Forest inventory research at the Canadian Wood Fibre Centre: Notes from a research coordination workshop, June 3–4, 2009, Pointe Claire, QC

by Doug Pitt[1] and John Pineau[2]

ABSTRACT

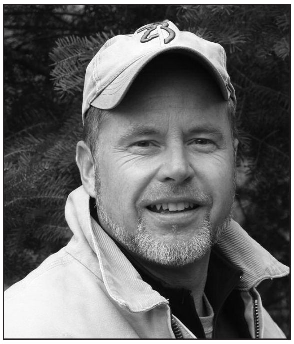
As part of its mandate to improve forest sector competitiveness, the Canadian Wood Fibre Centre (CWFC) has directed its research program towards the enhancement of forest inventory tools and systems to enable the spatial identification and forecasting of forest value. A June 2009 workshop attended by inventory researchers and provincial specialists from across the country reviewed current research needs and made recommendations for improvement of the CWFC-funded research program over the next 2- to 5-year period. Current efforts appear well positioned to improve stand-level inventory detail through cost-effective, semi-automated interpretation and quantification of tree species, size, and distribution. Means of incorporating specific attributes to better convey value, such as branch size and wood density, are being actively explored. More effort and resources are required to meet needs for better predictive models, sampling systems that incorporate data from a wide array of available sources, and proactive technology transfer and uptake of research results.

Key words: forest inventory, value chain optimization, fibre quality, LiDAR, multispectral digital imagery

RÉSUMÉ

Ayant pour mandat d’améliorer la compétitivité du secteur forestier, le Centre canadien de la fibre de bois (CCFB) a orienté son programme de recherche vers une amélioration des outils et systèmes d’inventaire forestier, de manière à ce qu’ils permettent de prédire et de caractériser spatialement la valeur des forêts. Un atelier tenu en juin 2009 a réuni des chercheurs et des spécialistes provinciaux de tous les coins du pays travaillant dans le domaine des inventaires forestiers. Cet atelier a permis de passer en revue les besoins actuels en matière de recherche et de formuler des recommandations visant à améliorer le programme de recherche financé par le CCFB pour les 2 à 5 prochaines années. Les efforts en cours semblent bien placés pour améliorer le niveau de détail des inventaires, à l’échelle du peuplement, au moyen d’outils d’interprétation et de quantification semi-informatisés et rentables, axés sur l’espèce, la taille et la répartition des arbres. On cherche activement des méthodes qui permettraient d’intégrer à ces systèmes certains attributs fournissant plus de précisions sur la valeur, comme la taille des branches et la densité du bois. Il faudra des efforts et des ressources supplémentaires pour pouvoir répondre aux besoins actuels suivants : meilleurs modèles de prédiction; systèmes d’échantillonnage permettant d’intégrer les données de sources très diverses; mesures proactives de transfert de technologie et d’exploitation des résultats de recherche.

Mots clés : inventaire forestier, optimisation de la chaine de valeur, qualité de la fibre, LiDAR, imagerie numérique multispectrale.



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Introduction

The mission of the Canadian Wood Fibre Centre (CWFC) is to create innovative knowledge that will allow the forest sector to expand economic benefits from Canadian wood fibre. The key intended outcome to which virtually all CWFC research is directed is Value Chain Optimization (MacKenzie and Bruemmer 2009, Stone 2009). In simple terms, this means knowing what fibre attributes are available or can be grown, where these attributes exist or can exist on the forest landbase, how to access or grow them with minimum cost, and how best to process them for maximum value. A sound forest inventory that focuses on both the quantity (volume) and quality (value) of specific attributes is an essential foundation upon which the

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process of value chain optimization must sit. It is also recognized that sound forest inventory is a prerequisite to sustainably managing Canada's forests in a manner that will convey a strong competitive advantage to the forest sector in the global marketplace. Accordingly, the enhancement of forest inventory tools and systems to enable the spatial identification and forecasting of value has become a priority research focus for the CWFC and one of 2 main project areas that encompass CWFC research (Fig. 1).

