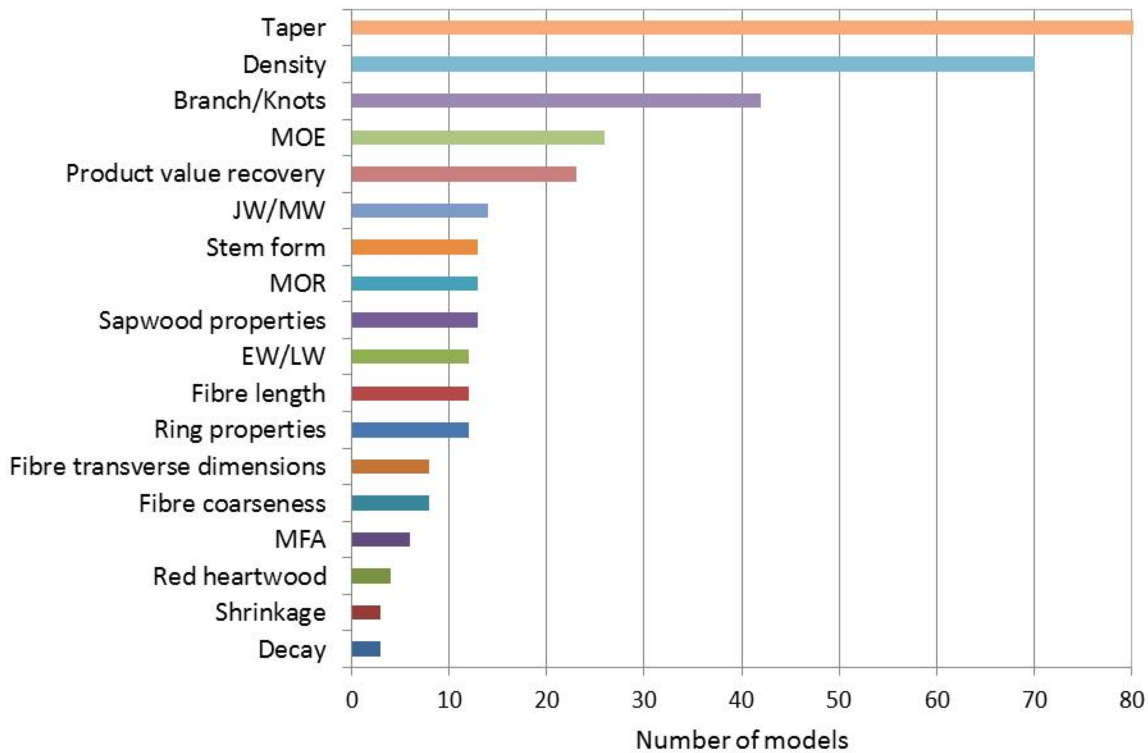


Figure 6. Number of models produced for different quality attributes. Only attributes for which more than two models have been developed are shown.

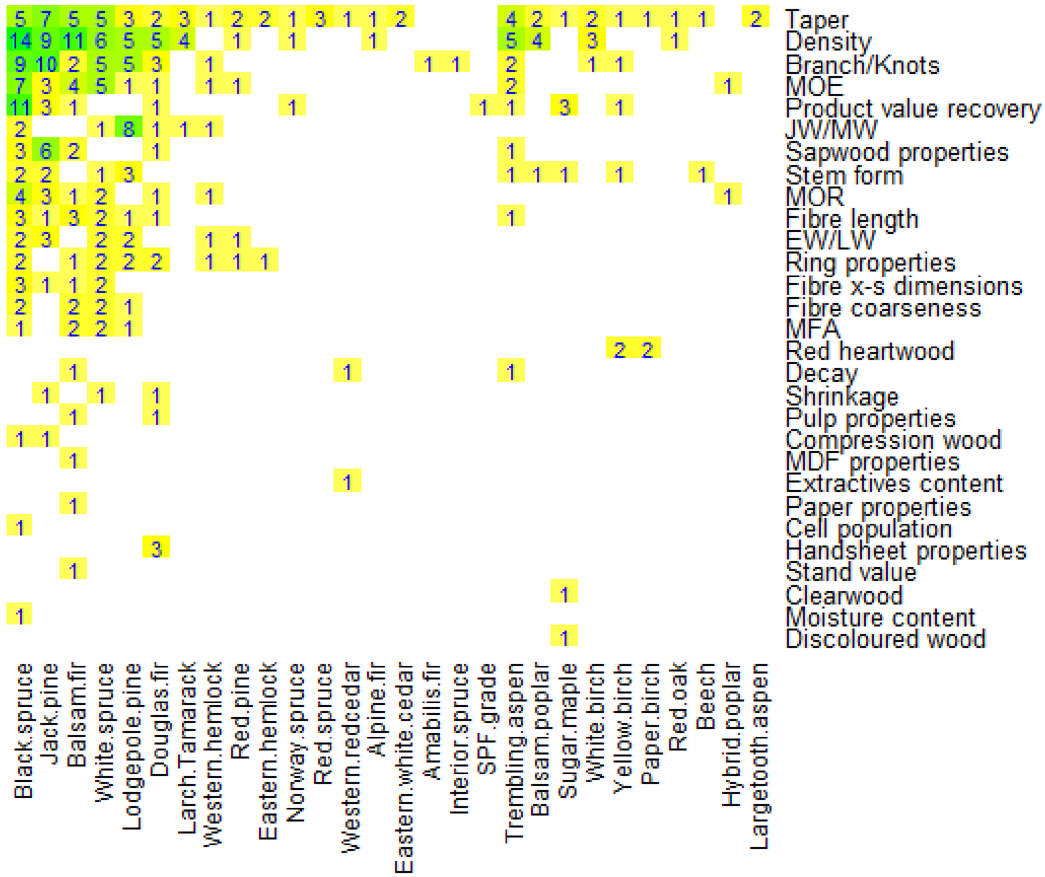


Figure 7. The number of wood quality models reported by species (grouped by hardwoods/softwoods) and quality attribute. PVR: product value recovery, XS: transversal; MDF: medium density fibreboard. Taper models are only included where there is at least one other attribute model.

Technically, i.e. in terms of product performance, relevant wood quality attributes are relatively well known in relation to their principal end-uses (lumber, composites, pulp and paper). But from an economic viewpoint, the impacts of many wood quality attributes are still unknown or can be questionable. How can these quality attributes be translated into dollar value? It is difficult to answer this question without a dedicated study involving scientists and professionals covering the entire span of the forest value chain, from the forest to the market. Such a study could help prioritize the attributes to model, and likely increase the interest and engagement of stakeholders in wood quality assessment and modelling.

3.1.5. Modelling scale and resolution

In attempting to integrate a wood quality model into a growth and yield simulator or DSS, one significant consideration is that of scale. In fact, while it may be easy to scale up a model (for example from ring level to disk level or from tree level to stand level), the scaling down is complex and requires special methods such as the disaggregation approach or the constrained approach (Weiskittel et al. 2011, Hevia et al. 2015). As such, it may be difficult to integrate wood quality models into some G&Y simulators or DSSs, depending on the scale of the latter (tree, size-class or stand level). Figure 8 shows that most of the internal wood quality attribute models are developed at the tree and ring levels. A few models have been developed to predict wood attributes at different vertical positions in a tree stem, as well as at plot level. In preparing data for Fig. 8, all of the external quality attributes (e.g., taper, stem form, branchiness) have been excluded as they are mostly at tree level.

Understanding wood quality variation across the landscape is important to answer management and planning questions. Initiatives such as the Newfoundland Fibre Inventory Project or the Québec Wood Quality Index Project (IQB-Indices de qualité du bois) that aim to assess wood quality at a large spatial scale with consistent sampling and sample analysis, provide a solid basis for optimizing the forest value chain (stand/cutblock selection, log allocation, processing optimization, marketing activities). Moreover, as stated by van Leeuwen et al. (2011), wide-scale collection of wood quality data under a broad range of stand and site conditions facilitates research on statistical modelling and prediction of fibre properties from tree, stand and site measurements derived from remote sensing technology and geospatial data. Several studies dealing with wood quality assessment exist but inconsistency in sampling procedure, and incompatibility between data due to use of different assessment techniques or methods and the lack of standards do not always allow comparison and mapping of wood quality attributes on a regional or national basis to draw the big picture. Only a comprehensive study involving all stakeholders can yield results that can benefit research and industry.

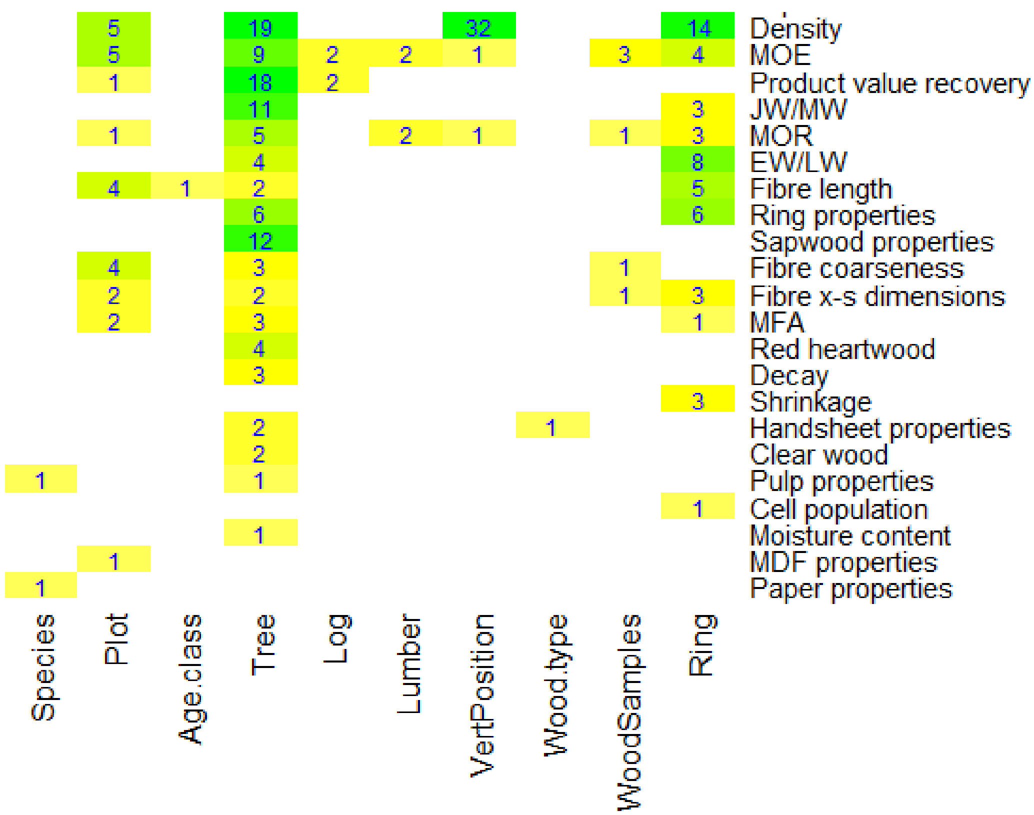


Figure 8. The number of wood quality models reported by internal wood quality attribute and scale.

3.1.6. Modelling approach

Several approaches have been used in the literature to model wood quality. We group them in four categories, adapted from classifications suggested by Zhang (2009) and Mäkela et al. (2010).

1) Conventional or empirical/statistical approach

In these models, wood quality attributes are predicted from measured stem, stand and site characteristics through equations fitted to data. They are simple to develop but their applications are limited to the stand or region where samples were collected.

2) Physics-based approach

Similar to empirical/statistical approach, the physics-based approach models internal properties of wood as a function of other internal properties. For example, a mechanical property can be modelled as a function of wood density and microfibril angle.

3) Structural growth-quality approach

In this case, the model is constructed dynamically as a tree develops in a growth simulator, by keeping track of many structural properties (crown development, diameter growth, juvenile wood formation, branch growth, etc.).

4) Process-based or physiology-based model

This approach considers the physiology of wood formation and how it is affected by environmental factors and availability of carbohydrates. It is used to model wood quality attributes related to crown development such as sapwood content, knottiness, juvenile wood, etc. Process-based models can be applied to different sites but they usually require more input variables such as physiological parameters, which are difficult to obtain. Also, they are still in their infancy.

As shown in Fig. 9, most of the wood quality models developed so far are empirical, which means they can only be applied to stands that have similar characteristics to those where models were calibrated. Furthermore, they do not help in understanding the fundamental processes that affect wood properties at different scales. It is just recently that an attempt has been made to build process-based models (Schneider et al. 2011).

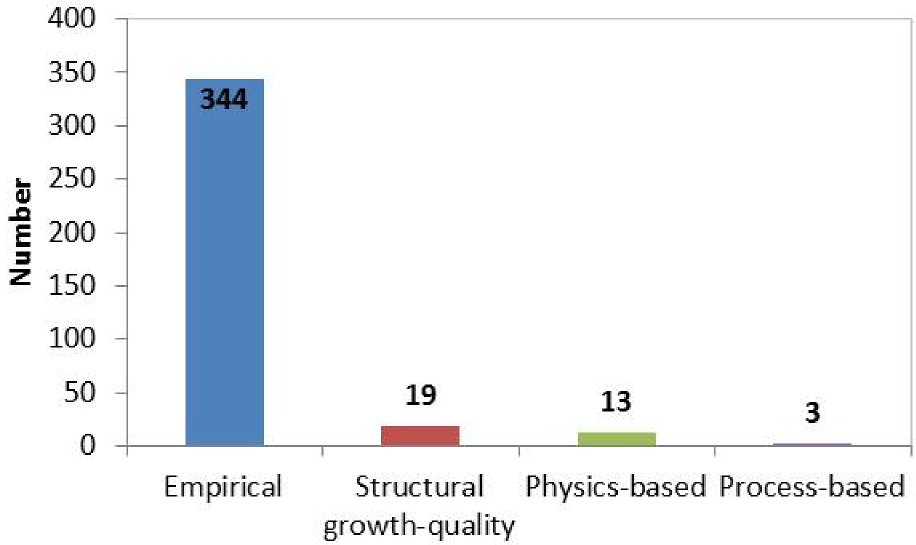


Figure 9. The number of models reported by modelling approach.

3.2. Questionnaire survey results

One objective of this project was to determine the status of the models developed so far for wood quality. In particular, we wanted to know whether the models are being used in G&Y simulators or DSSs for projecting future quality of timber in forest management planning or for value chain optimization. We sent questionnaires to 19 scientists and received 12 responses. From these responses, we received information on 143 models. Figure 10 shows that among the 143 models surveyed, only 30 are in operational use, and 15 are ready to be used. Most of the models are just simple equations, with no further development or prospective linkage with an operational platform. This is understandable as most of the wood quality models have been developed only recently. There is also a disconnect between scientists working in the area of wood quality modelling and those working in the areas of G&Y modelling or DSS development.

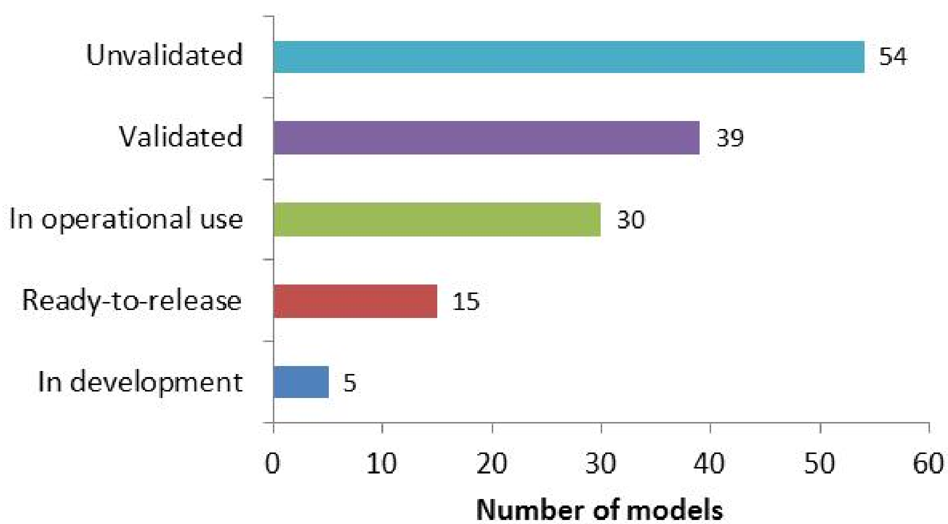


Figure 10. Status of the models reported in the questionnaire responses.

4. Growth and yield simulators

Table 1 shows the G&Y simulators reviewed in this project. More information can be found in Appendix A5. Each jurisdiction has developed their own G&Y simulators, with growth models adapted to their species. Almost all major commercial species have been covered. TASS is the simulator developed by BC's Ministry of Forests, Lands and Natural Resource Operations. Prognosis-BC and FVS-Ontario are simulators that have been adapted from the US Forest Service Forest Vegetation Simulator (FVS), which has been parameterized for the growing conditions and important tree species of different geographic regions (Hoover and Rebain 2010). A few simulators have been developed by universities for academic purposes (Spilab, Scube, and TAG) or are used by industry or government (MGM, TRIPLEX, COHORTE). The Open Stand Model is a growth and yield simulator that is being developed by a company in Fredericton (NB). According to its developer, Dr. Chris Hennigar, it is in use by the New Brunswick Growth and Yield Unit and has been designed as a generic platform from which any growth model can be implemented. AMSIMOD is a platform developed by the Canadian Forest Service (Larocque et al. 2014) to run Zelig-CFS, a process-based growth and yield model (Larocque et al. 2011).

Although not appearing explicitly in Table 1, Québec's ministère des Forêts, de la Faune et des Parcs currently uses CAPSIS (Computer-Aided Projection Strategies In Silviculture) to run its growth and yield models. CAPSIS is an open, generic and modular framework developed in France to facilitate implementation, running and visualization of forest growth models (Dufour-Kowalski et al. 2012).

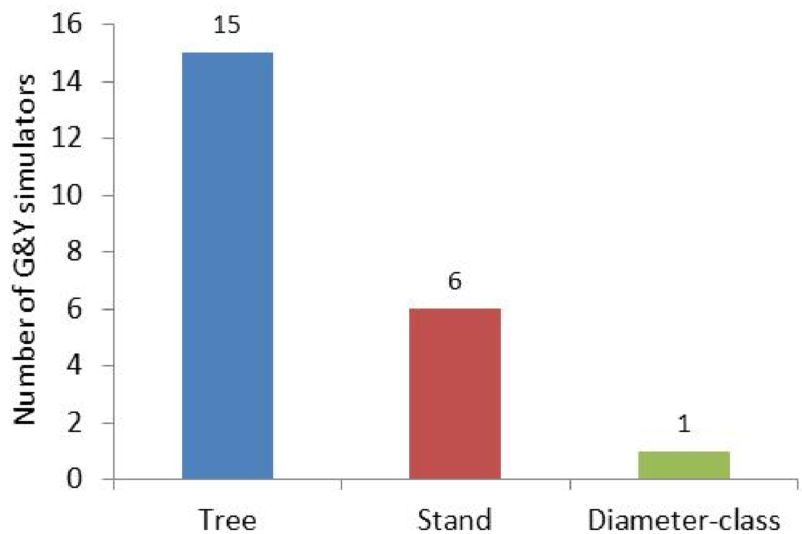
Table 1. List of growth and yield model simulators currently used in Canada.

Name	Institution	Approach	Resolution	Maturity	Species
GYPSY	ESRD, AB	Empirical	Stand	In use	White spruce, aspen, lodgepole pine and black spruce
Sortie-ND	MFLNRO, BC	Hybrid	Tree	In use	Northwestern BC species
TASS	MFLNRO, BC	Hybrid	Tree	In use	All major coniferous species in BC, aspen, and alder
Prognosis-BC	ESSA, UBC & BC MFLNRO	Empirical	Tree	In use	Various BC species
STAMAN	NBGYU, NB	Empirical	Diameter-class	In use	All major species in NB
NS G&Y Model	DNR, NS	Empirical	Stand	In use	Softwoods and hardwoods in NS
MIST	MNR, ON	Empirical	Tree	In use	All major ON species
FVS-Ontario	MNR, ON	Empirical	Tree	In development	All major ON species
CroirePlant	MFFP, QC	Empirical	Stand	In use	White spruce (plantation)
SaMARE	MFFP, QC	Empirical	Tree	In use	Sugar maple, red maple, yellow birch, American beech, balsam fir, other hardwood and softwood species
Artémis	MFFP, QC	Empirical	Tree	In use	All major hardwood and softwood species in QC
Natura	MFFP, QC	Empirical	Stand	In use	Hardwoods and softwoods in QC
AMSIMOD	CFS	Process-based	Tree	In use	Various softwood and hardwood species
IVY	CWFC	Hybrid	Tree	In development	Black spruce, jack pine, trembling aspen and potentially other species
MGM	University of Alberta	Hybrid	Tree	In use	White spruce, aspen, lodgepole pine, jack pine in pure/mixed stands
Siplab	UNBC	Process-based	Tree	Academic	Generic
Scube	UNBC	Hybrid	Stand	Academic	BC interior spruce (*P. glauca*, *P. engelmannii* and hybrids)
TAG	UNBC	Hybrid	Stand	Academic	Aspen in aspen-dominated even-aged stands in AB, BC, SK and MB
TRIPLEX	UQAM	Process-based	Tree	In use	Jack pine, black spruce, white spruce, and aspen
PipeQual	UQAR	Hybrid	Tree	In development	Jack pine, black spruce, white spruce
COHORTE	UQO (IQAFF)	Empirical	Tree	In use	Mostly hardwoods with some softwoods in QC and NB
Open Stand Model	Forus Research	Empirical	Tree	In development	Generic platform

Colour code: orange = crown (provincial or federal); black = university; red = private company

Most of the simulators make it possible to simulate growth for individual trees, while others operate only at the stand level (Fig. 11a). Most modelling efforts have been directed toward the development of empirical models (Fig. 11b), which have the advantage of being less complex and more easily used by forest managers and decision makers in addressing forest management questions (Bravo et al. 2012). Another advantage is that their development is facilitated by the use of the data types collected in inventory surveys (Larocque 2008). Process-based models (e.g., TRIPLEX) can provide more robust model projections under changing environmental conditions, but require more parameters, substantial calibration data, and increased simulation time (Porté and Bartelink 2002, Bravo et al. 2012). Some other models (MGM, PipeQual) use a hybrid approach where both empirical and process-based approaches are used.

a)



b)

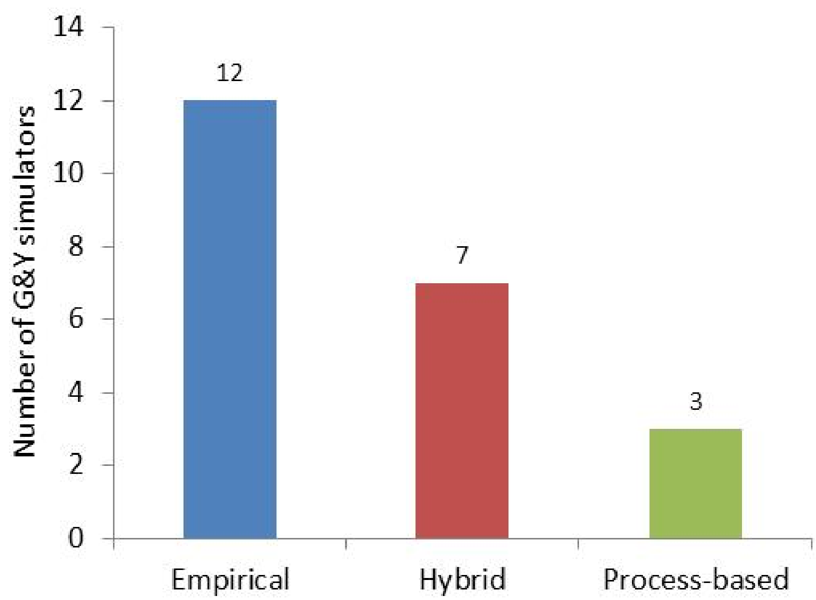


Figure 11. Growth and yield simulators categorized by a) their level of resolution and b) by the modelling approach.

5. Decision support systems (DSSs)

Table 2 and Fig. 12 present some features of DSSs surveyed in this project. A short description of these DSSs can be found in Appendix A6.

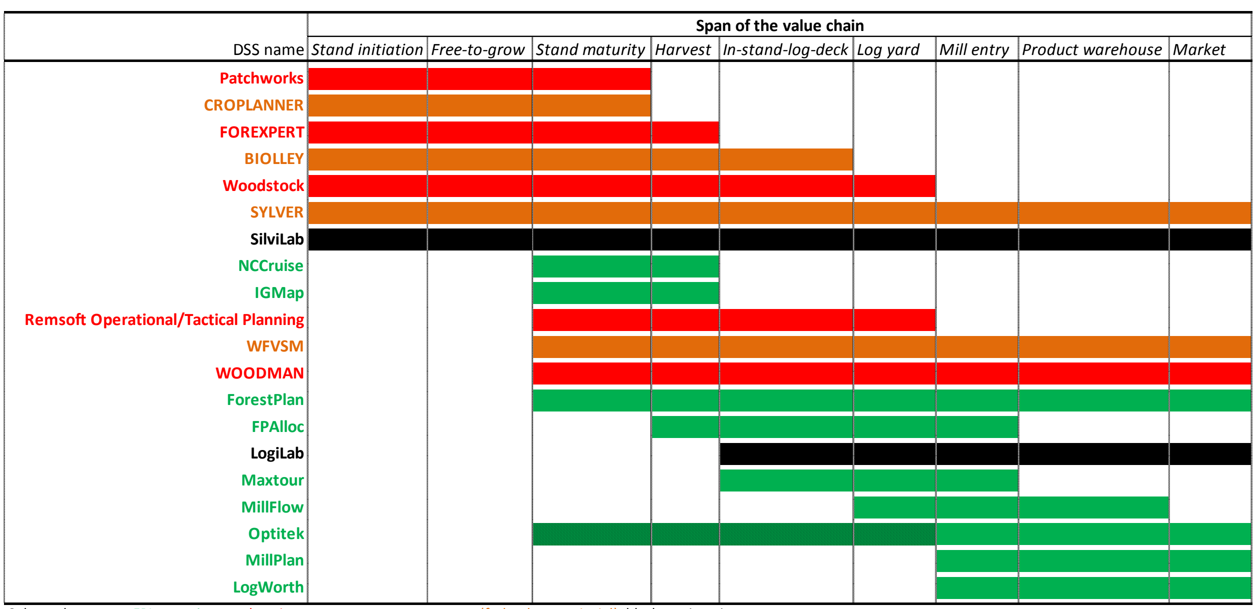
In Table 2, the DSSs are sorted by decision level, from highest to lowest, and colour-coded by institution type. BIOLLEY, CROPLANNER and WFVSM (Wood Fibre Value Simulation Model) have been developed by the CWFC. Outside the CWFC, DSSs have been developed by FPInnovations (Optitek, Maxtour, NCCRUISE, FPAlloc, MillFlow, LogWorth, MillPlan), the BC government (SYLVER), private companies (Woodstock, WOODMAN, FOREXPERT, Patchworks), and academics (SilviLab and LogiLab). Many FPInnovations DSSs are merged into a platform named FPInterface. Most DSSs surveyed can operate at a larger spatial scale (regional, forest or stand level) while others operate only at stand, tree or log level. Most are also sufficiently generic to support the addition of any growth and yield model. Exceptions to this are BIOLLEY, which was developed for hardwood stands in Québec and Ontario, and CROPLANNER, which was developed for black spruce/jack pine stands in Ontario. Although SYLVER was developed for BC species, it can be adapted for species in other jurisdictions.