At a recent meeting of CWFC scientists and its Divisional Steering Committee members, the output for CWFC forest Inventory Tools research (Fig. 1) was defined as: High accuracy inventory systems that spatially quantify forest structure and related attributes to enable product segregation and resource value maximization. Nationally, there are 5 inventory-related research components that are either underway or being proposed with CWFC funding to deliver on this Inventory Tools output. In response to the need to ensure that these research components collectively represent a comprehensive national program that will offer regional delivery and relevance to the output, the CWFC hosted and facilitated a meeting of key players, June 3 to 4, 2009, at the FPInnovations – Paprican Division office in Pointe Claire, QC. The workshop was attended by lead researchers and collaborators involved in these CWFC research components, as well as provincial personnel with high-level involvement in forest inventory (Table 1). While it was recognized that considerable expertise resides with forest industry, inventory/remote sensing contractors, and service providers, the invitation list for the workshop was purposely limited to involve specialists with responsibility for provincial uptake of the research being conducted and proposed.

The objectives of the workshop were to:

(1) Enhance awareness and understanding amongst CWFC researchers, collaborators, and provincial inventory personnel about the CWFC's research program related to forest inventory.
(2) Establish, as a baseline, current inventory objectives, tools, and products used across Canada.
(3) Identify inventory research needs related to the CWFC's Inventory Tools output (Fig. 1).
(4) Cross-check the current CWFC inventory research program against the identified research needs.
(5) Establish a set of recommendations for ensuring that CWFC inventory research components are strategically aligned to make substantive progress towards output delivery over the next 2- to 5-year period.

Prior to the workshop, a questionnaire was circulated to each of the provinces as a means of establishing the current state of forest inventory across the country, and to identify future operational data and information needs. The workshop was structured so that the first half day offered presentations from each of the CWFC component leads, outlining current and planned CWFC-funded inventory research. Presentations highlighting linkages to the CWFC's Inventory Correlations output (Fig. 1) and the National Forest Inventory (NFI) were also made. The second full day consisted of a series of facilitated discussions addressing questions related to how well the current CWFC research program meets client needs from provincial perspectives, and what should be done to improve and strengthen it. This paper is offered as a synopsis of the presentations and discussion at this workshop.

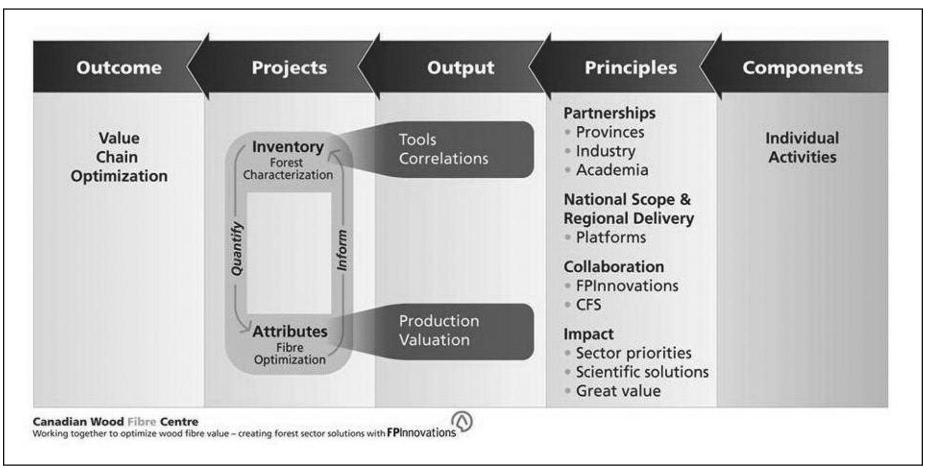

Fig. 1. Canadian Wood Fibre Centre research framework 2009–2011.

What is the Status Quo for Provincial Forest Inventories?