Among the DSSs surveyed, only SYLVER, developed by the BC government, and SilviLab in combination with LogiLab, both tools developed by FORAC at Université Laval, cover the whole span of the value chain (Fig. 12). The remaining DSSs are either dedicated to strategic decision-making in forest management planning (Patchworks, FOREXPERT, Woodstock, CROPLANNER and BIOLLEY), or operational decision-making for log allocations or product conversion maximization and logistics (FPInnovations tools, Remsoft operational/tactical planning, and WFVSM). While Optitek is intended for log-sawing optimization at the mill, it can be used to simulate lumber recovery from forest inventory data or output from G&Y simulators.

Table 2. List of decision support systems surveyed.

DSS name	Institution	Decision level	Specificity
ForestPlan	FPInnovations	Regional/Forest/Stand	Generic
Woodstock	Remsoft Inc.	Regional/Forest/Stand	Generic
Remsoft Operational/Tactical Planning	Remsoft Inc.	Regional/Forest/Stand	Generic
Patchworks	Spatial Planning Systems	Regional/Forest/Stand	Generic
SilviLab	Université Laval	Regional/Forest/Stand	Generic
LogiLab	Université Laval	Regional/Forest/Stand	Generic
Maxtour	FPInnovations	Regional/Forest/Stand/Log	Generic
IGMap	FPInnovations	Forest/Stand	Generic
SYLVER	BC MFLNRO	Forest/Stand/Tree/Log	BC species
FOREXPERT	WSP Canada Inc.	Forest/Stand/Tree/Log	Generic
WOODMAN	Halco Software Ltd.	Forest/Tree	Generic
NCCruise	FPInnovations	Stand/Tree/Log	Generic
BIOLLEY	CWFC	Stand	Hardwoods, ON & QC
WFVSM	CWFC	Stand	Generic
CROPLANNER	CWFC	Diameter-class	Black spruce & jack pine, ON
FPAlloc	FPInnovations	Stand	Generic
Optitek	FPInnovations	Tree/Log	Generic
MillFlow	FPInnovations	Log	Generic
LogWorth	FPInnovations	Log	Generic
MillPlan	FPInnovations	Sawmill shift level	Generic

Colour code: green = FPInnovations; red = private company; orange = crown (federal or provincial); black = university



Color code: green = FPInnovations; red = private company; orange = crown (federal or provincial); black = university

Figure 12. Span of DSSs in the value chain

Many other DSSs have been developed by other private companies and have not been surveyed in this study due to time constraints. A list of some of these tools can be found on the Canadian Forest Web site (http://www.canadian-forests.com/software.html). In the same way, we did not cover all the tools used by provincial governments for their decision making in forest management planning. One such tool is the SFMM (Strategic Forest Management Model), a non-spatial forest modelling tool used by the Ontario Ministry of Natural Resources that enables the user to gain an understanding of how a forest develops through time, and to explore alternative forest management strategies and trade-offs (http://www.aimms.com/ontario/).

6. Status of integration

From the wood quality model survey responses, we counted 143 models. Among these models, 74 (52%) are currently not linked to a G&Y simulator or DSS (Fig. 13). They are published in the literature with no consideration for future development. Among the 69 models that were reported as integrated in a G&Y simulator or DSS, 28 (20%) are in TASS/SYLVER, and the remaining are in CAPSIS (17%), MGM (5%), Optitek (3%), PipeQual (2%), and CROPLANNER (1%). As mentioned earlier, Québec's ministère des Forêts, de la Faune et des Parcs uses CAPSIS to run its growth and yield models that include taper modules. The models for density, MOE and knottiness developed at Université Laval (Duchateau et al. 2013, Kuprevicius et al. 2013, Torquato et al. 2014 and Xiang et al. 2014a, b) and known as QuEST are also integrated in CAPSIS.

These wood quality survey results may not represent the true picture since the 143 models found in the survey were only a subset of the 379 models found in the literature (excluding genetics/genomics models). It should also be mentioned that model developers, in academia or other research institutions, may not always know who will use their models once they are published in scientific journals (they have no tracking system). Nevertheless, the survey results give us a preliminary indication that the state of model integration is relatively low.

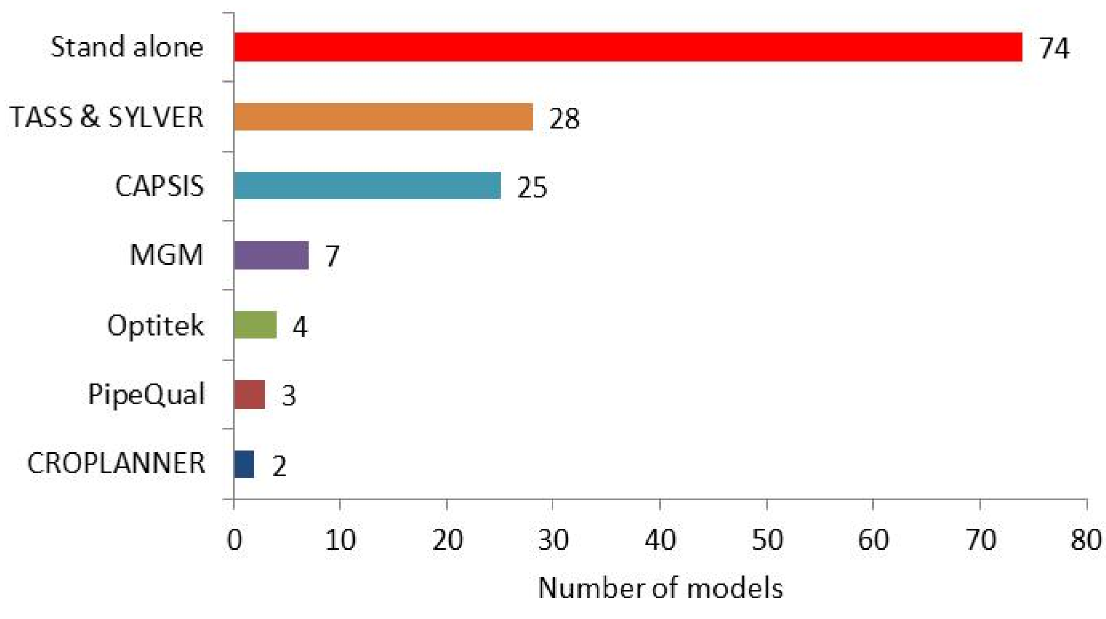


Figure 13. The number of wood quality models that have been incorporated into a G&Y simulator or DSS (from questionnaire responses).

Tables 3 and 4 show which of the G&Y simulators and DSSs surveyed have incorporated at least one quality attribute. While some G&Y simulators take into account an external quality attribute (taper, branch, stem quality) or internal wood quality attribute (wood density, MOE, sapwood, fibre length, etc.), many of them are volume-based only. All crown DSSs consider at least stem taper, and internal wood quality attributes are included in SYLVER and CROPLANNER. Some of the FPInnovations DSSs consider a quality attribute (Optitek, NCCruise, LogWorth), as do some commercial packages (WOODMAN).

Several G&Y simulators or DSSs do not include stem or wood quality attributes. This is a real issue since the timber value of a stand and products derived from it depend on stem form and internal fibre quality, as well as on tree size and volume. As mentioned by Briggs (2010), planning models that incorporate only growth and yield projections from growth models may produce information leading to biased analysis and inferior decisions.

Many reasons can explain this lack of integration of wood quality models into G&Y simulators or DSSs: lack of awareness about importance of wood quality, lack of awareness of what people are developing, and lack of resources (financial and skilled personnel). Some stakeholders may not yet be aware of the importance of wood quality in short- or long-term planning, and therefore feel no need to consider it in their models. Despite being aware of this importance, developers of G&Y simulators or DSSs may not know of the existence of wood quality models or, on the other hand, wood quality modellers may not know much about G&Y simulators or DSSs. If both groups continue working independently of each other, little improvement can be expected. When there is sufficient exchange of information among stakeholders, the lack of resources (human and budgetary) can compromise efforts to make wood quality models compatible with G&Y simulators or DSSs, especially if this was not part of the original project plan. A good example of an integrated platform is SYLVER, which encompasses both growth and wood quality models, has a long history, and has benefited from the strategic vision of scientists involved in its development and great support from the British Columbia government.

Table 3. Growth and yield simulators with realized or potential linkages to stem and/or wood quality attribute(s).

Name	Institution	Resolution	Model type	Time step	SQ attribute(s)	WQ attribute(s)
TASS	MFLNRO, BC	Tree	Hybrid	Yearly	Branch, taper	WD, MOE, MFA, FL, JW, SW, RW
MGM	University of Alberta	Tree	Hybrid	Yearly	Taper	WD, JW, MOE, FL
PipeQual	UQAR	Tree	Hybrid	Yearly	Taper	Sapwood
IVY	CWFC	Tree	Hybrid	Yearly	Knots	Clearwood, RW
SaMARE	MFFP, QC	Tree	Empirical	5 years	Volume by log grades	
Artémis	MFFP, QC	Tree	Empirical	10 years	Taper, volume by log grades	
COHORTE	UQO (IQAFF)	Tree	Empirical	Yearly	Branch, stem quality, defects	
Open Stand Model	Forus research	Tree	Empirical	Yearly	Taper, stem form	
MIST	MNR, ON	Tree	Empirical	?	Taper	
TRIPLEX	UQAM	Tree	Process-based	Daily		WD
GYPSY	ESRD, AB	Stand	Empirical	Yearly		
CroirePlant	MFFP, QC	Stand	Empirical	Yearly		
Natura	MFFP, QC	Stand	Empirical	10 years		
STAMAN	DNR, NB	Diameter-class	Empirical	5 years		
NS G&Y Model	DNR, NS	Stand	Empirical	5 years		
Scube	UNBC	Stand	Hybrid	Any		
TAG	UNBC	Stand	Hybrid	Any		
FVS-Ontario	MNR, ON	Tree	Empirical	Yearly/user defined		
Prognosis-BC	ESSA, UBC & BC MFLNRO	Tree	Empirical	Yearly/user defined		
AMSIMOD	CFS	Tree	Process-based	Yearly		
Sortie-ND	MFLNRO, BC	Tree	Hybrid	Yearly		
Siplab	UNBC	Tree	Process-based	Not time dependent		

Colour code: orange = crown (provincial or federal); red = private company; black = university
WD: Wood density; RW: ring width; SW: sapwood; JW: juvenile wood; FL: fibre length; MOE: modulus of elasticity; MFA: microfibril angle
SQ: stem quality; WQ: wood quality

Table 4. Decision support systems with realized or potential linkages to stem and/or wood quality attribute(s).

Name	Decision level	SQ attribute(s)	WQ attribute(s)	WQ resolution
SYLVER	Forest/stand/tree/log	Branch, taper	WD, SW, JW, CHEM	Tree
CROPLANNER	Diameter-class	Taper, branch	WD	Stand
BIOLLEY	Stand	Tree form		
WFVSM	Stand	Taper		
Optitek	Stem/Log	Taper, tree form, knot	WD, MOE, SW, JW	Log
NCCruise	Stand/Harvest block/Stem/Log	Taper, tree form, knot	FD	Tree
IGMap	Forest/Stand	Taper, tree form, knot	FD	Tree
LogWorth	Log	Taper		
WOODMAN	Forest/Tree	Taper, tree form, knot	WD, SW, JW, MOE, MFA, FD	Tree/Log
SilviLab	Regional/Forest/Stand	Branch		
LogiLab	Regional/Forest/Stand			
Maxtour	Regional/Forest/Stand/Log			
FPAlloc	Stand			
MillFlow	Log			
MillPlan	Sawmill shift level			
ForestPlan	Regional/Forest/Stand			
Woodstock	Regional/Forest/Stand			
Remsoft Operational/Tactical Planning	Regional/Forest/Stand			
Patchworks	Regional/Forest/Stand			
FOREXPERT	Forest/Stand/Tree/Log			

Colour code: green = FPInnovations; red = private company; orange = crown (federal or provincial); black = university
WD: density; SW: sapwood; JW: juvenile wood; CHEM: chemical properties; FD: fibre dimensions; MOE: modulus of elasticity; MFA: microfibril angle; SQ: stem quality; WQ: wood quality attribute

7. The CWFC wood quality toolkit: a compendium of models and decision support systems related to wood quality

Information on the wood quality modelling activities of CWFC researchers was obtained from two sources. First, models that had been completed and published as of March 2015 were identified through a literature search. Second, information on work in progress was obtained through communication with CWFC researchers. The following summarizes the “toolkit” of wood quality models and related software products that CWFC researchers have contributed to.

7.1. Completed models

CWFC researchers have collaborated with outside research agencies in all of their wood quality modelling work. The principal collaborators have been with the Foothills Research Institute, NASA, Nipissing University, Université Laval, Université de Sherbrooke, Université du Québec à Montréal, Université du Québec à Rimouski, and Université du Québec en Abitibi-Témiscamingue. Industrial partners have also played an important role. Key industrial partners have been West Fraser Hinton Wood Products (AB), Tembec (ON), and Corner Brook Pulp and Power (NL). Cooperation from provincial governments (BC, AB, ON, QC, NB, and NL) has also been integral to much of this work.

Unsurprisingly, the major commercial tree species (black and white spruce, balsam fir, jack and lodgepole pine) have received the bulk of modelling efforts. Some work has also been done on Douglas-fir, trembling aspen, white and yellow birch. The deciduous species are under-represented, a reflection of the overwhelming economic importance of the conifer species in the Canadian landscape.

Modelling efforts in the CWFC have addressed 17 kinds of wood quality attributes, mostly internal (Fig. 14). The exception is the external characteristic of branchiness or knot modelling, which has received the most attention across the broadest range of species. Wood density (or specific gravity) and MOE have been the subject of almost as many modelling efforts (16 and 15 models, respectively). Significantly less effort has been focussed on other attributes. It should be noted that there are also national/regional taper models (not shown in Fig. 14) developed by Ung et al. (2013); however, these appear to operate on too coarse a level to be used for wood quality assessment at the stand level.

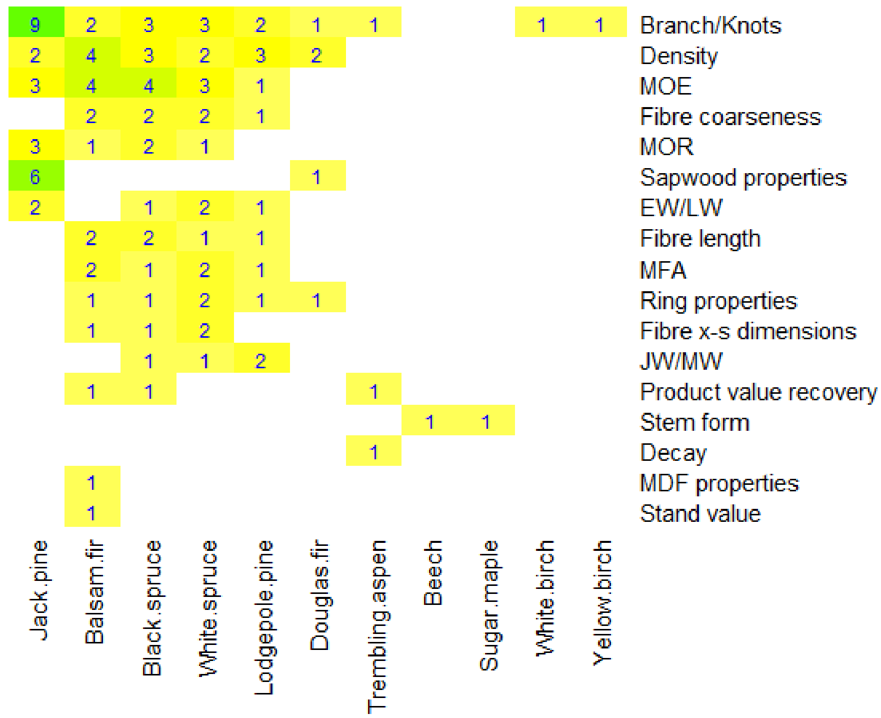


Figure 14. The number of models published by CWFC researchers, organized by species and wood quality attribute. MOE, modulus of elasticity; MFA, microfibril angle; MOR, modulus of rupture; fibre cross-sectional; EW/LW, earlywood/latewood characteristics; JW/MW, juvenile wood/mature wood proportion. Taper was excluded to avoid inflation of the figure with many single-model species.

Of the 113 models (excluding taper models) developed by CWFC researchers and their colleagues, 48 have used the individual tree as the unit of resolution, while 26 models focussed on coarser scales (e.g., stand or plot, Fig. 15). The scale of the model corresponds to the resolution of the remote sensing and other inventory data that are used to drive the models. For situations where finer scale data are available, 20 models have been developed that can resolve the within-tree distribution of wood quality attributes, most of these down to the level of the individual growth ring. Some of these models also include a component to describe the vertical distribution of attributes in the stem.

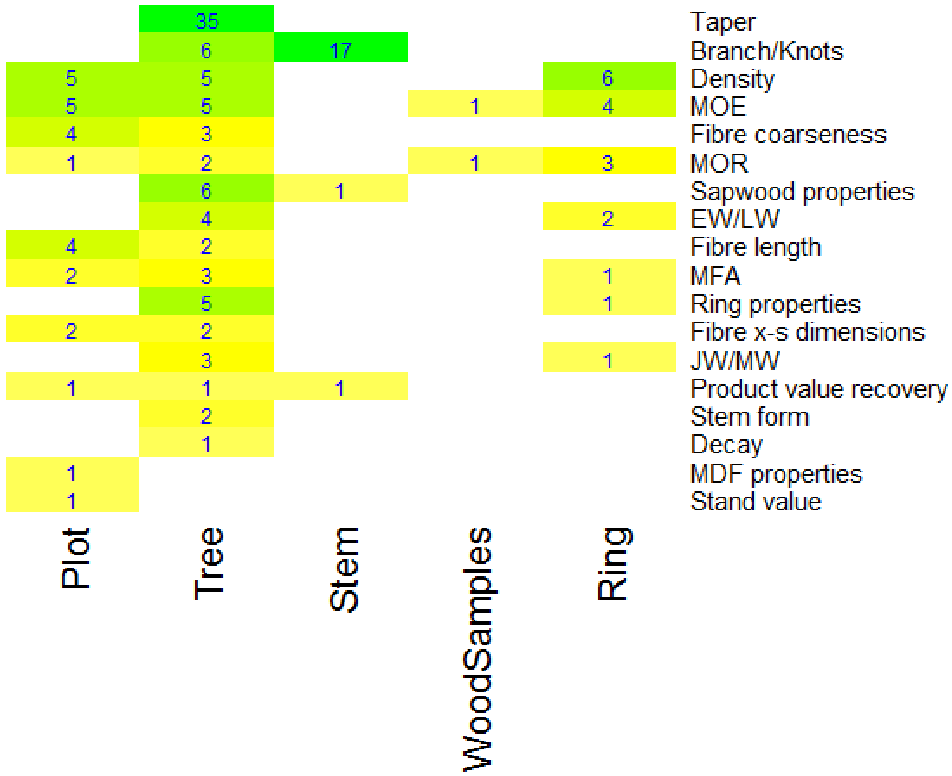


Figure 15. The number of models published by CWFC researchers, organized by level of resolution and wood quality attribute.

Data to drive these models come from many sources. At the stand or plot level, data come from existing forest inventory and/or remote sensing (typically LiDAR/ALS). Tree-level models use tree and stand characteristics gathered from ground-based observation. Within-tree (including ring-level) models require intensive sampling and/or longitudinal data series as input. These can come from disk or core samples, periodic mensuration of permanent sample plots, and long-term climate records. An alternate source of input data is annual measurement estimates from growth & yield models.

A review paper on the relationships between tree crowns and WQA, and their relation with enhanced forest inventory has recently been published (Groot et al. 2015). This review covers some of the wood quality modelling work done by the CWFC, along with related work by the Canadian Forest Service and other organizations.

7.2. Models in progress

Modelling work that has yet to be published was described in responses to the questionnaire survey in March 2015. This work includes:

1) Density in balsam fir and black spruce (Groot and Luther 2015), manuscript currently in press[2]

[2] Published as of 1 Sept. 2015 as Groot, A. and Luther, J.E. 2015. Hierarchical analysis of black spruce and balsam fir wood density in Newfoundland. Can. J. For. Res. 45: 805-815. doi:10.1139/cjfr-2015-0064.

2) Models of sapwood area vertical distribution in lodgepole pine and western hemlock in western Canada (Cruikshank, Cameron, Groot and Stewart 2015), manuscript currently in press[3]
3) Ring density of lodgepole pine as derived from models for earlywood density, latewood density and latewood proportion (Sattler, Finlay and Stewart 2015), manuscript currently in press[4]
4) Models of wood mechanical properties (MOE and MOR) for sugar maple and yellow birch grown in New Brunswick (Duchesne, Vincent, Wang, Ung, and Swift), manuscript currently in press[5]
5) Modelling of lumber stiffness (MOE) and strength (MOR) in black spruce (Power, Franceschini, Schneider, Duchesne, and Berninger), manuscript currently in review
6) Density in balsam fir and white spruce (Groot and Cortini), manuscript currently in review
7) Quantifying the maximum variation in wood density attributable to climate in lodgepole pine (Finlay, Sattler and Stewart), manuscript currently in review
8) IVY prediction of ring width in black spruce, jack pine and aspen (Groot), manuscript in preparation
9) Models of ring-level MOE and MFA in lodgepole pine (Peng and Stewart), manuscript in preparation
10) Evaluation of existing and new models for pith to bark MOE in white spruce (Sattler and Stewart), manuscript in preparation
11) Density in black spruce and jack pine (Newton): submodels for genetic worth effects and thinning responses, and ecological valuation have been recently accepted for publication in Forests; manuscript for density-dependent height effect model is under peer-review; manuscript detailing the development of variants for accounting for future changes in growing conditions is in preparation and empirical validation analysis is being initiated as is the development of a red pine variant.
12) Modelling annual ring mean wood density in white spruce (Peng, Sattler and Stewart) in analysis
13) A universal algorithm to determine the transition from juvenile to mature wood for the pith-to-bark trend in any wood quality attribute (Finlay and Stewart), unpublished and incorporated into WQ4MGM software (see next section).

Most of these models have a resolution down to ring level. Newton's density model resolves down to diameter-class level.

[3] Published as of 1 Sept. 2015 as Cruickshank, M.G., Cameron, I.R., Groot, A., Stewart, J.D., and Goudie, J.W. 2015. Models of the vertical distribution of sapwood area for Lodgepole Pine and Western Hemlock in western Canada. For. Sci. doi:10.5849/forsci.14-206.
[4] Published as of 1 Sept. 2015 as Sattler, D.F., Finlay, C., and Stewart, J.D. 2015. Annual ring density for lodgepole pine as derived from models for earlywood density, latewood density and latewood proportion. Forestry doi:10.1093/forestry/cpv030.
[5] Accepted as of 1 Sept. 2015 as Duchesne, I., Vincent, M., Wang, X., Ung, C.-H., and Swift, D.E. 2015. Wood mechanical properties and discoloured heartwood proportion in sugar maple and yellow birch grown in New Brunswick. Conference Proceedings of the International Scientific Conference on Hardwood Processing (ISCHP). Sept. 14-17, 2015, Quebec City, Canada.

7.3. Decision support systems

The CWFC has also developed programs that address the issue of wood quality, and could be used to support decision-making in operational forestry separately or, with some modification, in conjunction with the model described above.

Wood Fibre Value Simulator

The Wood Fibre Value Simulator is an integrated fibre inventory/attribute, supply-chain (inputs) and product option and value (outputs) simulation model that uses forest inventory data as input to generate product profiles and market values. This model allows end-users to identify the economic value outcomes of management prescriptions and product preferences to assess the best use of the fibre sources. The WFVS program is intended for formal integration into the Value Chain Optimization program of FPInnovations.

WQ4MGM

The software, Wood Quality for Mixedwood Growth Module (WQ4MGM), comprises two modules. The FibreAttributes module calculates fibre attributes at the ring level, from a .csv file of ring numbers and ring widths, and outputs a .csv file of predicted fibre attribute values. Users may optionally provide a parameter file specifying the parameter values used in each model. With no parameter file, FibreAttributes.exe uses default parameter values. Currently FibreAttributes.exe only provides ring-level estimates for MFA and MOE in lodgepole pine; models for density in lodgepole pine, and for density, MFA and MOE in white spruce are under development. Future work is planned for development and incorporation of models for fibre coarseness and perimeter for both species. The modular construction of this software is such that models for any species or wood quality characteristic at the ring level could potentially be incorporated. A second module, TransitionPoints, calculates the transition point between juvenile and mature wood for any profile of fibre attributes generated by the FibreAttributes module.

BIOLLEY

BIOLLEY is a stand-level optimization model, designed to help silviculturists and forest managers to select the trees to be cut, to maximize revenues in a sustainable way, in a context of an uneven-aged partial cutting system. Emphasis is put on the economics of short-term and long-term stand harvest, regeneration, and tending. The model was primarily developed for the application of the selection system, aiming at sustained net revenue over multiple cutting cycles.

Tree growth, survival and changes in quality/risk grades are modeled using a transition matrix calibrated from permanent plots in managed stands in Québec and Ontario. Tree recruitment is modeled using a modified version of the recruitment of Artemis-2009. Yields by log sorts and market value are modeled using bucking matrices from Québec’s ministère des Forêts, de la Faune et des Parcs, and current price tables available on the internet. Harvest costs are modeled using generic cost functions developed by FPInnovations.