Questionnaire responses received from the Yukon (YK), British Columbia (BC), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), New Brunswick (NB), Nova Scotia (NS), and Newfoundland and Labrador (NL) were presented and discussed at the workshop. The following excerpts generalize the answers provided, as well as the ensuing discussion.

Current provincial inventories are designed to meet strategic needs for land-use and management planning. All are based on complete aerial photographic coverage of the areas of interest, with manual photo interpretation for polygon delineation and quantification. Several provinces scan their photographic images and conduct interpretation in a SoftCopy environment; only ON and QC currently capture their images in digital form. Each polygon is visually assessed and categorized in terms of broad species composition, site occupancy, and site productivity/ecosite. Stand height is measured by parallax and age is inferred from a combination of limited field sampling, available silvicultural records, and yield curves (based on stand height measured by parallax and interpreted site productivity). Volumetric information is also inferred from yield curves, with adjustments being made for species composition and site occupancy. Photo interpretation is augmented with combinations of permanent and temporary sample plots for calibration, quality control, and model construction. There are currently few measures of statistical precision for inventory estimates, and rigorous stand-level validation is generally rare. Not part of the management inventory per se, ground-based operational cruising (OPC) is

Table 1. List of workshop participants

Bossert, Elizabeth	Direction des inventaires forestiers Foret Quebec
Boyd, Jim	Manitoba Conservation
Coops, Nicholas	University of British Columbia
Côté, Jean-François	Sherbrooke University
Dick, Robert	New Brunswick Depatment of Natural Resources and Energy
Favreau, Jean	FERIC
Fournier, Richard	Sherbrooke University
Gillis, Mark	NFI; CFS-PFC
Gougeon, François	CFS-PFC
Groot, Art	CWFC-GLFC
Kapron, Joe	Ontario Ministry of Natural Resources, Forest resources Inventroy Program
Leckie, Don	CFS-PFC
Li, Chao	CWFC-NFC
Lindenas, Dave	Saskatchewan Ministry of the Environment, Forest Service
Luther, Joan	CFS-NL
Nader, Joseph	FERIC
Ouellet, Denis	CWFC-LFC
Patry, Anick	Direction des inventaires forestiers Foret Quebec
Pineau, John	CIF/CEC-FRP
Pitt, Doug	CWFC-GLFC
Stewart, Jim	CWFC-NFC
Stinson, Al	Ontario Minstry of Natural Resources / CEC-FRP
Townsend, Peter	Nova Scotia Department of Natural Resources
Treitz, Paul	Queens University
Ung, Chhun-Huor	CWFC-LFC
Whitehead, Roger	CWFC-PFC
Woods, Murray	Ontario Ministry of Natural Resources, Southern Science and Information Section
Regrets:	
Beaudoin, André	CFS-LFC
Hall, Ron	CFS-NFC
MacQuarrie, Kate	Prince Edward Island Environment, Energy, and Forestry
Morgan, Dave	Alberta Sustainable Resource Development
Pittman, Boyd	Newfoundland Department of Natural Resources
Price, Kirk	Yukon Energy Mines and Resources, Forest Management Branch
Smith, Lisa	North West Territories Department of Resources, Wildlife and Economic Dev.
Wulder, Mike	CFS-PFC
Yuan, Xiaoping	British Columbia Ministry of Forests and Range

CEC = Canadian Ecology Centre; CFS = Canadian Forest Service; CFS-NL = Canadian Forest Service in Newfoundland and Labrador; CIF = Canadian Institute of Forestry; CWFC = Canadian Wood Fibre Centre; FRP = Forestry Research Partnership; GLFC = Great Lakes Forestry Centre; LFC = Laurentian Forestry Centre; NFC = Northern Foresry Centre; PFC = Pacific Forestry Centre

used in some jurisdictions for refinement of stand-level information and more detailed determinations of species composition, volume, age, stand structure, stand condition, product availability, and site conditions required for optimization of road construction, harvesting and processing. Disturbance updates are generally done within a 1- to 5-year cycle, depending on the nature of the disturbance, using satellite imagery, supplemental aerial photography, GPS data from silvicultural equipment, or a combination thereof. Most provinces aim for an inventory refresh cycle of 10 years; few are meeting this target, with some approaching 30-year cycles, or not specifying refresh targets at all. The production cycle for an inventory is 2 to 5 years. Production costs appear to be in the vicinity of $1.50/ha (exclusive of OPC and updates).