The current version is designed for researchers to create and test alternative treatment strategies, in order to give guidance to forest managers. The spreadsheet model can be adapted to other uneven-aged systems, and/or to incorporate ecological indicators and objectives, in conjunction with wood production.

CROPLANNER

Ongoing modeling activities include development of response models for thinning and genetic worth effects, evaluation of the biological validity of the underlying model, and development of a structural stand density management model variant for red pine. Future activities will consist of empirical testing in terms of precision of yield estimates, code translation, documentation and peer-review reporting. Pending acceptance by the provincial regulatory agency, i.e., Ontario Ministry of Natural Resources and Forestry (OMNRF) for use in the OMNRF forest planning system, this empirically unvalidated prototype requires additional model refinement and evaluation (with associated model changes if required), provision of comprehensive documentation (i.e., monograph) and supporting peer-reviewed articles, and programming research including computer code development, translation and testing. Limitations include the allometric yield-based modelling approach utilized, calibration data utilizing mostly natural-origin stand types with limited data from mature density regulated stands, current lack of evaluation metrics and comprehensive documentation. The end-user community regulated by the OMNRF is familiar with the modelling approach (stand density management diagrams) and it is expected that the OMNRF will eventually utilize the DSS in their forest management planning system providing that the pending prerequisites are completed. A participatory approach incorporating representatives from regulatory agencies (OMNRF) who govern the deployment of DSS models in operational forest management planning has been adopted. They have been involved in providing feedback and advice since project initiation. Providing the scientific foundation and hence transparency of the modelling approach has also been a principal focus as evident by the extensive publication record (Newton 2009, 2012).

Table 5. List of wood quality publications involving a CWFC scientist as principal author or coauthor

CWFC authors	Collaborating institution	Species	Wood quality attributes	Scale	Citation
Beaulieu	CFS	White spruce	Density, MOE, MOR, knots	Family/ provenance/ site	Beaulieu et al. (2006)*
Beaulieu	Université Laval	White spruce	MFA, MOE	Tree	Lenz et al. (2013)*
Beaulieu	Université Laval	White spruce	Density, MOE, MFA, fibre transverse dimensions	Ring	Lenz et al. (2011)*
Beaulieu	Université Laval	White spruce	Density, EW/LW, fibre coarseness, fibre XS dimensions, MFA, MOE, ring properties	Tree	Lenz et al. (2012)
Beaulieu	UQAT	White spruce	JW/MW	Ring	Mvolo et al. (2015)
Beaulieu, Clément	CWFC	White spruce	Density, MFA, MOE, fibre XS dimensions	Tree	Beaulieu et al. (2014)*
Beaulieu, Clément, Deslauriers	CWFC	White spruce	Density, MFA, MOE, fibre coarseness, ring width, EW/LW, fibre XS dimensions	Family	Beaulieu et al. (2011b)*
Beaulieu, Ung, Swift	UQAM	Jack pine	Branch/knots	Tree	Beaulieu et al. (2011a)
Cortini, Groot, Duchesne	CWFC	Balsam fir	Density, MOE, MFA	Tree	Cortini et al. (2014)

CWFC authors	Collaborating institution	Species	Wood quality attributes	Scale	Citation
Cortini, Groot, Filipescu	CWFC	Black spruce, balsam fir, white spruce, lodgepole pine	Ring properties	Tree	Cortini et al. (2013)
Cruikshank, Filipescu	CWFC	Douglas-fir	Sapwood	Stem	Cruickshank and Filipescu (2012)
Deslauriers, Ung, Beaulieu	Université Laval	White spruce	Density, EW/LW, fibre coarseness, fibre length, fibre XS dimensions, MFA, MOE	Tree	Lenz et al. (2014)
Duchesne	Université laval	Black spruce	Product value recovery	Stem	Barrette et al. (2012)
Duchesne	Université Laval	Black spruce	MOE, MOR	Samples within tree	Torquato et al. (2014)
Duchesne	Université Laval	White spruce, jack pine	MOE, MOR	Tree	Vincent and Duchesne (2014)
Duchesne, Pitt	CWFC	Balsam fir	Density, MOE, MOR, product value recovery, MDF properties (Bonding, MOE, MOR,…)	Plot/Stand	Duchesne et al. (2013)
Filipescu, Koppenaal, Mitchell	CWFC	Douglas-fir	Density, ring properties	Ring	Filipescu et al. (2014)
Groot	CWFC	Balsam fir, black spruce, Douglas-fir, jack pine, lodgepole pine, trembling aspen, white birch, white spruce, yellow birch	Branch/knots	Tree	Groot and Schneider (2011)
Groot, Pitt	Nipissing University	Black spruce	Density, EW/LW	Tree/Ecosite	Pokharel et al. (2014)
Luther	Université Sherbrooke	Black spruce, balsam fir	Density, fibre coarseness, fibre length, MOE	Plot/Stand	Lessard et al. (2014)
Luther, Côté	CWFC	Black spruce, balsam fir	Density, fibre coarseness, fibre length, fibre XS dimensions, MFA, MOE	Plot/Stand	Luther et al. (2013)
Newton	CWFC	Jack pine	Stem form	Tree	Newton and Sharma (2008)
Park	UBC	Douglas-fir	Density, ring width, EW/LW	Tree	Krakowski et al. (2005)*
Park	CWFC	White spruce	Density, EW/LW, fibre length, MFA	Tree/Clone	Park et al. (2012)*
Pitt, Lanteigne, Hoepting	CWFC	Balsam fir	Stand value	Plot/Stand	Pitt et al. (2013)

CWFC authors	Collaborating institution	Species	Wood quality attributes	Scale	Citation
Stewart	NASA, UBC, CSIRO	Lodgepole pine	Density, fibre coarseness, fibre length, MFA, MOE, branch/knottiness	Tree/Site	Hilker et al. (2013)
Stewart	Foothills Research Institute	Lodgepole pine	Density	Ring/Tree	Peng and Stewart (2013)
Stewart	Foothills Research Institute	Lodgepole pine	JW/MW based on MFA	Tree/Site	Wang and Stewart (2012)
Stewart	Foothills Research Institute	Lodgepole pine	JW/LW based on MOE	Tree	Wang and Stewart (2013)
Swift, Lussier	UQAM	Jack pine	Density, EW/LW, MOE, MOR	Ring	Schneider et al. (2008a)
Ung	Université Laval	Black spruce	MOE, MOR	Ring	Alteyrac et al. (2006)
Ung	Université Laval	Black spruce, jack pine	Branch/ knots	Tree	Duchateau et al. (2013)
Ung	Université Laval	Black spruce	JW/MW	Tree	Giroud et al. (2014)
Ung	CWFC	Various species across Canada	Taper	Tree	Ung et al. (2013)
Ung, Swift	UQAM	Jack pine	Branch/ knots, sapwood	Tree	Schneider et al. (2008c)
Ung, Swift	UQAR	Jack pine	Sapwood	Tree	Schneider et al. (2011)

*: Genetics/genomics studies
EW/LW: earlywood/latewood properties; JW/MW: juvenile wood/mature wood properties; MC: moisture content; MOE: modulus of elasticity; MFA: microfibril angle; MOR: modulus of rupture; XS: cross section

8. BrainLab workshop output synthesis

As a complement to the current report's review of wood quality models, growth and yield simulators, DSS, and questionnaire surveys, the CWFC organized a workshop entitled "Strategic Planning for Linking Wood Quality Models to Decision Support Systems" in March 2015. The objective was to bring together researchers in wood quality modelling and developers of decision support systems related to the forest value chain. In this workshop, participants reviewed the current state of wood quality modelling and related decision support systems in Canada (See Workshop agenda in Appendix A7), discussed key opportunities and challenges in linking wood quality models to operational DSSs, and reflected on a strategic plan to create these linkages. In general terms, the workshop was framed to answer the fourth and fifth questions of the Methodology section:

1) What are the challenges in linking wood quality models to G&Y simulators or DSSs? and;
2) What could be done to address these challenges?

To focus our discussions at the workshop, we proposed the following Vision: "Canada's forest industry is using wood quality information to optimize use of forest resources".

Inevitably and beneficially at a workshop, a lot of good ideas get tossed around and this meeting was no exception. To illustrate this, all "bulk" ideas expressed at the workshop are listed in Appendix A8, A9, and A10. In the synthesis of the workshop discussions below, however, only ideas related to the modelling of wood quality and integration into decision-support systems were retained.

8.1 Technical challenges and possible solutions

8.1.1. Data

Incompatibility of models and lack of standard methods - Successful integration of existing and future wood quality models with decision support platforms will require that they all 'speak the same language'. This means that they will not only have to utilize the same variables in their inputs and outputs, but also that these variables will have to have the same meaning, e.g., they have a standard definition and protocol for acquisition. Some of the differences are based on differences in the mode of measurement (e.g., static vs. dynamic modulus of elasticity (MOE)) or how they are defined (e.g. earlywood/latewood boundary). Not only must researchers develop a consistent approach to data, but the research community must also align their definitions and standards with those in use in industry, to ensure that the final products are operationally useful.

Input data acquisition - Large volumes of data are needed to develop statistically robust models and to validate them over a range of conditions. WQA data is labour-intensive and costly to measure relative to traditional forest mensuration, so that funding for the acquisition of the quantities of data required can be challenging. Although there has been an increase in wood quality modelling effort in the past decade, there are still not enough data to cover all WQA in Canadian commercial tree species.

WQA models often use forest inventory variables as the driving variables. Therefore, these WQA models will rely on the availability of high-quality inventory data. Currently, a major limitation in using traditional forest inventory is that the inventory cycle is usually 10 years or more, and often irregular. This means that data can be seriously out-of-date, and not reflective of the current stand conditions, especially where a significant disturbance event has occurred since the remote sensing data was collected. Recent remote-sensing technological advances, such as LiDAR, will help to lower the costs of inventory data acquisition and processing, while generating higher-precision larger-scale data. Moreover, remote sensing will allow shortening of inventory cycles.

It is also difficult to estimate wood properties arising from growing conditions and tree characteristics that existed in the past from observation of the current tree and stand conditions. Modelling WQA at the ring level requires ring-level or annual scale information on tree growth and growing conditions. Such data for developing models can come from stand reconstruction, stem analysis and climate data. Where WQA models are used for estimating the properties in the current forest inventory, such longitudinal data can be found in increment cores sampled from selected trees to acquire the annual growth record (ring number and width, and distance from pith being common model drivers). This can give high-quality data, but suffers from being costly and time-consuming to carry out.

Non-destructive testing tools offer an alternative to destructive sampling measurement of WQA, albeit with some limitations. Tools based on acoustic velocity, mechanical resistance, and IR spectrometry can be used to estimate wood density, stiffness and other properties, but this still leaves other properties to be inferred from relationships with measurable variables. Measurement error is also greater in these non-destructive methods compared with direct measurement of samples.

A less intensive approach is possible where the longitudinal data have come from periodic mensuration over the course of stand development. While the overall cost is still high, it can be spread over a longer time period and over multiple objectives. The result is of lower resolution than that provided by core samples, but is adequate for industrial purposes. It also provides a better picture of whole stand processes (e.g., mortality and density changes) than a retrospective reconstruction from core samples.

Data management - Given the high demand for, and value of, any WQA dataset, its utility can be maximized by making such data available to the wider modelling community. Initiatives like TreeSource (National wood quality database[6]) and LTRIC (Long term research installation catalogue) can be a useful tool for standardizing and disseminating datasets. Previous efforts to develop a data clearinghouse in the ForValueNet project encountered a number of challenges because it was difficult to find financial resources for structuring and managing databases. Funding was allocated mostly to graduate student salaries, for training of highly qualified personnel, and not for developing database infrastructure. Without proper data management, the risk of losing valuable datasets is high, especially when newly graduated students leave university. Therefore, government-based initiatives to manage databases appear to be a good way to ensure long-term accessibility to data.

8.1.2. Modelling

Where should WQA modelling focus its efforts? Maximum return on the development effort comes when models are designed to be easy to adapt to different platforms, different regions, and possibly different species. There is an apparent lack of highly qualified personnel who are able to understand and run sophisticated models (models that evaluate sophisticated behaviour). While such expertise is present in the research organizations, it is often lacking in the provincial agencies or forest companies. A modular plug-and-play approach would make it easier to share and build upon existing models, to share knowledge among developers and educate end users in their use. However, it must be recognized that general (universal) models may not provide solutions for every situation; there will likely be a need for particular models to address specific needs.

Another approach is to replace or adapt regional models with more generic models with regional parameterization. This would mean incorporating variables such as ecosite, climate and stand condition to account for differences in different forest regions. Most of our studies and modelling of WQAs have been based on fire-origin stands. To be able to apply our knowledge of WQA in planning new forests, we need to validate these models in post-harvest stands in which tree growth and stand development do not necessarily mirror that in the fire-origin stands.

WQA models that are to be integrated with G&Y models or DSSs need to use inputs that can be provided by the latter programs, and vice versa. This means using the same variables, or variables that can easily be converted into those needed by the models. The variables also need to be expressed at the same scale, both temporally and spatially. For example, stand level basal area increment (BAI) cannot replace annual ring area, unless it is also accompanied by an indication of the distribution of that BAI among the trees in the stand.

[6] TreeSource can be accessed on the internet at https://treesource.rncan.gc.ca

Modelling down to the annual ring level provides the greatest detail and is the scale at which the environmental and biological processes are interacting to produce the wood. However, it may not always be practical to model at that scale, nor cost-effective. It would be useful to identify the scale at which the cost of modelling WQAs is offset by the most value in using the information in the value chain.

Another area that should be investigated is the testing of new information sources, from e.g., remote sensing, non-destructive testing technologies, and long-term climate records, that could be used to drive models, or to allow localization (site calibration) of regional models.

What species and WQAs would provide the most benefit to the industry? It is important that the modelling community gets maximum benefit from their efforts by focussing effort on those species and conditions, and scale of modelling that will have the greatest operational impact, and works in collaboration with inventory experts. So far, softwoods have received the most effort, but there would likely be a greater payback from modelling the properties of the higher-value hardwoods (e.g., sugar maple, yellow birch). In the short- and mid-term, we should focus on species and wood properties that have the most impact on product value (market demand). However, it is difficult to predict market needs in the long term. Aspen was once considered as a weed a few decades ago in Canada but with technological development, the species became the principal supply for oriented strand board (OSB) mills. Compression wood has not been modelled, but there is some industry demand. Modelling knots and checks is a great concern to the industry, especially in lodgepole pine that has been killed by MPB. With the emergence of the bioeconomy, new wood components (e.g., extractives) may generate great value. Ultimately, a form of risk assessment is needed to decide where to strategically focus our efforts. However, because the future is uncertain, the modelling community should work to maintain diversity of the fibre basket, and avoid addressing only short-term solutions to immediate problems.

8.1.3 Software (DSS) development

DSSs should operate at timescales similar to those of the WQA models, to forecast the future state of the forest and fibre resource. DSSs will have to adapt their inputs and outputs to some extent to better accommodate integrating WQA models. There is some value in promoting the use of a common integrating platform (e.g., CAPSIS, AMSIMOD) for linking WQA models, G&Y models, and DSSs.

To enable information flow in (close to) real time along the value chain, we need to accommodate a wide base of digital devices that can run the various models and platforms. These range from server-supported workstations to laptops to tablets to smartphones, as well as some specialized proprietary devices. These all need to be able to pass data easily, once the common denominators for data are established. This will require an easy way to transfer data from one software program that has been stored in a particular format and convert it into another format for use in a second software program. This will be realized through format conversion software, or through format standardization among software. Working with DSS designers to develop a protocol/platform for interconnectivity between the future tools/models would facilitate integration.
Most wood quality models work at the level of the individual tree or even individual growth ring. There is a need to develop or adapt G&Y models and DSSs so that they can operate to that level.

Realizing the maximum benefit of modelling WQA distribution in trees and stands will not be possible unless the high-value wood can be identified, sorted, tracked and allocated to the appropriate processing line. This means tying in wood quality measurement, modelling and planning with other aspects of forest operations, e.g., bucking programs, log haul optimization, and log yard management.

Lastly, the efficacy and value of DSSs that incorporate wood quality must be demonstrated through proof-of-concept and case studies.

8.2. Organizational challenges and possible solutions

In addition to the technical and scientific challenges, there are also challenges related to communication, coordination, management, funding and training. There is no leadership group at the national level to direct or coordinate research and development efforts. Lack of coordination among research groups leads to a piecemeal approach, and resulting inefficiency. It is important that researchers keep current on what is being done in other regions and disciplines to help avoid duplicate work by having two groups developing models for the same species and WQA.

Presently, wood quality modelling work is represented by many small voices. We lack a clearinghouse and communication mechanism for expressing regional concerns at the national level. There is a need for collective, coordinated actions. This may involve developing a Community of Practice or a research network. We also need to have an open catalogue of tools to share advances in this field.

Researchers and application developers need better communication with industry and government to help them understand their challenges, and to educate them about the solutions that are being developed. An on-going participatory interaction between the provinces, industry and research community from the initiation of the project would ensure that research heads in the right direction, that solutions are acceptable to the regulators, and that they are appropriate and usable by industry once they are produced. Where there is little demand for wood quality information from industry, there will be limited support for this work in terms of both funding and moral support. Therefore, there is a need to develop a communication plan with a coordinated approach and messaging, along with developing a reciprocal relationship with industry and governments, and to identify early adopters.

A subset of the communication gap is with standards/code organizations, e.g., NLGA. Information on WQA must align with grading standards to realize the potential value of the wood products. Harmonization of definitions and standards related to quality attributes across the country is necessary to facilitate communication, define a collective vision, and develop strategic research directions. A common representation and understanding of quality attributes would be useful, as it would facilitate the development of models, and their implementation and dissemination to end-users and decision makers. Furthermore, a common framework would ease the comparison of various modeling practices and models across the country.

To make significant progress, there is a need for stable, long-term funding and maintaining the research capacity (HQP in research organizations). Lack of patience by funding agencies, agency management, and industry partners will jeopardize this work, therefore effort must be made to ensure that they recognize the importance of this research and how long it takes to accomplish. ForValueNet has been the first “national” effort to integrate growth and wood quality information into forest management decisions, and in its 5-year duration (2008-2013) significant progress has been made. However, the program has not been renewed, and since the end of the network in March 2013, there has been no coordinated effort to continue the endeavour. There is a strong need to develop such a nation-wide program and go beyond what has been accomplished. The CWFC, in collaboration with FPInnovations, industry and some key universities, could lead the development of such a collective proposal and advocate for sustainable funding. Most of the domestic growth and yield simulators and decision support systems are mature and are flexible enough to accommodate wood quality models. It is just a matter of developing strong, accurate, transparent, and validated wood quality models. With that and sufficient resources, wood quality models can successfully be incorporated into growth simulators or decision support systems for the benefit of the forest sector.

There is an apparent training gap in many disciplines connected with stand productivity and wood quality and their relationships with forest management. This may make it difficult for industry to implement the tools being developed if they do not have the staff with the technical competence to learn and apply the tools. Training of industry personnel and extension programs would facilitate adoption of models and tools.

9. Conclusions and recommendations

The objective of this project was to promote the incorporation of wood quality models developed by the CWFC and other institutions into growth and yield simulators or value chain optimization systems so that the forest and forest products sectors can derive maximum benefit from these models. The approach was to review existing wood quality models, growth and yield simulators and decision support systems to have a clear portrait of the situation in Canada, send a questionnaire survey to model developers to estimate the level of integration of their model(s), hold a national workshop with experts to discuss challenges related to the integration of wood quality models into decision-support systems, and reflect on a strategy to address these challenges.

The literature review has shown that the CWFC and other institutions have produced over 350 models to predict a variety of wood quality attributes for some important Canadian commercial tree species. In brief, work so far has been conducted in the western provinces on lodgepole pine, Douglas-fir and western hemlock, and in the eastern provinces on black spruce, jack pine, white spruce and balsam fir. Less effort has been spent on hardwood species. In terms of attributes, taper, wood density, branchiness/knottiness and modulus of elasticity have received more attention. Despite the large number of wood quality models developed, the questionnaire survey results indicate that only 48% have been integrated into a G&Y simulator or DSS. In this report, we have identified a number of issues that should be addressed for progress to be made in fully integrating wood quality information into inventory and planning tools used by the forest industry. Below we summarize the needs, propose an action and identify the objectives to be met.

Identification of significant issues, challenges, and gaps to be addressed

1. Communication among developers, modellers and stakeholders - There is a need for improved communication between wood quality modellers and the developers of growth and yield simulators and decision support tools. The current multiplicity of uncoordinated projects in space and time is a critical impediment to the adoption and integration of wood quality models in forestry operations. Modelling work is often wasted through independent modelling efforts for the same species and attributes, and where models use scales and data not compatible with other planning and projection tools.

2. Taking advantage of existing wood quality tools and models - Over 350 wood quality models have been developed in recent years. However, only about half of them are linked to growth and yield models or DSSs which are used for growth projection or decision making at the operational, tactical or strategic levels, respectively. In many cases, models are just developed and published as standalone equations, with no further developments planned.

3. Coordination of future wood quality modelling research program - Existing research projects in wood quality modelling across the country are not well designed to fully benefit the forest sector. Perhaps due to limited funding and time constraints, studies have often been confined to relatively small experimental sites scattered here and there in space and time. Consequently, many models are developed but remain in an embryonic state. Most of the domestic growth and yield simulators and decision support systems are mature and are flexible enough to accommodate wood quality models; however, some effort is still required to develop strong, accurate, transparent, and validated wood quality models that can provide robust decision support for forest management and are compatible in scale and the types of variables used. Ring-level wood quality models can most easily be integrated with growth simulators, while tree and stand level models, especially those involving external quality atributes, will be compatible with operational decision support and inventory systems.

There is a need for a nation-wide program to be the successor of ForValueNet, led by a scientific/technical committee involving scientists and professionals from various disciplines and industry sectors. Its role would be to provide a common vision for research goals, and to help define standards or best practices for sampling, data acquisition, and information delivery systems. This coordinated activity would benefit from a common conceptual framework for modelling, and identification of key variables to be used in modelling and application design, facilitating their development, implementation and dissemination to end-users and decision makers. Furthermore, a common framework would ease comparison of various modelling practices and models across the country.

4. Geographical variability of wood properties - Currently all commercial species and wood quality attributes have not been studied to the same degree. Understanding wood quality variation across the landscape is very important for management and planning questions (e.g., to adapt manufacturing processes to incoming fibre supply). Initiatives such as the Newfoundland Fibre Inventory Project or Québec Wood Quality Index Project (IQB-Indices de qualité du bois) provide a solid basis for optimizing the forest value chain (stand/cutblock selection, log allocation, processing optimization, marketing activities). Moreover, wide-scale collection of wood quality data under a broad range of stand and site conditions facilitates research on statistical modelling and prediction of fibre properties from tree, stand and site measurements derived from remote sensing technology and geospatial data (van Leeuwen et al. 2011).

With the exception of the ForValueNet initiative, a piecemeal approach to modelling, carried out by individual, largely independent research groups, has characterized much of the work to date. Any new initiatives should favour an integrated large-scale modelling approach. Avoiding small-scale projects would help to improve efficiency and limit duplication of effort. An important aspect would be building partnerships with the AWARE network researchers, and leveraging their work using cutting edge technologies to provide inventory information that can be used to drive wood quality models. This action should also take advantage of work already done by FPInnovations and of new assessment technologies such as SilviScan, acoustics and NIR to develop larger scale research projects. Collaboration with the National Forest Inventory of NRCan, and learning from their experience in coordinating data and effort across many organizations and jurisdictions, would help researchers to better exploit forest inventory data to map wood quality across the country. Data collected through this action could be made available to the wider community through initiatives such as TreeSource.

5. Economic value of wood attributes - While the economic impact of some wood quality attributes is well known for some products, for many of them, their economic value is still unknown or is difficult to quantify. FPInnovations has been doing this kind of work as case studies with different clients. A meta-analysis may be possible to develop a more generic application of the results of the individual case studies. This would help prioritize attributes in current forests, more efficiently forecast attributes of future forests and put resources to produce trees with desirable attributes in the future, which altogether would likely increase the interest and engagement of stakeholders in wood quality assessment and modelling.

6. Standardization of assessment methods - Several studies dealing with wood quality assessment exist; however, inconsistency in sampling procedures, incompatibility between data due to utilization of different assessment techniques or methods, and the lack of standards means that comparison among studies is often difficult or impossible. Mapping of wood quality attributes on a regional or national basis to draw the big picture will rely on data from multiple sources. Where data are derived from different methods or processes, there should be some means sought to provide robust conversion factors (e.g., between static and dynamic measures of MOE).

Recommendations for actions to be taken

A. CWFC and FPInnovations

We recommend setting up an "in-house" **Wood Quality Model Integration Team** for the CWFC and FPInnovations that will be a national advisory group, multidisciplinary in nature, including programmers, modellers, researchers, and managers from both organizations. They would attend to the above-mentioned issues, perhaps by striking sub-committees and bringing in outside subject experts. They would coordinate research efforts, promote exchanges of information in the modelling and tool development communities, and ensure that current and new research efforts address important needs and are broader in scope (issue 1).

They would evaluate the options for linking wood quality models into existing FPInnovations platforms (issue 2). To this end, a collaborative space should be developed where decision-support system developers and wood quality modellers share their expertise to gain awareness of one another's constraints and needs. In addition, modellers from the two organizations can plan together and adapt their approaches to ensure compatibility between different modules in the future. Programming of models should be centralized to avoid duplication.

The working group would assess and rate sampling protocols and assessment techniques to harmonize procedures for use within the CWFC and FPInnovations (issue 6). This action can also develop standards or guidelines that can be used as a model for others to adopt and benefit both research and industry.

Wood Quality Model Integration Team objectives:

A1: To make recommendations to the CWFC and FPInnovations on national modelling priorities.

A2: To survey the wood quality models and DSS available and choose which ones to integrate based on compatibility, importance to industry, and feasibility, and to integrate these as a demonstration project.

A3: To evaluate and set standards for wood quality measurement, and develop conversion factors where multiple methods are used. To publish these standards for other agencies to consider and adopt.

The FPInnovations Modelling and Decision Support (MDS) program will develop more case studies involving scientists and professionals (e.g., economists and market specialists for different supply chains) covering the entire span of the forest value chain, to determine the economic value of selected wood attributes (issue 5). The choice of which case studies to pursue will be informed by the deliberations and findings of the Wood Quality Model Integration Team.