Provincial models driven by the inventory data are used for sustainability modeling, including allowable harvest calculations, wildlife habitat, diversity, carbon accounting, and non-timber values. Most existing models are aspatial (e.g., Sustainable Forest Management Model [SFMM], Woodstock) in nature, despite the ultimate need for spatially explicit inputs and solutions for implementation (e.g., no-harvest wildlife habitat areas, specific harvesting allocations, landscape-scale targets). As a result, several provinces are now exploring the use of spatial models (e.g., Patchworks, Stanley).

Current strategic or forest-level demands are largely being met with existing inventories and the traditional approaches being used in their generation. Most feel that forest-level accuracy is high, although none of the provinces have any valid basis for quantifying inventory accuracy. However, all provinces note an increasing tendency by forest users to infer operational-level data from the strategic inventories—data these inventories were never designed to provide (e.g., more detailed stand-level data for operations optimization, spatial modeling, knowledge of products/value). Some provinces noted increasing difficulty in continuing to deliver the status quo strategic inventories due to shrinking budgets and increasing scarcity of trained/qualified photo interpreters.

Changing demands for inventory data over the next 2 to 5 years were identified consistently across provinces. All expect increasing demands for more tree- and stand-level detail and cite emerging emphasis on factors such as biomass, carbon, forest health, extreme pest activity, management by ecosite, silvicultural effectiveness monitoring, climate change, new markets, specialty markets, and non-timber values as drivers for this increased demand. The need for "increased quantitative and spatial accuracy, faster, and cheaper" was commonly expressed. Some explicitly identified the need to quantify value and product potential in future inventories, as well as the need to make inventory data more publicly available through the internet. A few provinces noted the need to conduct better silvicultural effectiveness monitoring (SEM) and the need to better integrate descriptive data for young, regenerating stands within the overall inventory.

Provincial involvement in inventory research tends to be limited to collaboration with the federal government and/or universities. Awareness and understanding of related research tends to be localized or regionalized. Some provinces expressed concern that current/past research does not address the problem of capturing conventional data at reduced cost and tends to shy away from quantifying the complex stand structures that are seen as an operational reality in many jurisdictions.

The "ideal inventory system" was described as being "fully automated, digital, multispectral, providing tree, stand, and forest-level detail with high quantitative and spatial accuracy and precision, updated on a near continuous basis, available on the desktop—all archived without the use of contractors, for $1.00/ha or less." Accurate, high-resolution digital elevation and canopy height models were seen as important components of the ideal system, as were flexible rules/definitions to accommodate changing merchandizing standards.

What do Provincial Clients See as Inventory Research Needs/Priorities?

In many ways, the above definition of the ideal inventory system captures what forest professionals and practitioners tend to feel are the priority research areas. These can be broadly categorized as increasing inventory quality and reducing inventory cost, so that we can ultimately improve inventory value.

Increasing inventory quality

The need to increase tree- and stand-level information and detail was referenced widely by all workshop participants. As mentioned above, emerging emphasis on themes such as biomass, carbon, forest health, management by ecosite, silvicultural effectiveness, climate change, new markets, specialty markets, and non-timber values are undisputed drivers for this increased demand for detail. It was widely acknowledged that we need spatially specific tree and stand attributes that include measures or indicators of fibre quality, product value, and site quality, along with species-specific volume, biomass, diameter/height distribution, and cover. In addition, increasing prevalence in the use of spatial models is placing a serious strain on existing inventory data that were never intended to support such models and generally lack the necessary stand-level detail and accuracy. Attached to increased quantitative and spatial accuracy, are demands for estimates of statistical confidence and precision. Simply quantifying the accuracy of existing inventories was cited as a research need, since we currently have little baseline data for the comparison of advancements.