FPInnovations MDS program objective:

A4: To assess the range and representation of the wood quality supply chain studies that already exist, to evaluate the options for a generalization of case-study results through a meta-analysis, and to direct future work to the areas most in need of information (by location, species, processor).

B. National Wood Quality R&D Working Group

The joint CWFC/FPInnovations Wood Quality Model Integration Team will also evaluate the options available outside the organizations in collaboration with external partners in universities, government and industry. Establishment of a broad-based national network or community of practice for all researchers and stakeholders will help promote exchanges of information on wood quality modelling efforts and development of both growth and yield simulators and decision support tools (issue 1). It is expected that this larger group will develop strong communication with the MDS program of FPInnovations working on supply/value chain DDS tools, an important receptor of the work done on wood quality and growth and yield models.

This larger group, with the support and collaboration of the Wood Quality Model Integration Team, has the potential to develop a nation-wide wood quality modelling and integration program with sustainable funding, involving the CWFC, FPInnovations, universities, forest industry staff and provinces. The research program would be led by a scientific/technical committee involving scientists and professionals from various disciplines and industry sectors (issue 3). Through its communication and coordination activities, this broad-based group could develop a national research sampling strategy that will help cover the full geographic range of variations in significant wood quality properties for important Canadian tree species (issue 4). Using the Wood Quality Model Integration Team's activities as a template and testbed, promising integrations of wood quality with DSSs can be identified and tests carried out (issue 2).

Working Group objectives:

B1: To create a wood quality community of practice to facilitate information exchange and coordination of effort among the organizations engaged in wood quality research and development across Canada.

B2: To survey the wood quality models and DSSs available outside the CWFC and FPInnovations and identify candidates for the integration process.

B3: To define a common vision, define standards and best practices, design a conceptual framework for modelling, and identify key variables to be used. (This objective is achievable only after completion of objective A2).

B4: To develop a national strategy for wood quality modelling and integration, developing the necessary partnerships, seeking appropriate funding, and carrying out the work.

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11. References

Achim, A.; Paradis, N.; Carter, P. and Hernández, R.E. 2011. Using acoustic sensors to improve the efficiency of the forest value chain in Canada: a case study with laminated veneer lumber. Sensors 11(6):5716-5728.

Adams, G.W. and Morgenstern, E.K. 1991. Multiple-trait selection in jack pine. Can. J. For. Res. 21(4):439-445.

Alteyrac, J.; Cloutier, A.; Ung, C. and Zhang, S. 2006. Mechanical properties in relation to selected wood characteristics of black spruce. Wood Fiber Sci. 38(2):229-237.

Angers, V.A.; Bergeron, Y. and Drapeau, P. 2012. Morphological attributes and snag classification of four North American boreal tree species: relationships with time since death and wood density. For. Ecol. Manage. 263:138-147.

Ballard, L.A. and Long, J.N. 1988. Influence of stand density on log quality of lodgepole pine. Can. J. For. Res. 18(7):911-916.

Bankowski, J. 1994. Effect of growing space on wood density in jack pine. M.Sc.F. Thesis, University of Toronto, Ontario, Canada.

Baral, S.K.; Schneider, R.; Pothier, D. and Berninger, F. 2013. Predicting sugar maple (*Acer saccharum*) discoloured wood characteristics. Can. J. For. Res. 43(7):649-657.

Barrett, J.D. and Kellogg, R.M. 1989. Strength and stiffness of dimension lumber. p. 50-58 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, BC. Spec. Publ. No. SP-32.

Barrette, J.; Pothier, D.; Auty, D.; Achim, A.; Duchesne, I. and Gélinas, N. 2012. Lumber recovery and value of dead and sound black spruce trees grown in the North Shore region of Québec. Ann. For. Sci. 69(5):603-615.

Basham, J.T. 1986. Biological factors influencing stem deterioration rates and salvage planning in balsam fir killed after defoliation by spruce budworm. Can. J. For. Res. 16(6):1217-1229.

Beaulieu, E.; Schneider, R.; Berninger, F.; Ung, C.-H. and Swift, D.E. 2011a. Modeling jack pine branch characteristics in Eastern Canada. For. Ecol. Manage. 262:1748-1757.

Beaulieu, J.; Doerksen, T.; Boyle, B.; Clément, S.; Deslauriers, M.; Beauseigle, S.; Blais, S.; Poulin, P.-L.; Lenz, P.; Caron, S.; Rigault, P.; Bicho, P.; Bousquet, J. and MacKay, J. 2011b. Association genetics of wood physical traits in the conifer white spruce and relationships with gene expression. Genetics 188(1):197-214.

Beaulieu, J.; Doerksen, T.; Clément, S.; MacKay, J. and Bousquet, J. 2014. Accuracy of genomic selection models in a large population of open-pollinated families in white spruce. Heredity 113:343-352.

Beaulieu, J.; Zhang, S.Y.; Yu, Q. and Rainville, A. 2006. Comparison between genetic and environmental influences on lumber bending properties in young white spruce. Wood Fiber Sci. 38(3):553-564.

Belleville, B.; Cloutier, A. and Achim, A. 2011. Detection of red heartwood in paper birch (*Betula papyrifera*) using external stem characteristics. Can. J. For. Res. 41(7):1491-1499.

Benjamin, J. 2006. Assessing lumber grade recovery improvement potential of black spruce (*Picea mariana* (Mill.) B.S.P.) by modelling knot characteristics. Ph.D. Thesis. University of New Brunswick (Canada). 187p.

Benjamin J.; Weiskittel A.; Kershaw Jr. J.; Chui Y. and Zhang S.Y. 2009. External knot size and frequency in black spruce trees from an initial spacing trial in Thunder Bay, Ontario. For. Chron. 85(4):618-624.

Blouin, D.; Beaulieu, J.; Daoust, G. and Poliquin, J. 1994. Wood quality of Norway spruce grown in plantations in Quebec. Wood Fiber Sci. 26(3):342-353.

Bravo, F.; Alvarez, J.G. and Del Rio, M. 2012. Growth and yield models in Spain: historical overview, contemporary examples and perspectives. Instituto Universitario de Investigation en Gestion Forestal Sostenable (Universidad de Valladolid-INIA) and Unidad de Gestion Forestal Sostenable (Universidad de Santiago de Compostela). Retrieved from http://sostenable.palencia.uva.es/document/gfs/publications/Libros/2011_GrowthYield_Spain.pdf

Briggs, D. 2010. Enhancing forest value productivity through fiber quality. J. For. 108(4):174-182.

Brown, J.P. and Sendak, P.E. 2006. Association of ring shake in eastern hemlock with tree attributes. For. Prod. J. 50(2):31-36.

Burgess, D.M.; MacAfee, K.; Wetzel, S., and Wang, B.S.P. 2011. Annotated Bibliography of Eastern White (*Pinus strobus* L.) and Red Pine (*P. resinosa* Ait.) 1960–2007. Canadian Wood Fibre Centre.

Corriveau, A.; Beaulieu, J. and Daoust, G. 1991. Heritability and genetic correlations of wood characters of upper Ottawa Valley white spruce [*Picea glauca*] populations grown in Quebec. For. Chron. 67(6):698-705.

Cortini, F.; Groot, A.; Tong, Q. and Duchesne I. 2014. Ring-level models for predicting wood and fibre properties of *Abies balsamea*. Wood Sci. Technol. 48(6):1181-1196.

Cortini, F.; Groot, A. and Filipescu, C.N. 2013. Models of the longitudinal distribution of ring area as a function of tree and stand attributes for four major Canadian conifers. Ann. For. Sci. 70(6):637-648.

Cruickshank, M.G. and Filipescu, C.N. 2012. Allometries of coarse tree, stem, and crown measures in Douglas-fir are altered by *Armillaria* root disease. Botany 90(8):711-721.

Di Lucca, C.M. 1989. Juvenile - mature wood transition. p. 23-38 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, BC, Spec. Publ. No. SP-32.

Di Lucca, C.M.; Goudie, J.W. and Stearns-Smith, S.C. 2009. TASS III: A new generation growth and yield prediction model for complex stands in British Columbia. BC Min. For. Res. Prog., XIII World Forestry Congress, Buenos Aires, Argentina

Duchateau, E.; Longuetaud, F.; Mothe, F.; Ung, C-H.; Auty, D. and Achim, A. 2013. Modelling knot morphology as a function of external tree and branch attributes. Can. J. For. Res. 43(3):266-277.

Duchesne, I.; Pitt, D.G. and Tanguay, F. 2013. Effects of precommercial thinning on the forest value chain in northwestern New Brunswick: Part 4 - lumber production, quality and value. For. Chron. 89(4):474-489.

Dufour-Kowalski, S.; Courbaud, B.; Dreyfus, P.; Meredieu, C. and de Coligny, D. 2012. Capsis: an open software framework and community for forest growth modelling. Ann. For. Sci. 69(2):221-233.

Filipescu, C.N.; Lowell, E.C.; Koppenaal, R. and Mitchell, A.K. 2014. Modeling regional and climatic variation of wood density and ring width in intensively managed Douglas-fir. Can. J. For. Res. 44(3): 220-229.

Fortin, M.; Guillemette, F. and Bédard, S. 2009. Predicting volumes by log grades in standing sugar maple and yellow birch trees in southern Quebec, Canada. Can. J. For. Res. 39(10):1928-1938.

Fujiwara, S. and Yang, K.C. 2000. The relationship between cell length and ring width and circumferential growth rate in five Canadian species. IAWA J, 21(3):335-345.

Gagné, L.-V.; Genet, A.; Weiskittel, A. and Achim, A. 2013. Assessing the potential stem growth and quality of yellow birch prior to restoration: A case study in Eastern Canada. Forests 4(4):766-785.

Garcia-Gonzalo, J.; Borges, J.G.; Tomé, M.; Palma, J.; Zubizarreta, A. and Soares, P. 2012. Integrating growth and yield models in decision support systems at different spatial levels. COST FP0603 Final meeting. Forest models for research and decision support in sustainable forest management. Pierroton (Bordeaux), France.

Gartner, B.L.; North, E.M.; Johnson, G.R. and Singleton, R. 2002. Effects of live crown on vertical patterns of wood density and growth in Douglas-fir. Can. J. For. Res. 32(3):439-447.

Genet, A.; Auty, D.; Achim, A.; Bernier, M.; Pothier, D. and Cogliastro, A. 2013. Consequences of faster growth for wood density in northern red oak (*Quercus rubra* Liebl.). Forestry 86(1):99-110.

Giroud, G.; Cloutier, A. and Alteyrac, J. 2008. Occurrence, proportion, and vertical distribution of red heartwood in paper birch. Can. J. For. Res. 38(7):1996-2002.

Giroud, G.; Defo, M.; Bégin, J. and Ung, C.-H. 2014. Application of near infrared spectroscopy to determine the juvenile-mature wood transition in black spruce. Forest Prod. J. 65(3-4):129-138.

Goudie, J.W. and Di Lucca, C.M. 2002. Modelling the relationship between crown morphology and wood characteristics of coastal western hemlock in British Columbia. In: G. Nepveu (Ed.), Proceedins 4th Workshop on Connection between forest resources and wood quality through modelling approaches and simulation software. Nancy, France.

Goudie, J.W. and Parish, R. 2010. Modelling the impact of silviculture treatments on the wood quality of interior spruce. Final report on Project No. Y081078. BC Min. For. Range Res. Knowl. Manage. Br.

Groot, A. and Schneider, R. 2011. Predicting maximum branch diameter from crown dimensions, stand characteristics and tree species. For. Chron. 87(4):542-551.

Groot, A.; Cortini, F. and Wulder, M.A. 2015. Crown-fibre attribute relationships for enhanced forest inventory: Progress and prospects. For. Chron. 91(3):266-279.

Hamm, E.A. 1989. Fibre length. p. 44-49 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, BC, Spec. Publ. No. SP-32.

Harper, G.J. 2008. Quantifying branch, crown and bole development in *Populus tremuloides* Michx. from north-eastern British Columbia. For. Ecol. Manage. 255(7):2286-2296.

Hatton, J.V. and Hunt, K. 1989. Unbleached kraft pulps. p. 87-113 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R. M. Kellogg. Forintek Canada Corp., Vancouver, BC, Spec. Publ. No. SP-32.

Hatton, J.V. and Johal, S.S. 1989. Refined mechanical pulps. p. 114-129 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, BC, Spec. Publ. No. SP-32.

Hatton, J.V. and Cook, J. 1992. Kraft pulps from second-growth Douglas-fir: relationships between wood, fiber, pulp, and handsheet properties. TAPPI J. 75 (1):137-144.

Havreljuk, F.; Achim, A. and Pothier, D. 2013. Regional variation in the proportion of red heartwood in sugar maple and yellow birch. Can. J. For. Res. 43(3):278-287.

Havreljuk, F.; Achim, A.; Auty, D.; Bédard, S.; and Pothier, D. 2014. Integrating standing value estimations into tree marking guidelines to meet wood supply objectives. Can. J. For. Res. 44(7):750-759.

Hazenberg, G. and Yang, K.C. 1991a. Sapwood/heartwood width relationships with tree age in balsam fir. IAWA Bull. 12(1):95-99.

Hazenberg, G. and Yang, K.C. 1991b. The relationship of tree age with sapwood and heartwood width in black spruce, *Picea mariana* (Mill.) B.S.P. Holzforschung 45(5):317-320.

Heger, L. 1974. Longitudinal variation of specific gravity in stems of black spruce, balsam fir, and lodgepole pine. Can. J. For. Res. 4(3):321-326.

Hevia, A.; Cao, Q.V.; Alvarez-Gonzalez, J.G.; Ruiz-Gonzalez, A.D. and von Gadow, K. 2015. Compatibility of whole-stand and individual-tree models using composite estimators and disaggregation. For. Ecol. Mange. 348:46-56.

Hilker, T.; Frazer, G.W.; Coops, N.C.; Wulder, M.A.; van Leeuwen, M.; Newnham, G.J.; Stewart, J.D. and Culvenor, D.S. 2013. Prediction of wood fiber attributes from LiDAR-derived forest canopy indicators. For. Sci. 59(2):231-242.

Hoover, C.M. and Rebain, S.A. 2010. Forest carbon estimation using the Forest Vegetation Simulator: Seven things you need to know. US Forest Service General Technical Report NRS-77.

Huda, A.S.M.A.; Koubaa, A.; Cloutier, A.; Hernández, R.E. and Fortin, Y. 2014. Variation of the physical and mechanical properties of hybrid poplar clones. BioResources 9(1):1456-1471.

Iliadis, L.; Mansfield, S.D.; Avramidis, S. and El-Kassaby, Y.A. 2013. Predicting Douglas-fir wood density by artificial neural networks (ANN) based on progeny testing information. Holzforschung 67(7):771-777.

Ivkovich, M.; Namkoong, G. and Koshy, M. 2002a. Genetic variation in wood properties of interior spruce. I. Growth, latewood percentage, and wood density. Can. J. For. Res. 32(12):2116-2127.

Ivkovich, M.; Namkoong, G. and Koshy, M. 2002b. Genetic variation in wood properties of interior spruce. II. Tracheid characteristics. Can. J. For. Res. 32(12):2128-2139.

Ivkovich, M. 1996. Genetic variation of wood properties in balsam poplar (*Populus balsamifera* L.). Silvae Genet. 45(2/3):119-124.

Kershaw, J.A. Jr.; Benjamin, J.G. and Weiskittel, A.R. 2009. Approaches for modeling vertical distribution of maximum knot size in black spruce: a comparison of fixed- and mixed-effects nonlinear models. For. Sci. 55(3):230-237.

King, J.N.; Yeh, F.C.; Heaman, J.C. and Dancik, B.P. 1988. Selection of wood density and diameter in controlled crosses of coastal Douglas-fir. Silvae Genet. 37(3/4):152-157.

King, J.N.; Cartwright, C.; Hatton, J. and Yanchuk, A.D. 1998. The potential of improving western hemlock pulp and paper quality. I. Genetic control and interrelationships of wood and fibre traits. Can. J. For. Res. 28(6):863-870.

Klos, R.J.; Wang, G.G.; Dang, Q.L. and East, E.W. 2007. Taper equations for five major commercial tree species in Manitoba, Canada. West. J. Appl. For. 22(3):163-170.

Koubaa, A.; Isabel, N.; Zhang, S.Y.; Beaulieu, J. and Bousquet, J. 2005. Transition from juvenile to mature wood in black spruce (*Picea mariana*). Wood Fiber Sci. 37(3):445-455.

Koubaa, A.; Zhang, S.Y.T. and Makni, S. 2002. Defining the transition from earlywood to latewood in black spruce based on intra-ring wood density profiles from X-ray densitometry. Ann. For. Sci. 59(5): 511.

Kozak, A. 1988. A variable-exponent taper equation. Can. J. For. Res. 18(11):1363-1368.

Krakowski, J.; Park, Y.S. and El-Kassaby, Y.A. 2005. Early testing of Douglas-fir: Wood density and ring width. For. Genet. 12(2):99-105.

Krause, C.; Laplante, S. and Plourde, P.Y. 2011. Transversal tracheid dimension in thinned black spruce and jack pine stands in the boreal forest. Scand. J. For. Res. 26(5):477-487.

Krause, C. and Plourde, P.Y. 2008. Stem deformation in young plantations of black spruce (*Picea mariana* (Mill.) B.S.P.) and jack pine (*Pinus banksiana* Lamb.) in the boreal forest of Quebec, Canada. For. Ecol. Manage. 255:2213-2224.

Krause, C.; Rossi, S.; Thibeault-Martel, M. and Plourde, P.Y. 2010. Relationships of climate and cell features in stems and roots of black spruce and balsam fir. Ann. For. Sci. 67(4):402p1-402p7.

Kuprevicius, A.; Auty, D.; Achim, A. and Caspersen, P. 2013. Quantifying the influence of live crown ratio on the mechanical properties of clear wood. Forestry 86(3):361-369.

Larocque, G.R. 2008. Forest models. In S.E. Jorgensen and B.D. Fath (Editor-in-chief), Ecological models. Vol. [2] of Encyclopedia of Ecology, 5 vols. pp. 1663-1673. Oxford: Elsevier.

Larocque, G.R. and Marshall, P.L. 1995. Wood relative density development in red pine (*Pinus resinosa* Ait.) stands as affected by different initial spacings. For. Sci. 41(4):709-728.

Larocque, G.R.; Archambault, L. and Delisle, C. 2011. Development of the gap model ZELIG-CFS to predict the dynamics of North American mixed forest types with complex structures. Ecol. Model. 222(14):2570-2583.

Larocque, G.R.; Bhatti, J. and Arsenault, A. 2014. Integrated modelling software platform development for effective use of ecosystem models. Ecol. Model. 288:195-202.

Lei, Y.C.; Zhang, S.Y. and Jiang, Z. 2005. Models for predicting lumber bending MOR and MOE based on tree and stand characteristics in black spruce. Wood Sci. Technol. 39(1):37-47.

Lemieux, H.; Beaudoin, M. and Zhang, S.Y. 2001. Characterization and modeling of knots in black spruce (*Picea mariana*) logs. Wood Fiber Sci. 33(3):465-475.

Lemieux, H.; Usenius, A. and Samson, M. 1997. A method for the characterization of knots in logs. For. Prod. J. 47(2):57-62.

Lemieux, H.; Beaudoin, M.; Zhang, S.Y. and Grondin, F. 2002. Improving structural lumber quality in a sample of *Picea mariana* logs sawn according to the knots. Wood Fiber Sci. 34(2):266-275.

Lenz, P.; Deslauriers, M.; Ung, C.-H.; MacKay, J. and Beaulieu, J. 2014. What do ecological regions tell us about wood quality? A case study in eastern Canadian white spruce. Can. J. For. Res. 44(11):1383-1393.

Lenz, P.; Auty, D.; Achim, A.; Beaulieu, J. and MacKay, J. 2013.Genetic improvement of white spruce mechanical wood traits – early screening by means of acoustic velocity. Forests 4(3):575-594.

Lenz, P.; Bernier-Cardou, M.; MacKay, J. and Beaulieu, J. 2012. Can wood properties be predicted from the morphological traits of a tree? A canonical correlation study of plantation-grown white spruce. Can. J. For. Res. 42(8):1518-1529.

Lenz, P.; MacKay, J.; Rainville, A.; Cloutier, A. and Beaulieu, J. 2011. The influence of cambial age on breeding for wood properties in *Picea glauca*. Tree Genet. Genomes 7(3):641-653.

Lessard, E.; Fournier, R.A.; Luther, J.E.; Mazerolle, M.J. and van Lier O.R. 2014. Modelling wood fiber attributes using forest inventory and environmental data. For. Ecol. Manage. 313:307-318.

Li, C. 2009. Toward full, multiple, and optimal wood fibre utilization: A modelling perspective. For. Chron. 85(3):377-381.

Li, R.; Weiskittel, A.; Dick, A.R.; Kershaw, J.A., Jr. and Seymour, R.S. 2012. Regional stem taper equations for eleven conifer species in the Acadian region of North America: Development and assessment. North. J. Appl. For. 29(1):5-14.

Liu, C. and Zhang, S.Y. 2005a. Models for predicting product recovery using selected tree characteristics of black spruce. Can. J. For. Res. 35(4):930-937.

Liu, C. and Zhang, S.Y. 2005b. Equations for predicting tree height, total volume, and product recovery for black spruce (*Picea mariana*) plantations in northeastern Quebec. For. Chron. 81(6):808-814.

Liu, C.; Zhang, S. and Jiang Z. 2007a. Models for predicting lumber grade yield using tree characteristics in black spruce. For. Prod. J. 57(1/2):60-66.

Liu, C.; Zhang, S.Y.; Cloutier, A. and Rycabel, T. 2007b. Modeling lumber bending stiffness and strength in natural black spruce stands using stand and tree characteristics. For. Ecol. Manage. 242(2/3):648-655.

Liu, C.; Zhang, S.Y.; Cloutier, A., and Rycabel, T. 2007c. Modeling lumber value recovery in relation to selected tree characteristics in black spruce using the Optitek sawing simulator. For. Prod. J. 57(4):57-65.

Loo-Dinkins, J.A. and Gonzalez, J.S. 1991. Genetic control of wood density profile in young Douglas-fir. Can. J. For. Res. 21(6):935-939.

Loo-Dinkins, J.A.; Ying, C.C. and Hamm, E.A. 1991. Stem volume and wood relative density of a non-local Douglas-fir provenance in British Columbia. Silvae Genet. 40 (1):29-35.

Luther, J.E.; Skinner, L.; Fournier, R.A.; van Lier, O.R.; Bowers, W.W.; Côté, J.-F.; Hopkinson, C. and Moulton, T. 2013. Predicting wood quantity and quality attributes of balsam fir and black spruce using airborne laser scanner data. Forestry 87(2):313-326.

Mäkelä, A. 1990. Modeling structural-functional relationships in whole-tree growth: Resource allocation. P. 81-95 in Process Modeling of Forest Growth Responses to Environmental Stress. Timber Press, Portland, OR.

Mäkelä, A.; Grace, J.C.; Deckmyn, G.; Kantola, A. and Campioli, M. 2010. Simulating wood quality in forest management models. For. Syst. 19(Special Issue): 48-68.

Maness, T.C. and Donald, W.S. 1994. The effect of log rotation on value recovery in chip and saw sawmills. Wood Fiber Sci. 26(4):546-555.

Mansfield, S. D.; Kang, K.-Y.; Iliadis, L., Tachos, S. and Avramidis, S. 2011. Predicting the strength of *Populus* spp. clones using artificial neural networks and ε-regression support vector machines (ε-rSVM). Holzforschung 65(6):855-863.

Mansfield, S.D.; Iliadis, L. and Avramidis S. 2007a. Neural network prediction of bending strength and stiffness in western hemlock (*Tsuga heterophylla* Raf.) Holzforschung 61(6):707-716.

Mansfield, S.D.; Parish, R.; Goudie, J. Kang, K.-Y. and Ott, P. 2007b. The effects of crown ratio on the transition from juvenile to mature wood production in lodgepole pine in western Canada. Can. J. For. Res. 37(8):1450-1459.

Mansfield, S.D.; Kang, K.-Y.; Parish, R.; Di Lucca, C.M.; Goudie, J. and Ott, P. 2009. Revisiting the transition between juvenile and mature wood: a comparison of fibre length, microfibril angle and relative wood density in lodgepole pine. Holzforschung 63(4):449-456.

Matolcsy, G.A. 1975. Correlation of fiber dimensions and wood properties with the physical properties of kraft pulp of *Abies balsamea* L. (Mill.). TAPPI J. 58(4):136-141.

Middleton, G.R., and Zhang, S.Y. 2009. Characterizing the wood attributes of Canadian tree species: A thirty-year chronicle. For. Chron. 85(3):392-400.

Mitchell, K.J., Kellogg, R.M., and Polsson, K.R. 1989. Silvicultural treatments and end-product value. p. 130-167 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, B.C. Spec. Publ. No. SP-32.

Morris, D.M. and Forslund, R.R. 1992. The relative importance of competition, microsite, and climate in controlling the stem taper and profile shape in jack pine. Can. J. For. Res. 22 (12):1999-2003.

Morris, D.M.; Parker, W.H. and Seabrook, R. 1992. Some considerations when selecting young jack pine families using growth and form traits. Can. J. For. Res. 22(4):429-435.

Morris, D.M. and Parker, W.H. 1992. Variable-quality form in mature jack pine stands: quantification and relationship with environmental factors. Can. J. For. Res. 22(3):279-289.

Muhairwe, C.K. 1994. Tree form and taper variation over time for interior lodgepole pine. Can. J. For. Res. 24(9):1904-1913.

Mvolo, C.; Koubaa, A.; Beaulieu, J.; Cloutier, A. and Mazerolle, M. 2015. Variation in wood quality in white spruce (*Picea glauca* (Moench) Voss). Part I. Defining the juvenile—mature wood transition based on tracheid length. Forests 6(1):183-202.

Nault, J.R. 1989. Longitudinal shrinkage. p. 39-43 in Second growth Douglas-fir: Its management and conversion for value. A report of the Douglas-fir Task Force. Edited by R.M. Kellogg. Forintek Canada Corp., Vancouver, BC. Spec. Publ. No. SP-32.

Nemec, A.F.L.; Goudie, J.W. and Parish, R. 2010. A Gamma-Poisson model for vertical location and frequency of buds on lodgepole pine (*Pinus contorta*) leaders. Can. J. For. Res. 40(10):2049-2058.

Nemec, A.F.L.; Parish, R. and Goudie, J.W. 2012. Modelling number, vertical distribution, and size of live branches on coniferous tree species in British Columbia. Can. J. For. Res. 42(6):1072-1090.

Newton, P.F. 2009. Development of an integrated decision-support model for density management within jack pine stand-types. Ecol. Model. 220(23):3301-3324.

Newton, P.F. 2012. A decision-support system for forest density management within upland black spruce stand-types. Environ. Model. Software 35:171-187.

Newton, P.F. and Sharma, M. 2008. Evaluation of sampling design on taper equation performance in plantation-grown *Pinus banksiana*. Scand. J. For. Res. 23(4):358-370.

Paradis, N.; Auty, D.; Achim, A. and Carter, P. 2013. Using a standing-tree acoustic tool to identify forest stands for the production of mechanically-graded lumber. Sensors 13(3):3394-3408.

Park, Y.-S.; Weng, Y. and Mansfield, S.D. 2012. Genetic effects on wood quality traits of plantation-grown white spruce (*Picea glauca*) and their relationships with growth. Tree Genet. Genomes 8(2):303-311.

Pavel, M. and Andersson, B.O. 2009. A model for predicting the value of forest stands in various market conditions in British Columbia. For. Chron. 85(3):387-391.

Peng, M.; Kershaw, J.A., Jr.; Chui, Y.H. and Gong, M. 2013. Modelling of tangential, radial, and longitudinal shrinkage after drying in jack pine and white spruce. Can. J. For. Res. 43(8):742-749.

Peng, M. and Stewart, J.D. 2013. Development, validation, and application of a model of intra- and inter-tree variability of wood density for lodgepole pine in western Canada. Can. J. For. Res. 43(12):1172-1180.

Petruncio, M.; Briggs, D. and Barbour, R.J. 1997. Predicting pruned branch stub occlusion in young, coastal Douglas-fir. Can. J. For. Res. 27(7):1074-1082.

Pitt, D.G.; Lanteigne, L.; Hoepting, M.K. and Plamondon, J. 2013. Effects of precommercial thinning on the forest value chain in northwestern New Brunswick: Part 1 - Roundwood production and stumpage value. For. Chron. 89(4):474-489.

Pliura, A.; Zhang, S.Y.; MacKay, J. and Bousquet, J. 2007. Genotypic variation in wood density and growth traits of poplar hybrids at four clonal trials. For. Ecol. Manage. 238:92-106.

Pnevmaticos, S.M.; Jaeger, T.A. and Perem, E. 1972. Factors influencing the weight of black spruce and balsam fir stems. Can. J. For. Res. 2(4):427-433.

Pokharel, B.; Dech, J.P.; Groot, A. and Pitt, D. 2014. Ecosite-based predictive modeling of black spruce (*Picea mariana*) wood quality attributes in boreal Ontario. Can. J. For. Res. 44(5):465-475.

Porté, A. and Bartelink, H. 2002. Modelling mixed forest growth: a review of models for forest management. Ecol. Model. 150:141-188.

Porth, I.; Klápště, J.; Skyba, O.; Lai, B.; Geraldes, A.; Muchero, W.; Tuskan, G.; Douglas, C.; El-Kassaby, Y.A. and Mansfield, S. D. 2013a. *Populus trichocarpa* cell wall chemistry and ultrastructure trait variation, genetic control and genetic correlations. New Phytol. 197(3):777-190.

Porth, I.; Klápště, J.; Skyba, O.; Friedmann, M.C.; Hannemann, J.; Ehlting, J.; El-Kassaby, Y.A.; Mansfield, S.D. and Douglas, C.J. 2013b. Network analysis reveals the relationship among wood properties, gene expression levels and genotypes of natural *Populus trichocarpa* accessions. New Phytol. 200(3):727-742.

Porth, I.; Klápště, J.; Skyba, O.; Hannemann, J.; McKown, A.; Guy, R.; DiFazio, S.; Muchero, W.; Ranjan, P.; Tuskan, G.; Friedmann, M.; Ehlting, J.; Cronk, Q.; El-Kassaby, Y.A.; Douglas, C. and Mansfield, S.D. 2013c. Genome-wide association mapping for wood characteristics in *Populus* identifies an array of candidate single nucleotide polymorphisms. New Phytol. 200(3):710-726.

Ratcliffe, B.; Hart, F.; Klápště, J.; Jaquish, B.; Mansfield, S.D. and El-Kassaby, Y.A. 2014. Genetics of wood quality attributes in Western Larch. Ann. For. Sci. 71(3):415-424.

Samson, M.; Bindzi, I. and Kamoso, L.M. 1996. Mathematical representation of knots in tree trunks. Can. J. For. Res. 26(2):159-165.

Sattler, D.F.; Comeau, P.G. and Achim, A. 2014a. Within-tree patterns of wood stiffness for white spruce (*Picea glauca*) and trembling aspen (*Populus tremuloides*). Can. J. For. Res. 44(2):162-171.

Sattler, D.F.; Comeau, P.G. and Achim, A. 2014b. Branch models for white spruce (*Picea glauca* (Moench) Voss) in naturally regenerated stands. For. Ecol. Manage. 325:74-89.

Savva, Y.; Koubaa, A.; Tremblay, F. and Bergeron, Y. 2010. Effects of radial growth, tree age, climate, and seed origin on wood density of diverse jack pine populations. Trees 24(1):53-65.

Scallan, A.M. and Green, H.V. 1974. A technique for determining the transverse dimensions of the fibres in wood. Wood Fiber Sci. 5(4):323-333.

Schneider, R.; Zhang, S.Y.; Swift, D.E.; Bégin, J. and Lussier, J.M. 2008a. Predicting selected wood properties of jack pine following commercial thinning. Can. J. For. Res. 38(7):2030-2043.

Schneider, R.; Riopel, M.; Pothier, D. and Côté, L. 2008b. Predicting decay and round-wood end use volume in trembling aspen (*Populus tremuloides* Michx.). Ann. For. Sci. 65(6):608p1-608p15.

Schneider, R.; Berninger, F.; Ung, C.-H.; Bernier, P.Y.; Swift, D.E. and Zhang, S.Y. 2008c. Calibrating jack pine allometric relationships with simultaneous regressions. Can. J. For. Res. 38(10):2566-2578.

Schneider, R.; Berninger, F.; Ung, C.-H.; Makela, A.; Swift, D. E. and Zhang, S. Y. 2011. Within crown variation in the relationship between foliage biomass and sapwood area in jack pine. Tree Physiol. 31(1):22-29.

Schneider, R.; Fortin, M. and Saucier, J.-P. 2013. Équations de défilement en forêt naturelle pour les principales essences commerciales du Québec. Gouvernement du Québec, ministère des Ressources naturelles, Direction de la recherche forestière. Mémoire de recherche forestière no. 167. 40 p.

Schneider, R., Fortin, M. and Saucier, J.-P. 2014. Équation de défilement pour le pin gris en peuplement naturel au Québec. Gouvernement du Québec, ministère des Ressources naturelles, Direction de la recherche forestière. Note de recherche forestière no. 139. 6 p.

Sharma, M. and Zhang, S.Y. 2004. Variable-exponent taper equations for jack pine, black spruce, and balsam fir in eastern Canada. For. Ecol. Manage. 198:39-53.

Singh, T. 1984. Variation in the ovendry wood density of ten prairie tree species in Alberta, Saskatchewan, Manitoba. For. Chron. 60(4):217-221.

Singh, T. 1986. Wood density variation of six major tree species of the Northwest Territories. Can. J. For. Res. 16(1):127-129.

Stirling, R.; Morris, P.I. and Grace, K. 2014. Prediction of decay and termite resistance in western red cedar. For. Prod. J. 65(3-4):84-92

Stoehr, M.U.; Ukrainetz, N.K.; Hayton, L.K. and Yanchuk, A.D. 2009. Current and future trends in juvenile wood density for coastal Douglas-fir. Can. J. For. Res. 39(7):1415-1419.

Tong, Q.J. and Zhang, S.Y. 2006. Modelling jack pine lumber value recovery in relation to tree characteristics using Optitek simulation. For. Prod. J. 56(1):66-72.

Tong, Q.J. and Zhang, S.Y. 2008. A correction model for estimating jack pine tree-level lumber recovery accurately using forest inventory. For. Prod. J. 58(3):65-70.

Torquato, P.L.; Auty, D.; Hernandez, R.E.; Duchesne, I.; Pothier, D. and Achim, A. 2014. Black spruce trees from fire-origin stands have higher wood mechanical properties than those from older, irregular stands. Can. J. For. Res. 44(2):118-127.

Ukrainetz, N.K.; Kang, K.Y.; Aitken, S.N.; Stoehr, M. and Mansfield, S.D. 2008a. Heritability and phenotypic and genetic correlations of coastal Douglas-fir (*Pseudotsuga menziesii*) wood quality traits. Can. J. For. Res. 38(6):1536-1546.

Ukrainetz, N.K.; Ritland, K. and Mansfield, S.D. 2008b. Identification of quantitative trait loci for wood quality and growth across eight full-sib coastal Douglas-fir families. Tree Genet. Genomes 4(2):159-170.

Ung, C.-H. 1989. Stem form of sugar maple and American beech in a young stand in relation to social position and tree age. Ann. Sci. For. 46(3):261-271.

Ung, C.-H.; Guo, X.J. and Fortin, M. 2013. Canadian national taper models. For. Chron. 89(2):211-224.

Van Eck, N.J. and Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84(2):523-538.

Van Eck, N.J. and Waltman, L. 2015. VOSviewer Manual. Manual for VOSviewer version 1.6.0. Leiden University's Centre for Science and Technology Studies (CWTS), Holland. 29 p.

van Leeuwen, M.; Hilker, T.; Coops, N.C.; Frazer, G.; Wulder, M.A.; Newnham, G.J. and Culvenor, D.S. 2011. Assessment of standing wood and fiber quality using ground and airborne laser scanning: a review. For. Ecol. Manage. 261(9):1467-1478.

Vincent, M. and Duchesne, I. 2014. Modeling flexural properties in white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*) plantation trees. Can. J. For. Res. 44(1):82-91.

Wang, M. and Stewart, J.D. 2012. Determining the transition from juvenile to mature wood microfibril angle in lodgepole pine: a comparison of six different two-segment models. Ann. For. Sci. 69(8):927-937.

Wang, M. and Stewart, J.D. 2013. Modeling the transition from juvenile to mature wood using modulus of elasticity in lodgepole pine. West. J. Appl. For. 28(4):135-142.

Wang, T. and Aitken, S.N. 2001. Variation in xylem anatomy of selected populations of lodgepole pine. Can. J. For. Res. 31(11):2049-2057.

Wang T.L.; Aitken, S.N.; Rozenberg, P. and Carlson, M.R. 1999. Selection for height growth and Pilodyn pin penetration in lodgepole pine: effects on growth traits, wood properties, and their relationships. Can. J. For. Res. 29(4):434-445.

Wang, Y.; Titus, S.J. and LeMay, V.M. 1998. Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. Can. J. For. Res. 28(8):1171-1183.

Weiskittel, A.R.; Hann, D.W.; Kershaw, J.A. and van Clay, J.K. 2011. Forest growth and yield modeling. John Wiley & Sons, pp. 415.

Xiang, W.; Leitch, M.; Auty, D.; Achim, A. and Franceschini, T. 2014a. Wood density-climate relationships are mediated by dominance class in black spruce (*Picea mariana* (Mill.) B.S.P.) Forests 5(6):1163-1184.

Xiang, W.; Leitch, M.; Auty, D.; Duchateau, E. and Achim, A. 2014b. Radial trends in black spruce wood density can show an age- and growth-related decline. Ann. For. Sci. 71(5):603-615.

Yanchuk, A.D. and Kiss, G.K. 1993. Genetic variation in growth and wood specific gravity and its utility in the improvement of interior spruce in British Columbia. Silvae Genet. 42(2/3):141-148.

Yang, K.C. and Hazenberg, G. 1991. Relationship between tree age and sapwood/heartwood width in *Populus tremuloides* Michx. Wood Fiber Sci. 23(2):247-252.

Yang, K.C., Benson, C.A. and Wong, J.K. 1986. Distribution of juvenile wood in two stems of *Larix laricina*. Can. J. For. Res. 16(5):1041-1049.

Zhang, S.Y. 2009. Modeling wood quality in the context of forest management. USDA Forest Service - General Technical Report PNW-GTR, (791), 135-144.

Zhang, S.Y.; Lei, Y.C. and Jiang, Z.H. 2006a. Modelling the relationship of tree-level product value with tree characteristics in black spruce. For. Chron. 82(5):690-699.

Zhang, S.Y.; Liu, C. and Jiang, Z. 2006b. Modeling product recovery in relation to selected tree characteristics in black spruce using an optimized random sawing simulator. For. Prod. J. 56(11/12):93-99.

Zhang, S.Y.; Lei, Y.C. and Bowling, C. 2005. Quantifying stem quality characteristics in relation to initial spacing and modeling their relationship with tree characteristics in black spruce (*Picea mariana*). North. J. Appl. For. 22 (2):85-93.

Zhang, S.Y. and Morgenstern, E.K. 1995. Genetic variation and inheritance of wood density in black spruce (*Picea mariana*) and its relationship with growth: implications for tree breeding. Wood Sci. Technol. 30(1):63-75.

Zhang, S.Y.; Simpson, D. and Morgenstern, E.K. 1996. Variation in the relationship of wood density with growth in 40 black spruce (*Picea mariana*) families grown in New Brunswick. Wood Fiber Sci. 28(1):91-99.

Zhang, S.Y. and Tong, Q. 2005. Modeling lumber recovery in relation to selected tree characteristics in jack pine using sawing simulator Optitek. Ann. For. Sci. 62(3):219-228.

Zhang, S.Y.; Yu, Q.B. and Beaulieu, J. 2004. Genetic variation in veneer quality and its correlation to growth in white spruce. Can. J. For. Res. 34(6):1311-1318.

Zhang, S.Y. and Chui, Y. 1996. Selecting dry fiber weight for higher and better quality jack pine fiber production. Wood Fiber Sci. 28(2):146-152.

Zhang, S.Y. and Koubaa, A. 2008. Softwoods of eastern Canada: Their silvics, characteristics, manufacturing and end-uses. FPInnovations, Special publication SP-526E.

Zhang, S.Y.; Yu, Q.; Chauret, G. and Koubaa, A. 2003. Selection for both growth and wood properties in hybrid poplar clones. For. Sci. 49(6):901-908.

Zhou, C.; Chui, Y. and Gong, M. 2012. Within-stem variation in wood properties of red pine (*Pinus resinosa* Ait). Wood Fiber Sci. 44(4):412-421.

Appendices

A1. Survey instrument used for wood quality attribute models in Canada

1. GENERAL INFORMATION ON THE MODEL

Model's name (if there is any):
Click here to enter text

Model type: ◉ Descriptive ◯ Predictive

Property or wood quality attribute modelled (e.g. density, juvenile wood proportion)
Click here to enter text

Species or species group:
Click here to enter text

Jurisdiction: Choose an item

Ecoregion (provincial classification):
Click here to enter text

Stand type: Click here to enter text

Author(s): Click here to enter text

Organization or institution:
Click here to enter text

User interface: Choose an item

Data visualization:

- ☐ No within-tree data visualization
- ☐ 2D or 3D within-tree/stem data visualization
- ☐ Graphs or Dashboard
- ☐ Other: Click here to enter text

Model maturity: Choose an item

2. INPUT VARIABLES

Stand (site) characteristics

- ☐ Stand type
- ☐ Stand growth model
- ☐ Stand age
- ☐ Stand density
- ☐ Site index
- ☐ Diameter class distribution
- ☐ Climate data

☐ Silviculture treatments
☐ Other(s): Click here to enter text

Tree data (if any)

☐ Species or species group
☐ Tree growth model
☐ Tree age
☐ Tree diameter
☐ Competition index
☐ Diameter class distribution
☐ Annual ring width/diameter increment
☐ Annual ring number from pith (cambial age)
☐ Annual ring distance from pith
☐ Vertical position in the tree
☐ Tree taper
☐ Crown size
☐ Branchiness/knottiness
☐ Sapwood/heartwood
☐ Juvenile/mature wood
☐ Other(s): Click here to enter text

Wood/fibre quality attributes data

If any wood property is used as input, please check and provide level of detail required:

Wood/fibre property	*Level of detail required*
☐ Density	Choose an item
☐ Modulus of elasticity	Choose an item
☐ Microfibril angle	Choose an item
☐ Fibre dimensions (e.g. length)	Choose an item
☐ Internal stem properties (e.g. knottiness)	Choose an item
☐ Latewood percentage	Choose an item
☐ Chemical properties	Choose an item

If other(s), please specify in the box below:

3. OUTPUT OF MODEL

A. Stem quality (external/internal)

☐ Taper
☐ Form (sweep, sinuosity)
☐ Knottiness
☐ Defects (disease, wet pockets)

If other(s), please specify: Click here to enter text

B. Wood/fibre quality attributes data

Please check wood/fibre quality attribute(s) yielded by the model:

☐ Juvenile/mature wood transition
☐ Juvenile/mature wood proportion
☐ Heartwood /sapwood
☐ Ring width
☐ Latewood percentage

Wood/fibre properties	***Lowest** resolution possible*
☐ Density	Choose an item
☐ Modulus of elasticity	Choose an item
☐ Microfibril angle	Choose an item
☐ Modulus of rupture	Choose an item
☐ Fibre coarsenesss	Choose an item
☐ Fibre diameter / perimeter	Choose an item
☐ Fibre length	Choose an item
☐ Chemical properties	Choose an item

If you would like to add more properties, use the box below:

C. Potential product recovery

☐ Log grade
☐ Lumber grade ☐ MSR lumber ☐ Visual
☐ Chip quality (e.g. density)
☐ Biomass quality (e.g. density)
☐ Other(s): Click here to enter text

4. END USER COMMUNITY

☐ Researchers/academics
☐ Policy makers
☐ Forest managers
☐ Forest operation planners
☐ Other(s): Click here to enter text

5. DOCUMENTATION

Please provide any references about the wood quality model:

Access information (contacts, download website, etc.):
Click here to enter text

Journal papers and technical reports:
Click here to enter text

User guide (printed/PDF):
Click here to enter text

Web-based guides (HTML/XML):
Click here to enter text

6. OTHER(S) FEATURE(S)

Please describe in the box below your model in general terms (one or two paragraphs): rationale, features (what it does/doesn't, pros and cons/limitations) and how/if/where it is currently used within the forest sector (to the best of your knowledge). This abstract will be used in our compendium report as the description of your project.

A2. Survey instrument for growth and yield models in Canada

1. GENERAL INFORMATION ON THE GROWTH AND YIELD MODEL

Model's name: Click here to enter text
Intellectual property: Select one item
  If other, please specify: Click here to enter text
Author(s): Choose an item
  If other, please specify: Enter text here
Responsible(s) for scientific development: Click here to enter text
Responsible(s) for implementation, maintenance, upgrades, etc.: Click here to enter text

2. INPUT VARIABLES

A. Forest inventory

☐ Landscape (e.g. forest map)

Stand (site) data

☐ Site index
☐ Stand age
☐ Diameter class distribution
☐ Stand density
☐ Soil characteristics
☐ Other(s): Click here to enter text

Tree data (if any)

☐ Species or species group
☐ Diameter at breast height (DBH)
☐ Total height
☐ Age at DBH
☐ Tree form (taper, curve, etc.)
☐ Crown characteristics (diameter, height, etc.)
☐ Other(s): Click here to enter text

Wood/fibre properties data

If any wood property is used as input, please check and provide level of detail required.

Wood property	***Level of detail required***
☐ Density	Choose an item
☐ Modulus of elasticity	Choose an item
☐ Microfibril angle	Choose an item
☐ Fibre properties (length, etc.)	Choose an item
☐ Internal stem properties (knottiness)	Choose an item
☐ Latewood percentage	Choose an item
☐ Chemical properties	Choose an item
☐ Other(s)	

If other(s), please indicate the property and level of detail required: Click here to enter text

3. OUTPUT OF THE MODEL

A. Growth and yield

Stand level

- ☐ Stand tables
- ☐ Stock tables
- ☐ Yield tables
- ☐ Timber supply projection
- ☐ Individual tree list
- ☐ Tree size distribution

Other(s): Click here to enter text

Tree/stem level

- ☐ Volume
- ☐ DBH
- ☐ Crown dimensions
- ☐ Branchiness
- ☐ Tree height
- ☐ Bark thickness

Other(s): Click here to enter text

B. Stem quality (external/internal)

- ☐ Taper
- ☐ Form (sweep/sinuosity)
- ☐ Knottiness
- ☐ Defects (disease, wet-pocket)

Other(s): Click here to enter text

C. Wood/fibre quality attributes data

Please check wood/fibre quality attribute(s) yielded by the model:

- ☐ Juvenile/mature wood
- ☐ Heartwood/sapwood
- ☐ Ring width
- ☐ Density
- ☐ Modulus of elasticity
- ☐ Microfibril angle
- ☐ Chemical properties
- ☐ Fibre dimensions (e.g. length, diameters)
- ☐ Fibre coarseness

If other(s), please specify:

D. Product recovery

- ☐ Log grade
- ☐ Lumber grade
- ☐ Lumber volume
- ☐ Chip volume
- ☐ Chip quality
- ☐ Biomass volume or quality
- ☐ Carbon
- ☐ Other(s)

Other(s) potential wood/fibre products
Click here to enter text

E. Economic

- ☐ Market value of products
- ☐ Market value of environmental services

Other(s): Click here to enter text

4. MODEL SCOPE AND ARCHITECTURE

A. Species and geographic location

Please, list species or species group (e.g. spruce, balsam fir, SPF, hem-fir) considered by the growth simulator and indicate political jurisdiction and ecoregion. **If the species or species group belongs to more than one jurisdiction or ecoregion, use another line**.

Species or species group	*Political jurisdiction*	*Ecoregion (provincial)*	*Stand type*
Click here to enter text	Choose an item	Click here to enter text	Click here to enter text
Click here to enter text	Choose an item	Click here to enter text	Click here to enter text
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Click here to enter text	Choose an item	Click here to enter text	Click here to enter text
Click here to enter text	Choose an item	Click here to enter text	Click here to enter text

If other(s), please specify in the box below:

B. Growth simulator architecture

Growth and yield modelling approach

- (●) Process-based (mechanistic) model
- ( ) Empirical model
- ( ) Hybrid model
- ☐ Individual tree model
  - (●) Distance-dependent
  - ( ) Distance-independent
- ☐ Size-distribution (e.g. diameter class distribution) model
- ☐ Whole-stand model

If other, please specify: Click here to enter text

Model's user interface: Choose an item
Programming language: Choose an item

If other, please specify: Click here to enter text

Model type: ( ) Descriptive ( ) Predictive
Spatiality (●) Spatially explicit ( ) Non-spatially explicit
Simulation time step

☐ Daily	☐ Yearly
☐ Weekly	☐ Not time dependent
☐ Monthly	☐ Other

If other, please specify: Click here to enter text

Simulation duration:

☐ Day	☐ Year
☐ Week	☐ Rotation
☐ Month	☐ Centuries
☐ Not time dependent	
☐ Other	

If other, please specify: Click here to enter text
Model maturity: Choose an item

C. Other model(s)/tool(s) linked to growth and yield simulator -

- ☐ No other model
- ☐ Crown model
- ☐ Silvicultural model
- ☐ Harvesting model
- ☐ Knottiness model
- ☐ Wood/fibre quality model
- ☐ Lumber recovery model
- ☐ Regeneration model
- ☐ Disease model
- ☐ Biomass model
- ☐ Physiological/photosynthesis model
- ☐ Carbon model

Please add any other module not listed above (e.g. seed dispersal, mortality):

If there is a sawmill simulator, please select which one is used:

☐ Optitek ☐ SawSim ☐ Other: Click here to enter text

5. DECISION(S) SUPPORTED BY THE GROWTH AND YIELD SIMULATOR

Decision level

☐ Strategic (long term, more than 5 years)

☐Tactical (mid-term, 1 to 5 years)

☐ Operational (short term, less than one year) -

Decision type

- ☐ Policy
- ☐ Business model design
- ☐ Investment analysis
- ☐ Production forecasting
- ☐ Inventory updating
- ☐ Zoning
- ☐ Management planning
  - ☐ Tree selection
  - ☐ Stand selection (harvest scheduling)
  - ☐ Silvicultural treatments evaluation or planning
- ☐ Bucking rules
- ☐ Wood allocation to mills

Please provide any detail that may help us understand the type of decision(s) made with the growth and yield simulator:

6. END USER COMMUNITY

- ☐ Research/academics
- ☐ Forest managers
- ☐ Policy makers
- ☐ Forest operation managers
- ☐ Other(s)

If other(s), please specify: Click here to enter text

7. DOCUMENTATION

Please provide any references about the growth and yield model -

Access information (contacts, download website, etc.): Click here to enter text
Journal papers and technical reports: Click here to enter text
User guide (printed/PDF): Click here to enter text
Web-based guides (HTML/XML): Click here to enter text

8. OTHER(S) FEATURE(S)

Please describe in the box below your model in general terms (one or two paragraphs): rationale, features (what it does/doesn't, pros and cons/limitations) and how/if/where it is currently used within the forest sector (to the best of your knowledge). This abstract will be used in our compendium report as the description of your project.

A3. Survey used for decision support systems

1. GENERAL INFORMATION ON THE DSS

DSS name: Click here to enter text.
Intellectual property: Choose an item.
If other, please specify: Click here to enter text.
Author(s): Choose an item.
If other, please specify: Click here to enter text.
Responsible(s) for scientific development: Click here to enter text.
Responsible(s) for implementation, maintenance, upgrades, etc.: Click here to enter text.
DSS maturity: Choose an item.

2. DECISIONS SUPPORTED BY THE DSS

Time scale

☐ Long term (more than 5 years)
☐Mid-term (1-5 years)
☐ Short term (less than one year)

Decision type

☐ Policy
☐ Zonation
☐ Business model design
☐ Investment analysis
☐ Solution of acceptable silviculture systems
☐ Treatment planning
  ☐ Stand selection
  ☐ Tree selection
  ☐ Treatment schedule
☐ Road construction/maintenance planning
☐ Harvest scheduling
☐ Bucking rules
☐ Allocation to mills
☐ Transportation routing
☐ Workforce scheduling
☐ Manufacturing

Please provide any detail that may help us understand the type of decision(s) made with the DSS platform:

Decision level

☐ Log/bole level ☐ Forest level
☐ Tree/stem level ☐ Regional/national level
☐ Stand level ☐ Other: Click here to enter text.

3. DSS PLATFORM DESCRIPTION

A. Architecture

DSS user interface: Choose an item.
If other, specify: Click here to enter text.
Programming language: Choose an item.
If other, please specify: Click here to enter text.

Programming paradigm:
☐ Procedural (collection of variables, data structures, and subroutines or functions)
☐ Object-oriented (programming task breakdown into objects with attributes and methods)

Data visualization:
☐ No data (tree/stand) visualization ☐ GIS
☐ Three-dimensional data visualization ☐ Graphs/Dashboard
☐ Other: Click here to enter text.

A1. DSS mode

◉ Interactive (user can interact with the program during simulation)
○ Batch mode (user cannot interact with the program during simulation)

A2. Assumptions of the DSS model

☐ Static model (Model state can't change over time)
☐ Dynamic model (model state can change over time)

A3. Decision-making process

Please indicate how decision is made :
☐ Simulation only ☐ Scenarios analysis ☐ Optimization
☐ Monte-Carlo analysis (stochastic) ☐ Other : Click here to enter text.

A4. Scope

○ Generic (can handle any model/tool, any species, any stand, in any region)
○ Specific (was developed for a particular region, for a particular species or group of species, or for a particular stand or for some specific models/tools)

If the platform is generic, what specifications are required for customization or integrating a new model/tool in the platform?

Please, answer here:

A5. Span of the value chain

Upstream limit: Choose an item.

Downstream limit: Choose an item.

If the platform can handle many streams, please use this table:

Stream Number	Upstream limit	Downstream
1.	Choose an item.	Choose an item.
2.	Choose an item.	Choose an item.
3.	Choose an item.	Choose an item.
4.	Choose an item.	Choose an item.
5.	Choose an item.	Choose an item.

If you'd like to provide more details about the span of the value chain covered by the DSS, please fill the box below :

B. Model(s)/tool(s) actually incorporated in the DSS platform

B1. Growth and yield (G&Y) model(s) with related sub-model(s) or module(s)

For each G&Y model included in the platform, please list species or species group (e.g. Spruce, Balsam fir, SPF, hem-fir) considered by the DSS platform and indicate political jurisdiction and ecoregion. **If the species or species group belongs to more than one jurisdiction or ecoregion, please use another line**.

G&Y model's name	Species or Species group	Jurisdiction	Ecoregion (provincial)
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text
Click here to enter text	Click here to enter text	Choose an item.	Click here to enter text

If other, specify: Click here to enter text.

Are there a submodules/components linked to G&Y model(s) :

☐ No there is no submodule/component

☐ Yes there is one or more submodule/component
- ☐ Crown model
- ☐ Branch model
- ☐ Regeneration model
- ☐ Silviculture model
- ☐ Physiology/photosynthesis model
- ☐ Climate effects
- ☐ Disturbance model (disease, fire, etc.)
- ☐ Biomass model
- ☐ Carbon model
- ☐ DBH/Height growth
- ☐ Survival/mortality model
- ☐ Other(s)

If other(s), please specify: Click here to enter text

B2. Stem and wood/fibre quality attribute model

Please select which stem or wood/fibre quality model is included in the platform.

Stem quality model:

☐ Taper ☐ Form (lean/sweep) ☐ Knottiness ☐ Other(s)

If other(s), please specify: Click here to enter text

Wood/fibre quality attributes model:

☐ Juvenile wood ☐ Density
☐ Sapwood ☐ Modulus of elasticity
☐ Ring width ☐ Microfibril angle
☐ Chemical properties ☐ Fibre coarseness
☐ Fibre dimensions (e.g. length, diameters)
☐ Other(s)

If other(s), please specify: Click here to enter text

C. Operational process tools

☐ Forest operations

☐ Harvesting ☐ Transportation ☐ Other(s): Click here to enter text

☐ Forest management planning

☐ Product recovery model

☐ Sawmill simulator ☐ Pulp mill simulator
☐ Panel mill simulator ☐ Secondary wood products mill simulator
☐ Bucking simulator ☐ Other(s)

If other(s), please specify: Click here to enter text

If there is a sawmill simulator, please select which one is used:

☐ Optitek ☐ SawSim ☐ Other: Click here to enter text

Please, select products recovered :

☐ Log grade ☐ Chip quality
☐ Lumber grade ☐ Biomass volume

☐ Lumber volume ☐ Biomass quality
☐ Chip volume ☐ Carbon

For other(s) potential wood/fibre products, please use the box below:

D. Other(s) modules

☐ Economic model (market/financial analysis)
☐ Ecological model (risk/impact assessment)
☐ Social model
☐ Supply chain optimization
☐ Delivery schedule
☐ Timber supply projection

Other(s) modules:

4. END USER COMMUNITY

☐ Research/academia ☐ Forest management planners
☐ Policy makers ☐ Forest operation managers
☐ Other(s)

If other(s), please specify: Click here to enter text.

Distribution

☐ Commercial
☐ Free
  ☐ On demand
  ☐ Web-access
  ☐ Membership
☐ Other: Click here to enter text.

5. DOCUMENTATION

Please provide any references about the DSS:

Access information (contacts, download website, etc.): Click here to enter text.
Journal papers and technical reports: Click here to enter text.
User guide (printed/PDF): Click here to enter text.
Web-based guides (HTM/XML): Click here to enter text.

6. OTHER(S) FEATURE(S)

Please describe in the box below your tool in general terms (one or two paragraphs): rationale, features (what it does/doesn’t, pros and cons/limitations) and how/if/where it is currently used within the forest sector (to the best of your knowledge). This abstract will be used in our compendium report as the description of your project.

Cliquez ici pour taper du texte.

A4. List of wood quality publications reviewed

Authors	Institution	Species	WQA	Resolution	Study area
Achim et al. (2011)	Université Laval	Trembling aspen	MOE	Log	Various locations, QC
Adams and Morgenstern (1991)*	UNB	Jack pine	Branch, stem form	Family	Eastern half of NB
Alteyrac et al. (2006)	Université Laval	Black spruce	MOE, MOR	Ring	Chibougamau, QC
Angers et al. (2012)	UQAM	Black spruce, balsam fir, jack pine, trembling aspen	Density	Tree	Northwestern QC
Ballard and Long (1988)	Utah State University	Lodgepole pine	Branch/knots, stem form	Tree	Utah State Univ. Exp. For., USA
Bankowski (1994)	University of Toronto	Jack pine	Density	Ring	ON
Baral et al. (2013)	UQAR	Sugar maple	Discoloured wood, clearwood	Tree	Mont Laurier, Biencourt and Duchesnay, QC
Barrett and Kellogg (1989)	UBC	Douglas-fir	MOE, MOR	Lumber	Various coastal locations, BC
Barrette et al. (2012)	Université Laval	Black spruce	Product value recovery	Stem	North Shore region, QC
Basham (1986)	CFS	Balsam fir	Decay	Tree	Mattawa and Chapleau, ON
Beaulieu et al. (2006)*	CFS	White spruce	Density, MOE, MOR, knots	Family/provenance/site	Valcartier, QC
Beaulieu et al. (2011)	UQAM	Jack pine	Branch/knots	Stem	Eel River NB; Petawawa, ON; Saint-Maurice, QC
Beaulieu et al. (2011)*	CWFC	White spruce	Density, MFA, MOE, fibre coarseness, ring width, EW/LW, fibre transverse dimensions	Family	Various locations, QC
Beaulieu et al. (2014)*	CWFC	White spruce	Density, MFA, MOE, fibre transverse dimensions	Tree	QC
Belleville et al. (2011)	Université Laval	Paper birch	Red heartwood	Tree	Mont-Laurier, QC
Benjamin (2006)	UNB	Black spruce	Branch/knots, product value recovery	Tree	NB
Benjamin et al. (2009)	University of Maine	Black spruce	Branch/knots	Tree	Thunder Bay, ON
Blouin et al. (1994)	CFS	Norway spruce	Density	Ring	Grand-Mère, QC
Brown and Sendak (2006)	USDA Forest Service	Eastern hemlock	Ring properties	Tree	Many states, USA
Corriveau et al. (1991)*	CFS	White spruce	Density, ring width, MC	Family	Valcartier For. Exp. Station, QC

Authors	Institution	Species	WQA	Resolution	Study area
Cortini et al. (2013)	CWFC	Black spruce, balsam fir, white spruce, lodgepole pine	Ring properties	tree	Cochrane, ON
Cortini et al. (2014)	CWFC	Balsam fir	Density, MOE, MFA	Tree	Green River, NB
Cruickshank and Filipescu (2012)	CWFC	Douglas-fir	Sapwood properties	Stem	Various locations, BC
Di Lucca (1989)	UBC	Douglas-fir	J/M wood transition	Ring	Various coastal locations, BC
Duchateau et al. (2013)	Université Laval	Black spruce, jack pine	Branch/knots	Tree	North Shore, QC
Duchesne et al. (2013)	CWFC	Balsam fir	Density, MOE, MOR, product value recovery, MDF properties (Bonding, MOE, MOR, …)	Plot/Stand	Green River, NB
Filipescu et al. (2014)	CWFC	Douglas-fir	Density, ring properties	Ring	Pacific Northwest
Fortin et al. (2009)	QC MFFP	Sugar maple, yellow birch	Product value recovery	Tree	Southern QC
Fujiwara and Yang (2000)	Lakehead University	Balsam fir, black spruce, jack pine, trembling aspen, white spruce	Fibre length	Ring	Northwestern Ontario
Gagné et al. (2013)	Université Laval	Yellow birch	Stem form	Tree	Portneuf and Saguenay-Charlevoix, QC
Gartner et al. (2002)	OSU, OR	Douglas-fir	Density, EW/LW, ring properties	Ring	Central Cascades, OR
Genet et al. (2013)	Université Laval	Red oak	Density, EW/LW	Ring	Southwestern QC
Giroud et al. (2008)	Université Laval	Paper birch	Red heartwood	Tree	Montmorency, QC
Giroud et al. (2014)	Université Laval	Black spruce	JW/MW	Tree	Multiple locations, QC
Goudie and Di Lucca (2002)	BCMFLNRO	Western hemlock	EW/LW, JW/MW, ring properties	Ring	Various locations, BC
Goudie and Parish (2010)	BCMFLNRO	Interior spruce	Branch/knots	Tree	Northern interior BC
Groot and Schneider (2011)	CWFC	Balsam fir, black spruce, Douglas-fir, jack pine, lodgepole pine, trembling aspen, white birch, white spruce, yellow birch	Branch/knots	Stem	Various locations in Canada
Hamm (1989)	Forintek Canada Corp.	Douglas-fir	Fibre length	Age class	Various coastal locations, BC
Harper (2008)	BCMFLNRO	Trembling aspen	Branch/knots	Tree	Fort Nelson and Peace River, BC

Authors	Institution	Species	WQA	Resolution	Study area
Hatton and Cook (1992)	Paprican	Douglas-fir	Pulp properties, handsheet properties	Tree	Coastal BC
Hatton and Hunt (1989)	Paprican	Douglas-fir	Kraft pulp handsheet properties	Wood type (top, juvenile, mature)	Various coastal locations, BC
Hatton and Johal (1989)	Paprican	Douglas-fir	Mechanical pulp handsheet properties	Wood type (top, juvenile, mature)	Various coastal locations, BC
Havreljuk et al. (2013)	Université Laval	Sugar maple, yellow birch	Red heartwood, product value recovery	Tree	Various locations across southern QC
Havreljuk et al. (2014)	Université Laval	Sugar maple, yellow birch	Stand value	Tree	Mont-Laurier & Duchesnay, QC
Hazenberg and Yang (1991)	Lakehead University	Balsam fir	Sapwood properties	Tree	Thunder Bay, ON
Hazenberg and Yang (1991)	Lakehead University	Balsam fir, black spruce	Sapwood properties	Tree	Thunder Bay, ON
Hegel (1974)	CFS	Balsam fir, black spruce, lodgepole pine	Density	Tree	Quebec
Hilker et al. (2013)	NASA Goddard Space Flight Center	Lodgepole pine	Density, fibre coarseness, fibre length, MFA, MOE, branch/knottiness	Tree/Site	Hinton Forest Management Area, AB
Huda et al. (2014)*	UQAT	Hybrid poplar	Density, shrinkage, MOE, MOR	Tree	Pointe-Platon, Saint-Ours & Windsor, QC
Iliadis et al. (2013)	UBC	Douglas-fir	Density	Tree	Coastal BC
Ivkovich et al. (2002a,b)*	UBC	White spruce	Density, ring width, EW/LW	Radial section	East Kootenays and Prince George, BC
Ivkvich (1996)*	Lakehead University	Balsam poplar	Density, MC, ring width, fibre & vessel length	Clone	Thunder Bay, ON
Kershaw, Jr.et al. (2009)	UNB	Black spruce	Branch/knots	Tree	Thunder Bay, ON
King et al. (1988)*	University of Alberta	Douglas-fir	Density	Ring	Cowichan Lake Research Station, BC
King et al. (1998)*	BCMFLNRO	Western hemlock	Density, fibre length, fibre coarseness	Tree/family	Mission Tree Farm, BC
Klos et al. (2007)	Lakehead University	Balsam poplar, black spruce, jack pine, trembling aspen, white spruce	Stem form	Tree	Boreal Plains and Boreal Shield ecozone, MB
Koubaa et al. (2002)	SEREX	Black spruce	EW/LW	Tree	Victoriaville, QC
Koubaa et al. (2005)	UQAT	Black spruce	JW/MW	Tree	Victoriaville, QC

Authors	Institution	Species	WQA	Resolution	Study area
Kozak (1988)	UBC	Balsam fir, broadleaf maple, cottonwood, Douglas-fir, larch, lodgepole pine, ponderosa pine, red alder, spruce sp., trembling aspen, western hemlock, western red cedar, western white pine, white birch, yellow cedar	Stem form	Tree	BC
Krakowski et al. (2005)*	UBC	Douglas-fir	Density, ring width, EW/LW	Tree	Saanichton, BC
Krause and Plourde (2008)	UQAC	Black spruce, jack pine	Compression wood area	Tree	Lac St-Jean, QC
Krause et al. (2010)	UQAC	Black spruce	Cell population, fibre transverse dimensions	Ring	Lac St-Jean, QC
Krause et al. (2011)	UQAC	Black spruce, jack pine	Fibre transverse dimensions, cell pop.	Ring	Boreal forest, QC
Kuprevicius et al. (2013)	University of Toronto	White spruce	MOE, MOR	Various positions in the stem	Central Ontario
Larocque and Marshall (1995)	CFS	Red pine	Density, EW/LW, ring properties	Ring and tree (BH)	Chalk River, ON
Lei et al. (2005)	Forintek Canada Corp.	Black spruce	MOE, MOR	Lumber	Thunder Bay, ON
Lemieux et al. (1997)	Université Laval	Norway spruce	Branch/knots	Log	QC
Lemieux et al. (2001)	Université Laval	Black spruce	Branch/knots	Log	QC
Lemieux et al. (2002)	Université Laval	Black spruce	Product value recovery	Log	QC
Lenz et al. (2013)*	Université Laval	White spruce	MFA, MOE	Tree	QC
Lenz et al. (2011)*	Université Laval	White spruce	Density, MOE, MFA, fibre transverse dimensions	Ring	Central and southern parts of QC
Lenz et al. (2012)	Université Laval	White spruce	Density, EW/LW, fibre coarseness, fibre transverse dimensions, MFA, MOE, ring properties	Tree	Mauricie region, QC
Lenz et al. (2014)	Université Laval	White spruce	Density, EW/LW, fibre coarseness, fibre length, fibre transverse dimensions, MFA, MOE	Tree	Multiple locations, QC

Authors	Institution	Species	WQA	Resolution	Study area
Lessard et al. (2014)	Université Sherbrooke	Black spruce, balsam fir	Density, fibre coarseness, fibre length, MOE	Plot/Stand	Island of NFL
Li et al. (2012)	University of Maine	Balsam fir, black spruce, eastern hemlock, jack pine, larch, northern white cedar, Norway spruce, red pine, red spruce, white pine, white spruce, black spruce	Stem form	Tree	Multiple locations in Canada
Liu and Zhang (2005)	Forintek Canada Corp.	Black spruce	Product value recovery	Tree	Abitibi-Temiscaming, QC
Liu and Zhang (2005)	Forintek Canada Corp.	Black spruce	Product value recovery	Tree	Abitibi-Temiscaming, QC
Liu et al. (2007)	Forintek Canada Corp.	Black spruce	Lumber grade	Tree	Thunder Bay, ON
Liu et al. (2007)	Forintek Canada Corp.	Black spruce	Lumber value	Tree	Abitibi-Temiscaming, QC
Liu et al. (2007)	Forintek Canada Corp.	Black spruce	MOE, MOR	Tree	Abitibi-Temiscaming, QC
Loo-Dinkins and Gonzalez (1991)*	UBC	Douglas-fir	Density	Ring	Victoria watershed and Lake Cowichan Research Station, BC
Loo-Dinkins et al. (1991)	UBC	Douglas-fir	Density	Tree	Coastal BC
Luther et al. (2013)	CWFC	Black spruce, balsam fir	Density, fibre coarseness, fibre length, fibre transverse dimensions, MFA, MOE	Plot/Stand	Island of NFL
Magnussen and Keith (1990)*	CFS	Jack pine	Taper, density, heartwood	Tree	Petawawa, ON
Maness and Donald (1994)	UBC	SPF groups	Product value recovery	Log	BC
Mansfield et al. (2007)	UBC	Lodgepole pine	JW/MW transition	Tree	Western Alberta and interior BC
Mansfield et al. (2007)	UBC	Western hemlock	MOE, MOR	Stem	Coastal BC
Mansfield et al. (2009)	UBC	Lodgepole pine	JW/MW transition	Tree	Central BC
Mansfield et al. (2011)	UBC	Hybrid poplar	MOE, MOR	Stem	Harrison Mills and Fort Nelson, BC
Matolcsy (1975)	Ontario Research Foundation	Balsam fir	Pulp and paper properties		ON

Authors	Institution	Species	WQA	Resolution	Study area
Mitchell et al. (1989)	BCMFLNRO	Douglas-fir	Product value recovery	Log, lumber	Various coastal locations, BC
Morris and Forslund (1992)	Ontario Forest Research Institute	Jack pine	Stem form	Tree	Northwestern region of ON
Morris and Parker (1992)	Ontario Forest Research Institute	Jack pine	Branch/knots, stem form	Tree	Northwestern Ontario
Morris et al. (1992)*	Ontario For. Res. Institute	Jack pine	Stem form, branch	Tree/family	Thunder Bay Nursery, ON
Muhairwe (1994)	UBC	Lodgepole pine	Stem form	Tree	Burns Lake, Anahim Lake, Prince George, BC
Mvolo et al. (2015)	UQAT	White spruce	JW/MW	Ring	Petawawa, ON
Nault (1989)	Forintek Canada Corp.	Douglas-fir	Longitudinal shrinkage	Ring	Various coastal locations, BC
Nemec et al. (2010)	BCMFLNRO	Lodgepole pine	Branch/knots	Tree	Various coastal locations, BC
Nemec et al. (2012)	BCMFLNRO	Amabilis fir, Douglas-fir, lodgepole pine, western hemlock, white spruce	Branch/knots	Tree	Coastal BC
Newton and Sharma (2008)	CWFC	Jack pine	Stem form	Tree	Northern Ontario
Paradis et al. (2013)	Université Laval	Black spruce	MOE, product value recovery	Tree	North Shore region of QC
Park et al. (2012)	CWFC	White spruce	Density, EW/LW, fibre length, MFA	Tree/Clone	Acadia Research Forest, NB
Pavel and Andersson (2009)	FPInnovations	Generic	Stand value	Forest	BC
Peng and Stewart (2013)	Foothills Research Institute	Lodgepole pine	Density	Ring and tree	Central foothills, AB
Peng et al. (2013)	UNB	Jack pine, white spruce	Shrinkage	Ring	NB
Petruncio et al. (1997)	Heritage College, WA	Douglas-fir	Branch/knots	Tree	Pacific Northwest, USA
Pitt et al. (2013)	CWFC	Balsam fir	Stand value	Plot/Stand	Green River, NB
Pliura et al. (2007)*	Forintek Canada Corp.	Hybrid poplar	Density	Site	Southern Quebec
Pnevmaticos et al. (1972)	CFS	Black spruce, balsam fir	Density, MC, stem form	Tree	Central Transition Section of the Boreal Forest, QC
Pokharel et al. (2014)	Nipissing University	Black spruce	Density, EW/LW	Tree/Ecosite	Northeastern Ontario
Porth et al. (2013)*	UBC	Black cottonwood	Density, MFA, fibre length, chemical properties	Ring	BC

Authors	Institution	Species	WQA	Resolution	Study area
Porth et al. (2013)*	UBC	Black cottonwood	Density, MFA, fibre length, chemical properties	Ring	BC
Porth et al. (2013)*	UBC	Black cottonwood	Density, MFA, fibre length, chemical properties	Ring	BC
Ratcliffe et al. (2014)*	UBC	Western larch	Density, MOE	Tree	East Kootenay, BC
Samson et al. (1996)	Université Laval	Generic	Branch/knots		QC
Sattler et al. (2014)	University of Alberta	Trembling aspen, white spruce	MOE	Samples within tree	Northern AB
Sattler et al. (2014)	University of Alberta	White spruce	Branch/knots	Tree	Central mixedwood natural subregion, Alberta
Savva et al. (2010)	UQAT	Jack pine	Density, EW/LW	Ring	Petawawa, ON
Scallan and Green (1974)	Paprican	Various species	Fibre coarseness, fibre transverse dimensions		Unknown
Schneider et al. (2008)	UQAM	Jack pine	Branch/knots, sapwood	Tree	NB
Schneider et al. (2008)	UQAM	Jack pine	Density, EW/LW, MOE, MOR	Ring	Grand Lake Road, NB
Schneider et al. (2008)	UQAM	Trembling aspen	Decay, product value recovery	Tree	Bas-St-Laurent and Gaspésie, QC
Schneider et al. (2011)	UQAR	Jack pine	Sapwood properties	Stem	NB
Sharma and Zhang (2004)	Forintek Canada Corp.	Black spruce	Stem form	Tree	Thunder Bay, ON
Schneider et al. (2013)	QC MFFP	Paper birch, white spruce, red spruce, black spruce, balsam fir, white spruce, eastern white cedar, large-toothed aspen, trembling aspen	Taper	Tree	QC
Schneider et al. (2014)	QC MFFP	Jack pine	Taper	Tree	QC
Singh (1984)	CFS	Alpine fir, balsam fir, balsam poplar, black spruce, jack pine, larch, lodgepole pine, trembling aspen, white birch, white spruce	Density	Vertical disk	AB
Singh (1986)	CFS	Black spruce, balsam poplar, jack pine, larch, trembling aspen, white spruce	Density	Vertical disk	Northwest Territories

Authors	Institution	Species	WQA	Resolution	Study area
Stirling et al. (2014)	FPInnovations	Western redcedar	Decay, extractives content		BC
Stoehr et al. (2009)	BCMFLNRO	Douglas-fir	Density	Tree	Coastal BC
Tong and Zhang (2006)	Forintek Canada Corp.	Jack pine	Product value recovery	Tree	Miramichi, NB
Tong and Zhang (2008)	Forintek Canada Corp.	Jack pine	Lumber volume recovery	Tree	Miramichi, NB
Torquato et al. (2014)	Université Laval	Black spruce	MOE, MOR	Samples within tree	Abitibi, Lac-Saint-Jean & North Shore, QC
Ukrainetz et al. (2008)*	UBC	Douglas-fir	Density, EW/LW, fibre length, fibre coarseness, MFA, chemical properties	Family	Vancouver Island, BC
Ukrainetz et al. (2008)*	UBC	Douglas-fir	Density, fibre length, fibre coarseness, fibre transverse dimensions, MFA, chemical properties, EW/LW	Tree	Southeastern BC
Ung (1989)	CFS	Beech	Stem form	Tree	Temiscouata, QC
Ung et al. (2013)	CWFC	Various species across Canada	Stem form	Tree	Canada-wide
Vincent and Duchesne (2014)	Université Laval	White spruce, jack pine	MOE, MOR	Tree	Woodstock, NB
Wang and Aitken (2001)	UBC	Lodgepole pine	EW/LW, ring properties	Ring	Central BC
Wang and Stewart (2013)	Foothills Research Institute	Lodgepole pine	EW/LW	Tree	Southeastern BC
Wang et al. (1998)	University of Alberta	Balsam poplar, black spruce, lodgepole pine, trembling aspen, white spruce	Stem form	Tree	AB
Wang et al. (1999)*	UBC	Lodgepole pine	Density	Ring/tree	Willow-Bowron Seed Orchard Planning zone in central BC
Wang et Stewart (2012)	Foothills Research Institute	Lodgepole pine	JW/MW	Tree/site	Foothills, AB
Xiang et al. (2014)	Lakehead University	Black spruce	Density	Ring	Thunder Bay, ON
Xiang et al. (2014)	Lakehead University	Black spruce	Ring properties	Ring	Thunder Bay, ON
Yanchuk and Kiss (1993)*	BCMFLNRO	Interior spruce	Density	Tree/Family/site	Red Rock and Quesnel, BC
Yang and Hazenberg (1991)	Lakehead University	Trembling aspen	Sapwood properties	Tree	Thunder Bay, ON

Authors	Institution	Species	WQA	Resolution	Study area
Yang et al. (1986)	Lakehead University	Larch/Tamarack	JW/MW	Tree	Thunder Bay, ON
Zang and Tong (2005)	Forintek Canada Corp.	Jack pine	Product value recovery	Tree	Miramichi, NB
Zhang and Chui (1996)*	Forintek Canada Corp.	Jack pine	Density	Family	Dubee Settlement, Southeastern NB
Zhang and Morgensten (1995)*	Forintek Canada Corp.	Black spruce	Density, EW/LW	Ring	Tobique River watershed in northern NB
Zhang et al. (1996)	Forintek Canada Corp.	Black spruce	Density	Ring	Edmundston, NB
Zhang et al. (2003)*	Forintek Canada Corp.	Hybrid poplar	MC, density	Tree/clone	St-Ours & Windsor, QC
Zhang et al. (2004)*	Forintek Canada Corp.	White spruce	Density, MOE, ring width, veneer quality (MOE, MOR, roughness)	Tree/family	Valcartier & Lac St-Ignace, QC
Zhang et al. (2005)	Forintek Canada Corp.	Black spruce	Stem form, branch/knots, Product value recovery	Tree	Thunder Bay, ON
Zhang et al. (2006)	Forintek Canada Corp.	Black spruce	Product value recovery	Tree	Thunder Bay, ON
Zhang et al. (2006)	Forintek Canada Corp.	Black spruce	Product value recovery	Tree	Northern Ontario and Quebec
Zhou et al. (2012)	UNB	Red pine	MOE	Log	NB

* : Genetics/genomics studies
EW/LW: earlywood/latewood properties
JW/MW: juvenile wood/mature wood properties
MC: moisture content
MOE: modulus of elasticity
MFA: microfibril angle
MOR: modulus of rupture

A5. List of growth and yield models/simulators

Name	Author(s) Institution	Model type	Scale	Spatiallity	Species	Scope	Time step	Quality attribute(s)	Maturity	Contact
GYPSY Growth and Yield Projection System	Huang et al. Forest Resource Analysis Section, Alberta	Empirical	Stand	No	White spruce, aspen, lodgepole pine and black spruce	Provincial (AB)	Yearly		In use	Shongming Huang Environment and Sustainable Development, Edmonton, Alberta Shongming.Huang@gov.ab.ca
TASS Tree and Stand Stimulator	BC MFLNRO	Hybrid	Tree	Yes	All major coniferous species in BC plus aspen and alder	Provincial (BC)	Yearly	Branch, taper WD, MOE, MFA, FL, JW, SW, RW	In use	Jim Goudie BC Ministry of Forest, Lands and Natural Resources Operations Jim.Goudie@gov.bc.ca
Sortie-ND	K. David Coates BC MFLNRO Charles D. Canham Cary Institute of Ecosystem Studies	Hybrid	Tree	Yes	Western red cedar, western hemlock, amabilis fir, interior spruce, subalpine fir, lodgepole pine, trembling aspen, paper birch and black cottonwood	Northwest and central BC	Yearly		In use	David K. Coates Dave.Coates@gov.bc.ca> Charles D. Canham ccanham@caryinstitute.org
Prognosis-BC	Valerie Lemay UBC Don Robinson ESSA Technologies	Empirical	Tree	No	White pine, western larch, Douglas-fir, Grand fir, western hemlock, western red cedar, lodgepole pine, balsam fir, Engelmann spruce, subalpine fir,	Provincial (BC)	5 or 10 years		In use	Don Robinson drobinson@essa.com Valerie Lemay valerie.lemay@ubc.ca

Name	Author(s) Institution	Model type	Scale	Spatiallity	Species	Scope	Time step	Quality attribute(s)	Maturity	Contact
					ponderosa pine, paper birch, trembling aspen, cottonwood					
AMSIMOD	Guy Larocque Canadian Forest Service	Process-based	Tree	Yes	Many softwood and hardwood species	Generic	Yearly		In use	Guy Larocque Canadian Forest Service guy.larocque@canada.ca
CroirePlant	Guy Prégent et al. MFFP, Québec	Empirical	Stand	No	White spruce	Provincial (QC)	Yearly		In use	Guy Prégent MFFP, Direction de la recherche forestière guy.pregent@mffp.gouv.qc.ca ftp://ftp.mrn.gouv.qc.ca/Public/Drf/Capsis/CroirePlant
SaMARE	Mathieu Fortin et al. MFFP, Québec	Empirical	Tree	No	Sugar maple, red maple, yellow birch, American beech, balsam fir, other hardwood and softwood species	Provincial (QC)	5 years	Volume by log grades	In use	François Guillemette MFFP, Direction de la recherche forestière francois.guillemette@mffp.gouv.qc.ca ftp://ftp.mrn.gouv.qc.ca/Public/Drf/CAPSIS/SaMARE/
Artémis	Mathieu Fortin et al. MFFP, Québec	Empirical	Tree	No	All major hardwood and softwood species in Québec	Provincial (QC)	10 years	Taper Volume by log grades	In use	MFFP, Direction de la recherche forestière ftp://ftp.mrn.gouv.qc.ca/Public/Drf/Capsis/Artemis-2014
Natura	David Pothier Isabelle Auger MFFP, Québec	Empirical	Stand	No	Hardwoods Softwoods	Provincial (BC)	10 years		In use	Isabelle Auger MFFP, Direction de la recherche forestière isabelle.auger@mffp.gouv.qc.ca

Name	Author(s) Institution	Model type	Scale	Spatiallity	Species	Scope	Time step	Quality attribute(s)	Maturity	Contact
										ftp://ftp.mrn.gouv.qc.ca/Public/Drf/Capsis/Natura-2014
STAMAN	NB Growth & Yield Unit	Empirical	Diameter-class	No	Softwoods Hardwoods	Provincial (NB)	5 years		In use	New Brunswick Growth and Yield Unit
NS G&Y Model	Nova Scotia DNR	Empirical	Stand	No	Softwoods Hardwoods	Provincial (NS)	5 years		In use	novascotia.ca/natr/forestry/programs/timberman/growthyield.asp
MIST Modelling and Inventory Support Tool	Ontario MNRF	Empirical	Tree	No	Many ON species	Provincial (ON)		Taper	In use	Ontario Ministry of Natural Resources
FVS-Ontario Forest Vegetation Simulator, Ontario	Ontario MNRF ESSA Technologies	Empirical	Tree	No	Many ON species	Provincial (ON)	Yearly or user defined		Under development	Scott McPherson scott.mcpherson@ontario.ca Don Robinson drobinson@essa.com
Siplab	Oscar Garcia UNBC	Process-based	Tree	Yes	Generic	Canada	Not time dependent		Academic	Oscar Garcia UNBC oscar_garcia@unbc.ca
Scube	Oscar Garcia UNBC	Hybrid	Stand	No	Interior spruce	BC	Any		Academic	Oscar Garcia UNBC oscar_garcia@unbc.ca
TAG	Oscar Garcia UNBC	Hybrid	Stand	No	Aspen dominated stands in BC, AB, SK, and MB	BC, AB, MB, SK	Any		Academic	Oscar Garcia UNBC oscar_garcia@unbc.ca
TRIPLEX	Changhui Peng UQAM	Process-based	Tree	Yes	Jack pine, black spruce, white spruce, aspen	?	Daily	WD	In use	Changui Peng UQAM www.crc.uqam.ca
PipeQual	Robert Schneider UQAR A. Makelä	Hybrid	Tree	No	Jack pine, black spruce, white spruce	Provincial	Yearly	Taper SW	Under development	Robert Schneider UQAR robert_schneider@uqar.ca

Name	Author(s) Institution	Model type	Scale	Spatiallity	Species	Scope	Time step	Quality attribute(s)	Maturity	Contact
	University of Helsinki									
COHORTE	Frédérik Doyon UQO (IQAFF)	Empirical	Tree	No	Hardwoods and softwoods	Southern QC and Northern NB	Yearly	Branch Stem quality defects	In use	Frédérik Doyon UQO (IQAFF) frederik.doyon@uqo.ca
MGM Mixedwood Growth Model	Bokalo et al. University of Alberta	Hybrid	Tree	No	White spruce, trembling aspen, lodgepole pine, jack pine	Alberta Manitoba British Columbia Sask.	Yearly	Taper WD, JW, MOE, FL	In use	Phil Comeau University of Alberta phil.comeau@ualverta.ca
IVY Increment in Volume per Year	Art Groot CWFC	Hybrid	Tree	Yes	Black spruce, jack pine, trembling aspen	Customi-zable		Knot size/distribution RW Clearwood		Art Groot CWFC art.groot@gmail.com
OSM Open Stand Model	Chris Hennigar Forus Research	Empirical	Tree	No	Generic	Generic	Yearly	Taper Tree form Disease	Unvalidated	Chris Hennigar www.forusresearch.com hennigar@forusresearch.com

WD: wood density; MOE: modulus of elasticity; MFA: microfibril angle; FL: fibre length; JW: juvenile wood; SW: sapwood; RW: ring width

A6. List of Decision Support Systems

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
SYLVER	BC MFLNRO	Forest Stand Tree Log	BC species	Long term Midterm	Primarily SYLVER is designed to aid decisions on second growth stands, including silvicultural treatments, product simulation and investment analyses. These lead to yields that are used in forest-level allowable cut determinations. TASS II (Mitchell, 1975) and its derivative TIPSY (Mitchell et al. 2004) are components of SYLVER (Mitchell et al. 1989) first developed in BC as part of the Douglas-fir task force (Kellogg 1989). The linked components of SYLVER also include a bucking simulator (BUCK), sawmill simulator (SAWSIM), lumber grading routine (GRADE) and financial analysis system (FAN$IER). In SYLVER, trees are established, stands are manipulated (thinning, pruning, fertilization), and effects on the quality and quantity of logs or lumber are estimated. Financial and economic analyses have already shown the positive effects of pruning and commercial thinning of coastal Douglas-fir on many sites (Mitchell et al 1989, Stone 1993). Recent additions include predictions of branch distributions and size (Nemec et al. 2012). We are also now linked to OPTITEK, a three-dimensional sawmill simulator, which will recognize knots and other internal log defects to produce graded lumber. Currently the BC Ministry of Forests, Lands and Natural Resource Operations and numerous companies use SYLVER to assess many forest management decisions, including silvicultural predictions that can be assessed at the volume, product or financial perspectives. A new version of TASS (III) is in development and will allow projections of complex stands with multiple species and age cohorts.	Free	Jim Goudie BC Ministry of Forests, Lands and Natural Resources Operations Jim.Goudie@gov.bc.ca
BIOLLEY	Jean-Martin Lussier CWFC	Stand	Managed hardwood stands	Long term	BIOLLEY is a stand-level optimization model, designed to help silviculturists and forest managers to select the trees to be cut, or maximize revenues in a sustainable way, in a context of an uneven-aged partial cutting system. Emphasis is put on the economics of short-term and long-term stand	Free	Jean-Martin Lussier Natural Resources Canada

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					harvest, regeneration, and tending. The model is at first developed for the application of the selection system, aiming at sustained net revenue over multiple cutting cycles. Tree growth, survival and changes in quality/risk grades are modeled using a transition matrix calibrated from permanent plots in managed stands in Quebec and Ontario. Tree recruitment is modeled using a modified version of the recruitment of Artemis-2009. Yields by log sorts and market value are modeled using bucking matrices from the QMNR, and current prices tables available on the Web. Harvest costs are modeled using generic cost functions by FPInnovations. The current version is designed for researchers to design and test alternative treatment strategies, in order to give guidance to forest managers. The spreadsheet model can be adapted to other uneven-aged systems, and/or to incorporate ecological indicators and objectives, in conjunction with wood production.		Canadian Forest Service Canadian Wood Fibre Centre jean-martin.lussier@canada.ca
WFVSM Wood Fibre Value Simulation Model	Chao Li CWFC	Stand	Generic	Short term	WFVMS is an integrated information system that links tree and stand characteristics (inventory) with internal fibre attributes, supply chain costs, and end-product based value options.	Free	Chao Li Natural Resources Canada Canadian Forest Service Canadian Wood Fibre Centre chao.li@canada.ca
CROPLANNER	Peter Newton CWFC	Diameter-class	Jack pine & Black spruce	Long term	Structural stand density management within upland black spruce stand-types. Modeling activities continuing including development of response models for thinning and genetic worth effects, evaluation of the biological validity of the underlying model, and development of a structural stand density management model variant for red pine. Future activities will consist of empirical testing in terms of precision of yield estimates, code translation,	Free to stakeholders	Peter F. Newton Natural Resources Canada Canadian Forest Service Canadian Wood Fibre Centre

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					documentation and peer-review reporting. Pending acceptance by regulatory agencies (i.e., OMNR+F) for use in the OMNR+F forest planning system, this unvalidated prototype requires additional model refinement and empirical evaluation (with associated model changes if required), provision of comprehensive documentation (i.e., monographs) and supporting peer-review articles, and programming research including computer code development, translation and testing. Limitations include the allometric yield-based modelling approach utilized, calibration databases utilized mostly natural-origin stand-types with limited data from mature density regulated stands, current lack of evaluation metrics and comprehensive documentation. End-user community regulated by the OMNR+F is familiar with the modelling approach (stand density management diagrams) and it is expected that the OMNR+F will eventually utilize the DSS in their forest management planning system providing that the pending prerequisites are completed.		Peter.Newton@canada.ca
Optitek	FPInnovations	Stem Log	Generic	Short term	Canadian lumber manufacturing stakeholders are now familiar with the flexibility, accuracy and user friendliness of the Optitek lumber breakdown simulation program. Available since 1994, it has benefited from constant improvements reflecting the developers' innovative ideas as well as comments and suggestions from users. In 1997, the Conseil de la recherche forestière du Québec awarded Forintek (now FPInnovations) its Prix Méritas for the development of Optitek. As sawmilling technology underwent changes over the years, Optitek was adapted to these changes and acquired the necessary abilities to reproduce new technology features such as curve sawing, true shape scanning and internal defect detection (e.g., knots). Thanks to its flexibility and versatility, Optitek can be used in a number of applications, including: - Addition of new products - Modifications to wane rules and price lists in optimizers - Installation of optimized equipment	Free for FPInnovations members	FPInnovations Modeling and Optimization Group fpinnovations.ca

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					- Different slashing (bucking) strategies - Reduction of target thickness or kerf width		
ForestPlan	FPInnovations	Regional Forest Stand	Generic	Midterm	ForestPlan is a mixed integer programming model that determines which cut blocks to harvest, which sorts to produce at each cut block, which logs to purchase, where to allocate log sorts, what cutting programs to run at each mill, the number of shifts to run at each mill and which products to sell. It is a tactical model that was designed to be used by senior planners at forestry companies to determine an overall plan for the next 6-12 months and to evaluate the impact of changes throughout the value chain. Once an optimal plan is found, users can run additional "what-if" scenarios to determine the impact of adding or removing constraints – more manufacturing capacity, less demand for certain products, changing market prices, and harvesting a different log profile, for example. Users can constrain the model to focus in on areas of interest or consider the entire value chain as a whole. ForestPlan is a single period model and therefore does not consider issues related to scheduling. ForestPlan is currently only available to member companies of FPInnovations. It has been implemented with several companies across Canada.	Commercial to FPInnovations members	FPInnovations Modeling and Optimization Group fpinnovations.ca
NCCruise	FPInnovations	Harvest block Stem Log	Generic	Short term	The New Compilation and Cruising model (NCCruise) is a tool that allows forest companies to describe and maximize the value of forest resources, and thus increase their flexibility and market responsiveness. The model can predict the value of harvest blocks and stands in various market conditions. In this approach, stand value is measured by computing the distribution of wood volume by species and end-use log sort. To accurately describe the distribution of volume by sort, cruise data is customized to include the same tree attributes used in the sorts' descriptions. The model is applied by various companies in BC with assistance from FPInnovations and is being customized for application in other jurisdictions.	Free for FPInnovations members	FPInnovations Modeling and Optimization Group fpinnovations.ca

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
MillFlow	FPInnovations	Log	Generic	Short term	MillFlow models are used to emulate all significant steps that occur within a processing/manufacturing facility, from the perspective of productivity, flow of material, throughput, piece flow. MillFlow models can be used to understand the current limitations of a process, such as finding the maximum throughput, identifying bottlenecks as well as unused capacity in the process, and identifying how bottlenecks shift after changes are made to the process. MillFlow models can be used, among others, to analyze: the impact of changes in the log supply (log diet), feed speeds, capacity etc. on the productivity of a manufacturing facility, the impact of different layouts and different machine configurations on the productivity of log sort yards. They are also a very valuable communication tool, helping to visually diagnose problem areas and providing feedback to operators. MillFlow models are also an important decision making tool, helping to evaluate ideas, run what-if scenarios and evaluating whether investments in new equipment or new facilities are justified.	Commercial	FPInnovations Modeling and Optimization Group fpinnovations.ca
MillPlan	FPInnovations	Sawmill shift level	Generic	Short term	Production planning for sawmills, kilns and planer mills is a very challenging exercise. There are usually order files of varied products that need to be produced by given dates and limited capacity in the facilities to produce them; while the process of converting a log into a finished product is often time consuming, requiring forward planning. MillPlan was designed to assist production planners to determine the optimal production schedule for a sawmill, kilns and planer mill in order to maximize total profit across the three facilities, while meeting their product demands, given their inventory and capacity constraints. MillPlan is a mixed integer program (MIP) that uses algorithms to find the best possible solution out of many feasible solutions. The user interface is in Microsoft Excel and the MIP is written in the Generalized Mathematical Programming Language (GMPL).	Commercial	FPInnovations Modeling and Optimization Group fpinnovations.ca
Maxtour	FPInnovations	Regional Forest	Generic	Short term	Transportation routing	Commercial	FPInnovations Modeling and

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
		Stand Log					Optimization Group fpinnovations.ca
IGMap	FPInnovations	Forest Stand	Generic	Short term	IGMap stands for Inventory and Geostatistical Mapping. The Inventory and Geostatistical Mapping model (IGMap) is a tool developed to extend the results obtained by NCCruise on large areas. The model uses the volumes by end-use log sort compiled by NCCruise at different points and interpolates new values at unsampled locations by using geostatistical methods. Results of this model can be used by forest planners to identify stands with certain fibre characteristics. The prototype was tested at various locations and stand types in BC and its implementation with a large forest company is in progress.	Free to FPInnovations members	FPInnovations Modeling and Optimization Group fpinnovations.ca
LogWorth	FPInnovations	Log	Generic	Short term	LogWorth was designed to estimate the potential value recovery from different cutting programs. The user describes a series of logs and the way in which they intend to saw them into end products. The program also requires information on product prices, delivered log costs, operating costs, fixed costs and production rates. It uses this information to estimate the margin, lumber recovery factor and return to log (break-even delivered log cost). As business conditions are dynamic, it was designed to be easily updated to reflect current conditions. LogWorth is not an optimizer. It doesn't determine the best way to saw logs to maximize profits or to meet order files. Instead, it allows the user to try out different cutting patterns and provides feedback on the expected volume and value recovery.	Commercial	FPInnovations Modeling and Optimization Group fpinnovations.ca
FPAlloc	FPInnovations	Stand	Generic	Short term	Wood allocation optimization	Free to FPInnovations members	FPInnovations Modeling and Optimization Group fpinnovations.ca
WOODMAN	Halco Software Systems Ltd.	Forest Stands Tree	Generic	Midterm Short term	WOODMAN™ helps companies to maximize profits by determining: • The value of particular stands of timber, for timber sale bidding purposes	Commercial	info@halcosoftware.com

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					• The effect of alternative logging plans (or wood supply alternatives) on the operation of manufacturing facilities • The optimum allocation of a timber supply to alternative mill sites, or allocation to alternative products (lumber, veneer, or chips) • The optimum breakpoint between sawlogs and pulpwood • The optimum schedule of logging operations and log yard inventories to ensure the mill log supply is as consistent over time as possible, to improve operating efficiency.		
Remsoft Operational/ Tactical Planning	Remsoft Inc.	Regional Forest Stand	Generic	Midterm	The Woodstock Modeling System is used to address a wide range of forest planning themes. The Woodstock Strategic Planning Solution includes the following commercial-off-the-shelf products: Woodstock, Allocation Optimizer, Spatial Optimizer, Remsoft Integrator, Publisher and 3rd party commercial LP/MIP solvers. The solution is commonly used to establish allowable cut determinations, determine appropriate silvicultural regimes, discounted cash flow analyses for timberland valuation, harvest schedules, policy evaluation, carbon modelling, resource allocation strategies, strategic supply chain optimization, etc. While the objectives change across this wide range of model formulations, the basic questions answered are the same: what forest areas to treat, what treatment to employ, when the treatment should take place and where and how should the wood be delivered downstream in the supply chain. Complementing the Woodstock Modeling System, the Remsoft Analytics suite is designed to make available the detailed information embedded in detailed harvest scheduling/allocation models, beyond the forest planning subject matter experts who build these models. Field staff, engineers, accounting personnel and managers have direct access to the model detail and the Remsoft Analytics applications allow these users to query tabular and graphical model results, view scheduled activities spatially in a map environment and if permitted, to make changes to the schedule of activities and observe the impacts of these changes. Since forest planning tends to be an iterative exercise, the Remsoft Analytics Platform greatly facilitates	Commercial	Marie Eve Fillion marie@remsoft.com

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					the feedback process and generally enhances and accelerates the overall planning process.		
Woodstock	Remsoft Inc.	Regional Forest Stand	Generic	Long term	The Woodstock Modeling System is used to address a wide range of forest planning themes. The Woodstock Strategic Planning Solution includes the following commercial-off-the-shelf products: Woodstock, Allocation Optimizer, Spatial Optimizer, Remsoft Integrator, Publisher and 3rd party commercial LP/MIP solvers. The solution is commonly used to establish allowable cut determinations, determine appropriate silvicultural regimes, discounted cash flow analyses for timberland valuation, harvest schedules, policy evaluation, carbon modelling, resource allocation strategies, strategic supply chain optimization, etc. While the objectives change across this wide range of model formulations, the basic questions answered are the same: what forest areas to treat, what treatment to employ, when the treatment should take place and where and how should the wood be delivered downstream in the supply chain. Complementing the Woodstock Modeling System, the Remsoft Analytics suite is designed to make available the detailed information embedded in detailed harvest scheduling/allocation models, beyond the forest planning subject matter experts who build these models. Field staff, engineers, accounting personnel and managers have direct access to the model detail and the Remsoft Analytics applications allows these users to query tabular and graphical model results, view scheduled activities spatially in a map environment and if permitted, to make changes to the schedule of activities and observe the impacts of these changes. Since forest planning tends to be an iterative exercise, the Remsoft Analytics Platform greatly facilitates the feedback process and generally enhances and accelerates the overall planning process.	Commercial	Marie Eve Fillion marie@remsoft.com
Patchworks	Spatial Planning Systems	Regional Forest Stand	Generic	Long term	Patchworks is a spatially explicit sustainable forest management model that is able to assess the outcomes and consequences of management policies over long time horizons (multiple rotations), using stand-level operational	Commercial	Tom Moore info@spacial.ca

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					planning detail. Advanced features include: - explicit development of a spatial harvest plan over long time horizons; - simultaneous solution of multiple goals; - patch targets based on a flexible specification of criteria and size classes; - optimizing the allocation of multiple-products to multiple-destinations, taking into account road and transportation economics; - a high degree of transparency. Patchworks is in use by multiple government and industrial agencies across Canada and in the United States to explore policy options and develop cost effective forest management plans.		
FOREXPERT	Louis-Jean Lussier WSP Canada Inc.	Forest Stand Tree Log	Generic	Long term	Forexpert est un outil d'aide à la décision qui permet d'analyser divers scénarios sylvicoles à l'échelle du peuplement. Il comprend un module de croissance par tige et par essence basé sur l'accroissement du diamètre et ajusté en fonction de la densité. Un module de mortalité est également intégré. La simulation s'effectue sur 10 périodes de 5 ans ou moins. L'usager peut intervenir à chaque période pour simuler un prélèvement. Forexpert comprend un module d'analyse de rentabilité financière qui utilise une matrice de répartition par produits, une table de prix de produits et des coûts de récolte fixes ou variables au choix de l'usager. Le module calcule les coûts et les revenus et montre la valeur actualisée nette du scénario. Forexpert peut être calibré en fonction des caractéristiques du territoire d'étude.	Commercial	jean.francois. boileau@wspgroup .com
SilviLab	FORAC Université Laval	Regional Forest Stand	Generic	Long term/ Mid./ Short term	SilviLab is a decision support tool for forest management. It is a Web application to visualize (user interface with geographical data representation), evaluate and compare strategic industrial development plans of the forest. SilviLab produces a plan considering the economic value of	University	forac.ulaval.ca

Name	Author(s) Institution	Decision level	Specificity	Time scale	Description	Distribution	Contact
					the market while respecting the established constraints of performance and protection. It assesses the impact of the forest planning models on the industrial network. To calculate the AAC, SilviLab utilizes data from forest inventory, growth and yield models, anticipated effects of silvicultural treatments and stem quality index.		
LogiLab	FORAC Université Laval	Regional Forest Stand	Generic		Generic tool for supply chain modelling (user interface with geographical localization of business units) with tactical production and transportation decisions planning. It allows optimization of a logistic network, from the forest to the final client. LogiLab optimizes networks by trying to maximize profits for the whole logistic network, while diminishing transport, inventory and production costs.	University	forac.ulaval.ca

A7. Workshop Agenda

"Strategic Planning for Linking Wood Quality Models to Decision Support Systems"
March 10, 2015

Pacific Time	Eastern Time	Length	Presentation	Speaker	Description
8:00	11:00	10	**Objectives of the workshop** • what we want to accomplish • how we are going to accomplish this • The Vision: Canada's forest industry is using WQ information to optimize use of forest resources. **Introduction of participants (icebreaker)** • Name, organization, some fun fact about yourself (10 sec each)	Jim Stewart Solange, Morgan*	Introduce the Vision – an organizing theme for the workshop. Explain the process of capturing questions, observations and ideas on sticky notes and posting on IDEA WALL at each centre These will help fuel our discussions in the planning sessions. Photos of Idea Wall at PFC will be sent to LFC periodically JML will create MindMap on the fly and display at the breaks JML provides a framework MindMap to structure the sticky note input
			Background: the foundation of existing work		
8:10	11:10	15	**1. Wood Quality modelling research** • Legacy work • FPInnovations • ForValueNet • CWFC (Genetics, CFAR, etc.) • WQ research outside of Canada (highlights)	Maurice, Isabelle, Jim	Key learnings from the literature review and surveys on wood quality models in Canada. A summary of the survey results reported in the compendium. People will be asked to comment/complement the information during the workshop.
8:25	11:25	15	**(cont.) G&Y and DSS development (relevant to WQ)** • Government (e.g., SYLVER) • Academia (e.g., ForValueNet) • Commercial (e.g., RemSoft) • FPInnovations (e.g., FPInterface, LOGWORTH) • Relevant initiatives outside of Canada (e.g., CAPSIS)	Maurice, Isabelle, Jim	Key learnings from the literature review and surveys on G&Y models and Decision Support Systems relevant to wood quality in Canada. A summary of the survey results reported in the compendium. People will be asked to comment/complement the information during the workshop.
			Current initiatives in wood quality modelling		How is this building on past R&D in wood quality? What is driving/facilitating this work (funding, data, policy)?

Pacific Time	Eastern Time	Length	Presentation	Speaker	Description
					What technical challenges/ obstacles are being addressed? How have industry needs shaped the objectives?
8:40	11:40	20	**2. Active research trends – CWFC** • Fibre Centre program in Newfoundland, Quebec, Ontario?, Alberta, BC	Joan, Cosmin, Isabelle, Jim, Art	2-3 slides each
9:00	12:00	20	**3. Active research trends – University** • AWARE and other initiatives in academe	Alexis Achim, Alain Cloutier	(Joan, Jean-François et al. can also comment during Q&A)
9:20	12:20	10	**4. Active research trends – database issues** • Data sets available for modelling • National wood quality database	Sébastien Clément	Issues with management of and access to databases Experience of collaboration with FPInnovations, MFFPQ, Université Laval
9:30	**12:30**	**30**	**LUNCH BREAK at LFC** **COFFEE BREAK at PFC**	Catered Display JMLs MindMap	People reflect on the questions we will address in the planning sessions People put sticky notes on Idea Wall
			Current issues in developing Decision Support Systems These sessions aim to share modelling experiences and discuss key issues and challenges about wood quality and value chain modelling.		What is the current state of integration of WQ into the DSS? What are the opportunities for integrating wood quality into them? What are the technical issues, data gaps, conceptual difficulties? What are future directions with respect to WQ, and what is driving them?
10:00	13:00	20	**5. Active research trends presentation – SYLVER** • What we have learned from integration of WQ – successes and failures.	Jim Goudie	
10:20	13:20	20	**6. Active research trends presentation –Québec's « Indice de Qualité du Bois » Project** • Current status and plans for WQ	Guillaume Giroud	
10:40	13:40	20	**7. Active research trends presentation – FPInnovations** • DSS development and future directions (FPInterface, LOGWORTH, etc.)	Dave Lepage, Joel Mortyn	
11:00	14:00	20	**8. Active research trends presentation – A philosophical overview**	Art Groot	Issues that need to be considered when integrating

Pacific Time	Eastern Time	Length	Presentation	Speaker	Description
			• WQ models and integration into forest management – successes and failures. • Key issues and challenges regarding temporal scale, spatial scale, biological to operational gaps, sources of input data.		wood quality models into DSSs or G&Y modelling platforms
11:20	**14:20**	**30**	**COFFEE BREAK at LFC** **LUNCH BREAK at PFC**	Catered Display JMLs MindMap	People reflect on the questions we will address in the planning sessions People put sticky notes on Idea Wall
			Strategic Planning - Linking WQ models to G&Y or DSSs **The Vision: Canada's forest industry is using WQ information to optimize use of forest resources**		Exploring issues that will shape our future work
11:50	14:50	10	**Review of Input via a MindMap**	Jean-Martin Lussier	
12:00	15:00	50	***Achieving the Vision: What should we be doing and How?*** *1. What should we do or not do?* • *Which WQAs and species should we focus on?* • *Which G&Y simulators and DSSs should we focus on?* • *Where are the real opportunities?* • *What pitfalls should we avoid?* *2. What are the current needs?* • *What does industry say they want?* • *What do we think will be useful?* *3. What are biggest obstacles or challenges?* • *Technical/conceptual: how can we modify our G&Y models and DSSs to facilitate inclusion of WQ attributes?* • *Administrative / process, etc.* • *Resources (people, funding, etc.)* *4. What are the missing parts to achieve this vision, the gaps* • *What are the gaps that need to be filled?*	All	Four stations are set up in each centre, one for each question. One laptop is dedicated to each station, with a flipchart as backup. People at each centre are divided into four break-out groups. Each group goes to a station, and spends 10 minutes responding to the question and capturing their responses on the laptop (Word document) or on the flipchart, if laptops are unavailable. After the 10 minutes, groups rotate to the next station, review what has been written, add checkmarks (agree), Xs (disagree), or question marks (needs clarification), then adds anything that they think is missing. After 7 minutes, they rotate to the next station. The process continues until each group has been through all stations. Facilitator adjusts the timing on the fly to keep the process moving. Requires 4 laptops at each centre, at least one of which is connected to the intranet. Flashdrives can be used to copy files from unconnected laptops to connected laptop.

Pacific Time	Eastern Time	Length	Presentation	Speaker	Description
			• *What do we need to pay more attention to?*		
12:50	**15:50**	**10**	***Break***		At the end, the facilitators copy files to other location.
13:00	16:00	20	***Achieving the Vision: What should we be doing and How?*** Compiling the results	All	Groups are assigned one of the four questions, two groups at CFL, and two at PFC. They collate the input and rank these according to the checks and Xs, flagging clarifications to be dealt with.
13:20	16:20	40	***Achieving the Vision: What should we be doing and How?*** Reporting the results	All	A spokesperson from each group reports back in plenary. Clarifications are solicited at this time.
14:00	17:00	20	**Next Steps** • Formation of working groups and future meetings Reporting and feedback / timeline	All	Roundtable discussion in plenary Identify key activities Develop timeline/action plan
14:20	17:20	10	**Closing remarks**		
14:30	17:30		**Adjournment**		

*Facilitators: Solange Nadeau (Québec) and Morgan Cranny (Victoria)

A8. Workshop outputs – Four questions

Question 1: What should we do or not do?

Collaboration and Partnerships

1. Link wood properties to forest certification. i.e. if you manage a stand a certain way (e.g. pruning), there would be implications on wood quality.
2. + More communication with standards/code organizations e.g. building code CLT engineered wood
3. ++ Focus efforts on a few selected G*Y simulators. Avoid "pet rocks". Choose on the basis of maturity, generality, and relation to important commercial spp.
4. ?++Be careful of closed shop – open source model
5. Avoid duplications of work. Greater teamwork and collaboration.
6. Develop a common approach or vision regarding WQ Sampling strategy, common methodology to adopt etc. (not sure)
7. Not to recreate existing software or DSS. Have an open catalog of existing tools (our own Canadian Tire!)
8. Network a lot more: interaction among different institutions and decision makers.
9. Have strong working collaborations with DSS designers and scientists.
10. Scientists need to try to better understand forest sector needs.
11. Engage end-users in research from the beginning. End-users can be other scientists!
12. Do not assume the needs of forest industry are the same as the needs of forest owners.
13. Find a way to develop a protocol/platform for interconnectivity between the future tools/models (work with DSS designers)

Industry focus

14. +? Need to address a real or imminent industry need
15. ?? Focus on DSSs currently used by much of industry.
16. ++ Need more stand-to-mill trials to evaluate our understanding of how stand/tree conditions affect actual WQ and the impact on actual lumber properties and values. Some have been done, but not nearly enough.
17. We should be ahead of industry needs, along with trying to solve more short-term operational needs that industry has today. (agree)

Management

18. Pitfalls to avoid – maintain diversity of fibre basket. We want to avoid short-term solutions.
19. Avoid loss of expertise. Need to maintain knowledge and skillsets.
20. Develop a long term vision, the vision may not come from industry but more from forest owners (provinces) (not sure: vision of what?)
21. Hard to manage scientists (disagree)
22. Have a good mixture between fulfilling short-term, clear needs, and taking risks for providing ground-braking solutions for the future.
23. +++ Managers need to be patient and not too short term in their focus. Managers shouldn't always need to be doing new things.

Impact and value

24. ++ Identify which species WQ info will help the most

25. Greater focus is needed on the highest value wood where attributes have the greatest impact (e.g. WRC)
26. More focus on value rather than volume recovery. Improved inventory to capture value.
27. Be better at putting a $ value to wood attributes or properties – for each end-use product (agree)

Tools/Models/Methods

28. Continue to develop inventory tools to feed DSS development and implementation.
29. DSS should include a timescale, similarly to models, to predict the future state of the forest and fibre resource
30. Non-destructive and rapid evaluation of tree WQ on the field with handheld tools
31. Use models that researchers think are important to meet specific needs, as one single model cannot fit all uses.

Network

32. We should NOT lose sight of our vision.
33. Keep this network alive and growing

Question 2: What are the current needs?

1. Programmers/DSS Designers
2. Better modelling of hardwood quality and value: better bucking models, inclusion of heartwood predictions.
3. Demonstration of application of DSS using WQ models – "Proof-of-concept", case studies of the utility of these tools = YES + YES
4. Replace regional models by more "exportable" models, for ex. By incorporating climatic predictors. = YES
5. Modular, plug-and-play approach of modelling for easier sharing and building-upon model/knowledge development. = YES
6. They want to decrease the cost of their operations, and have little time for looking at maximizing the value (which may require investments). Industry needs to have tools to do that! (Not sure)
7. The industry needs to know the current forest resource in order to adapt their processes and maximize value, and develop new products and answer market needs.
8. Concerted research efforts with steering from industry. (Not sure – both client and research based approaches are possible – sometimes need to be ahead of the curve as well as responding to current industry needs)
9. Leadership to take at the government level with the help of all partners. (It depends on what leadership – it can and should come from various sources depending on the issue)
10. Need to balance short-term versus long-term optimization (short-term optimization can mean high grading!)
11. Need a market development strategy for high value products – how can we take advantage of high value attributes?
12. Money
13. Have the negative image of wood cutting changed
14. Develop new markets, especially to fill the P&P market disappearance
15. Industry needs to be more proactive and receptive on new technologies and innovations, and we have to make those new technologies simpler to use.
16. Industry needs stand tables

17. DSSs that can utilize WQ info to help with allocation and processing decisions
18. +? The need to understand the knots and check profiles in lodgepole pine in order to properly allocate logs between mills
19. +Ability to capture information at time of harvesting in order to sort products effectively
20. ++Truly understand industry needs in terms of which attributes are critical in terms of value recovery. *And which WQAs their competitors are using to up-sell their products (value-adding WQAs vs non-value-adding WQAs)- link fibre attributes to product value*
21. +What is the current fibre inventory? How can we continue to use technologies such as LiDAR to improve inventory. *Resolution, scale, basically better quality inventories are most apt to be able to incorporate WQAs effectively.*
22. ++ Being able to apply our knowledge of WQ attributes to new stands *Need to apply knowledge about WQA to planning new forests, and also current forests that are being harvested now. Regen standards and management regimes of forests we establish NOW.*
23. + Compression wood – is it important? Do mills care about it? *Especially if we will moving on steeper slopes.*
24. Determining whether WQA info will actually result in grade shifts at mill outturn, or not. (=increased value, or simply increased cost to test WQA without incr in value)- related to #4 above.
25. Starting with an appropriate scale – stand? Tree?, intra-tree? To maximize $ return.
26. Shift focus from minimizing cost to optimizing value.

****

Choice of properties

1. + Compression wood – is it important? Do mills care about it? *Especially if we will moving on steeper slopes.*
2. ++ Being able to apply our knowledge of WQ attributes to new stands *Need to apply knowledge about WQA to planning new forests, and also current forests that are being harvested now. Regen standards and management regimes of forests we establish NOW.*
3. +? The need to understand the knots and check profiles in lodgepole pine in order to properly allocate logs between mills

Model improvements

1. Starting with an appropriate scale – stand? Tree?, intra-tree? To maximize $ return.
2. Better modelling of hardwood quality and value: better bucking models, inclusion of heartwood predictions.
3. Demonstration of application of DSS using WQ models – “Proof-of-concept”, case studies of the utility of these tools = YES + YES
4. Need to balance short-term versus long-term optimization (short-term optimization can mean high grading!)
5. DSSs that can utilize WQ info to help with allocation and processing decisions

Industry research needs

1. Concerted research efforts with steering from industry. (Not sure – both client and research based approaches are possible – sometimes need to be ahead of the curve as well as responding to current industry needs)
2. Industry needs stand tables

3. ++Truly understand industry needs in terms of which attributes are critical in terms of value recovery. *And which WQAs their competitors are using to up-sell their products (value-adding WQAs vs non-value-adding WQAs)- link fibre attributes to product value*
4. Shift focus from minimizing cost to optimizing value.
5. Money
6. Determining whether WQA info will actually result in grade shifts at mill outturn, or not. (=increased value, or simply increased cost to test WQA without incr in value)- related to #4 above.
7. ASSUMPTIONS TO VALIDATE
    a. They want to decrease the cost of their operations, and have little time for looking at maximizing the value (which may require investments). Industry needs to have tools to do that! (Not sure)
    b. The industry needs to know the current forest resource in order to adapt their processes and maximize value, and develop new products and answer market needs.

Changes in attitude/environment

8. Develop new markets, especially to fill the P&P market disappearance
9. Industry needs to be more proactive and receptive on new technologies and innovations, and we have to make those new technologies simpler to use.
10. Need a market development strategy for high value products – how can we take advantage of high value attributes?
11. Have the negative image of wood cutting changed

Technical needs

1. Programmers/DSS Designers
2. Replace regional models by more “exportable” models, for ex. By incorporating climatic predictors. = YES
3. Modular, plug-and-play approach of modelling for easier sharing and building-upon model/knowledge development. = YES
4. +Ability to capture information at time of harvesting in order to sort products effectively
5. +What is the current fibre inventory? How can we continue to use technologies such as LiDAR to improve inventory. *Resolution, scale, basically better quality inventories are most apt to be able to incorporate WQAs effectively.*

Government

1. Leadership to take at the government level with the help of all partners. (It depends on what leadership – it can and should come from various sources depending on the issue)
2. Money

Question 3: What are the biggest obstacles or challenges?

Industry, adoptability, linkages, collaboration, value proposition

1. Make/help the industry understand the importance of wood quality - Do we have a good value proposition?
2. Need a software modelling platform that will facilitate the combination and use of different models at the ecosystem, landscape and regional levels, with utilities to display results on graphs, geographic information systems and virtual imagery systems. This application would include analytical and numerical processing utilities. e.g. Sylver, Amsimod (the two could be

merged together). This platform should be designed for scientists/students for easy development; user-friendly, fool-proof commercial solutions should come later… Mostly agree, but one uber-solution may not be feasible.

3. Make the models accessible and easily usable for the whole forest sector
4. Have a better exchange in wood quality information between the forest sector partners Yes
5. Lack of IQP in our client's offices
6. No clear wood production policies/objectives from the forest land owners. (no pull) (More true for wood quality than for production – most owners do have long-term production plans)
7. Develop a common vision to mobilise the research community.
8. Not enough communication- more collaboration (+)
9. Traditionally, forest industries have been volume based. Challenge to overcome prevailing attitudes and approaches. ++
10. Understanding the implications of transition to 2nd growth and the resulting impacts on WQ. +++
11. Understanding the links between WQ attributes to finished lumber grades. +++
12. Loss of information about logs when they are delivered to a sawmill wood yard. When they reach the sawmill infeed, we no longer know where the log came from or info about the stand management. *This is a mill issue, relates to tracking logs in mill studies to prove to mills that they should keep track of logs and segregate throughout the production chain. Must be worthwhile to do this tracking and segregation.*
13. Short-term needs of industry often don't align with the long-term requirements of model building. *Current harvest vs future harvest, models often used to inform future harvest, links to tenure system and tenure reform.*
14. Acceptance by policy makers of quality new science about WQA, listen to the science, need climate accepting of the science and the models and that recognizes the need to look at WQ.

Data, Research issues, modeling issues

15. Lack of long-term data of changes in tree/stand attributes. (May need better reconstruction techniques --- data are available from PSPs, cores, repeated inventories)
16. Need more WQ measures on permanent plots!!!
17. Variability of species – we need to focus on economically important species
18. Need for more consistency in data acquisition and aggregation standards (e.g., PSPs) to support modelling efforts. (e.g., between jurisdictions, research studies)
19. Wood quality needs to adjust to growth and yield model and vice versa (+)
20. Differences scale a barrier between models (?)
21. Lack of sufficient inventory. *For WQA especially. Might need to look at stocking standards.*
22. Difficulty of having a current snap shot of a tree, to back-cast stand development or WQ. We only have a snap shot of the trees right now, and this can be limiting.

Funding, time scales, management

23. Long-term funding issues,
24. Lack of patience by management and recognition of importance of this research and how long it takes.

Question 4: What are the missing parts (gaps) to achieve this mission?

1. We are missing an ongoing conversation about the decisions that need to be informed.
2. We are missing a good understanding of how fibre attributes affect forest products and processes.

3. We are missing a knowledge of how wood quality improvement will increase product value.
4. We are missing an integrating platform (such as CAPSIS and AMSIMOD) for linking wood quality models and decision support systems.
5. We are missing individual tree (as opposed to stand level) growth and wood quality models for forecasting volume and quality.
6. We are missing scientific understanding of the influences at all levels of hierarchy on many fibre attributes (i.e., we don`t always know enough).
7. …
8. An easy way to acquire large volumes of good quality data on wood fibre
9. A better interoperability of software applications between platforms (laptops, desktops, phones, other electronic devices), and an easier way to convert data formats from one software to another (format conversion software, or format standardisation between software)
10. Better communication between science and industry, using a common language.
11. Better understanding of industry needs
12. Better ways to transfer technology to the industry
13. Availability of state-of-art inventory/remote sensing basic data for all forest management units. (the slow forest inventory cycle (10 years) is an impediment).
14. Enrich the basket of models with more process-based models
15. Provide error terms in our predictions and find methods to incorporate them for better decisions (taking account risks).
16. Development/Proof-of-concept of wood quality management/sorting on harvest operations.
17. We lack a leadership group to work at the national scale, while listening to provincial needs.
18. Communication between experts
19. Very difficult to have program developers to integrated WQ information. Gov. or universities do not have the capacity to hire HQP to do that and ensure continuity in the DSS development etc.
20. Lack of tree-level growth and yield models to which we can connect WQ models.
21. +? Common Definition of wood quality is needed. Industry has different view than researchers.
22. +? Definition of juvenile and mature wood.
23. ++ Industry's concerns are focussed on the current mature wood being harvested. The next generation of wood will have different properties, and bring with it different concerns.
24. + We need to be able to sell the research agenda for WQ to industry and govt, to gain their support – important for collaborating with FPInnovations. – or focus on end user needs maybe better.
25. + Training gap in many things re: stand productivity, wood quality and their relationships with forest management. Training of industry personnel; extension programs.
26. + Info on which WQA will provide the best bang for buck for industry for different value chains. Needs to be relatively inexpensive relative to the benefit in improved grade. – maybe not doable at present time
27. ++ Product grade change thresholds need to be addressed. Where do the plateaus / thresholds lie for different WQAs.
28. ? Gap: industry – current wood supply; future wood supply – closer link to provinces
29. Quality inventory of WQAs by Province
30. Better information on knot size, branchiness and its effect on lumber grades
31. Need to better understand which attributes the end users of the wood value. Would they be willing to pay more for lumber with specific attributes?
32. Need to diversify the species basket that is considered to ensure we capture the high-end value species (e.g. hardwoods, red alder, black walnut) where attributes have the greatest impact on value.

Themes

Decisions that need to be informed

Value proposition of attributes (identify grade threshold)

Data acquisition needs

- Standards for acquisition
- Definitions
- Inventory tools
- Acquisition of large volumes of good WQ data

Software development

- Data connectivity/compatibility/management
- DSS development

Communications and coordination of research and technology transfer efforts

- Between organisations, experts
- Connection with industry
- Training of personnel

Risk assessment

- Error estimations, uncertainty and sensitivity analysis of models
- Of decision-making

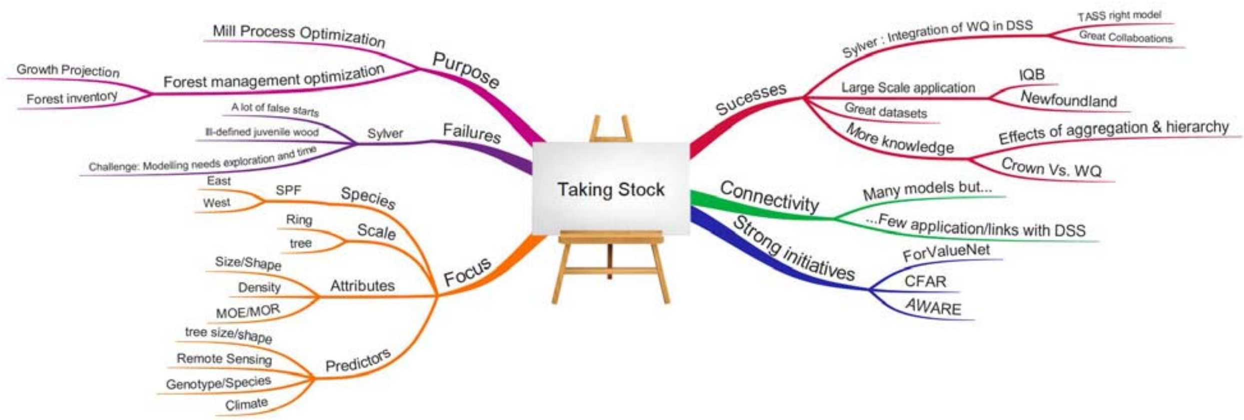
On-going model development

- Tree-level G&Y models
- Influences at all levels of hierarchy on fibre attributes

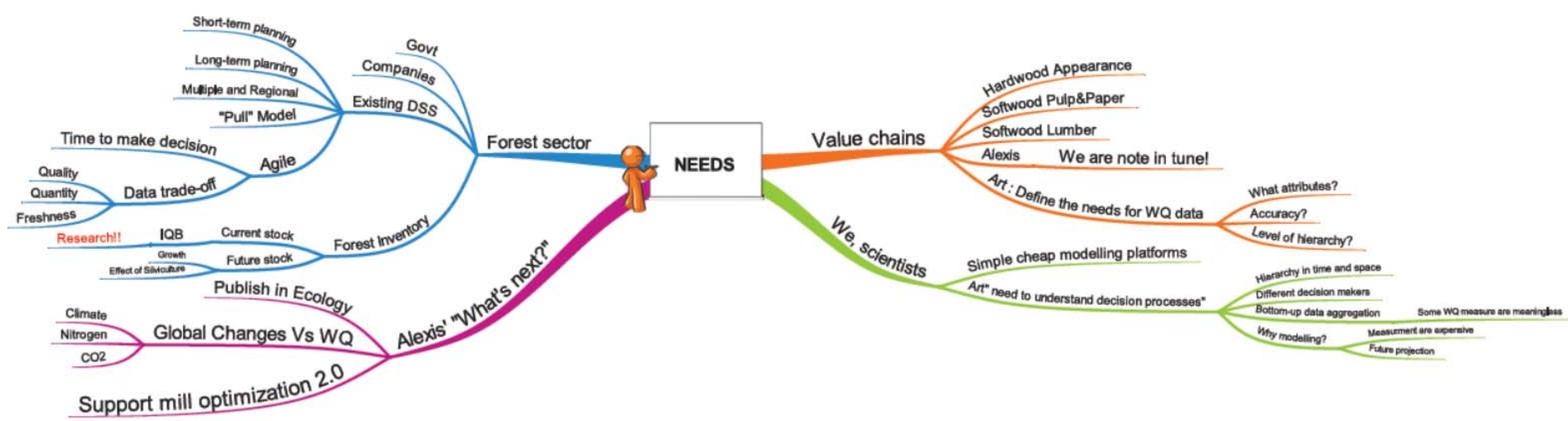
A9. Workshop outputs – Mind maps

These mind maps were drawn by Jean-Martin Lussier during presentations at the Workshop. They highlight the main ideas presented.

TAKING STOCK



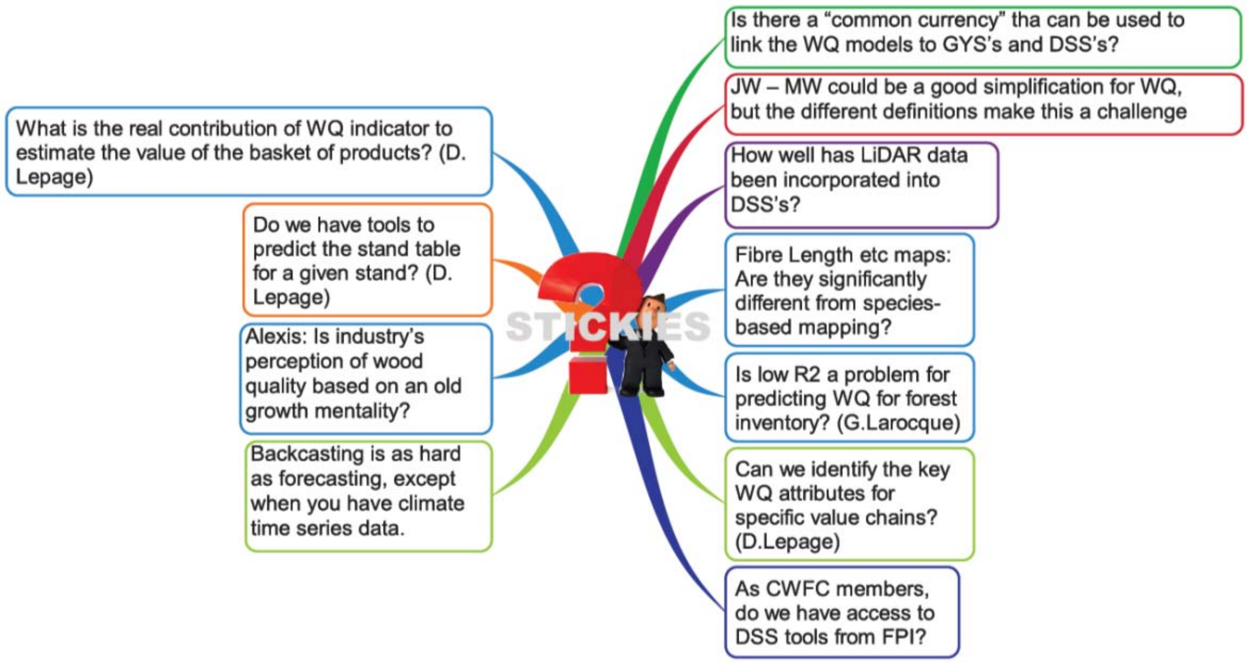
NEEDS



NEEDS
Forest sector
Govt
Companies
Existing DSS
Short-term planning
Long-term planning
Multiple and Regional
"Pull" Model
Agile
Time to make decision
Data trade-off
Quality
Quantity
Freshness
Forest Inventory
Current stock
Future stock
IQB
Research!!
Growth
Effect of Silviculture
Alexis' "What's next?"
Publish in Ecology
Global Changes Vs WQ
Climate
Nitrogen
CO2
Support mill optimization 2.0
Value chains
Hardwood Appearance
Softwood Pulp&Paper
Softwood Lumber
Alexis
We are note in tune!
Art : Define the needs for WQ data
What attributes?
Accuracy?
Level of hierarchy?
We, scientists
Simple cheap modelling platforms
Art" need to understand decision processes"
Hierarchy in time and space
Different decision makers
Bottom-up data aggregation
Why modelling?
Measurment are expensive
Future projection

A10. Workshop outputs – Stickies

These are concerns raised by some participants at the Workshop.



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