There is also a need for better predictive models, both for extrapolation (i.e., the spatial extension of existing knowledge to similar areas), and forecasting (i.e., the temporal projection of inventory parameters to extend the life of inventory data). For both of these forms of prediction, there is a need to better enable the incorporation of existing data (e.g., StanForD-compatible *.STM files from harvesters [that record individual tree species, taper profiles, and log product dimensions], scaling data, growth and yield [G and Y] data, NFI data, and historical data) to strengthen predictions. Similarly, practical sampling systems are needed to incorporate different scales of remotely sensed data and ground information (e.g., multiphase sampling that incorporates satellite, low-level photography, and ground sampling), particularly for dealing with more complex stand structures. All cited the need to move research into the operational realm before calling a project "completed."

Lowering inventory costs

The need to "produce increased quantitative and spatial accuracy, faster, and cheaper" was emphasized by all provincial participants. Many felt that there should be more research emphasis placed on simply producing traditional inventory data at less cost. The fact that few forestry schools are still teaching classical photo interpretation was cited as a reason for a declining population of photo interpreters across the country, and a potential limitation to maintaining the status quo. Such shortages of qualified interpreters, coupled with the need to reduce costs, increase objectivity, and conduct more frequent updates, emphasize the need for automation to streamline the inventory production process. While it is recognized that human intervention in the inventory production process will never be eliminated, it appears that automation may have a place in several phases, including image processing, interpretation of both tree species and site conditions, and polygon delineation. There is a need to "package" inventory tools for increased user uptake and application. Similarly, there is a need to make inventory data more available to users and the general public; the NFI Web site (https://nfi.nfis.org) was applauded as a good example of what should be aspired to in terms of public accessibility.

Increasing inventory value

Perhaps the greatest research need and challenge lies in sound cost–benefit analyses for enhanced inventories; i.e., addressing the question what is the "value" of having a good inventory? An enhanced inventory may very likely cost more than a conventional inventory, but the power it conveys to better decision-making, more efficient operations, and an ability to maximize resource value may far outweigh any increased costs. There is a need to ensure that value-added opportunities associated with the new technologies are being sufficiently identified, transferred, and accounted for in cost–benefit analyses (e.g., high-resolution digital elevation models [DEMs], structural data, landform, and water data have high value to other users). Thus, the concept of sharing costs and benefits among government agencies, businesses, and other users should be fully explored. Some stressed the need for research that might enable the extraction of more information from the existing remote sensing tools being used (e.g., the Leica ADS40 imagery used in ON).

What is The Status of CWFC Research (Ongoing and Planned)?

There are currently 5 Inventory Tools (Fig. 1) research components that are either planned or ongoing with CWFC funding. These components are, or should be, strongly linked to a sixth component that is exploring relationships between inventory and fibre attributes (Inventory Correlations, Fig. 1), and should be linked to the NFI. Half-hour slide presentations were delivered by project leads in each of these areas. Our summary and interpretation of these presentations follows.

Alberta: Roger Whitehead (CWFC – Pacific Forestry Centre [PFC]) and Jim Stewart (CWFC –Northern Forestry Centre [NFC])

Weldwood Canada, Hinton AB operations, initiated a large study of the effects of stand age and site on lodgepole pine and spruce wood quality in 2001. Research objectives of this original study included the integration of findings into Weldwood's planning system, to improve log allocation for sawmills and forecast the quality of residual chips for pulping. More than 540 trees were selected across 54 stands in 2 Forest Management Agreements (FMAs), with samples subjected to the Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Silviscan and Paprican's Fibre Quality Analyser. Wood quality variables such as fibre length, coarseness, density, log shape, knots, compression wood, and interior defect were related to potential predictive variables including site quality, stand age and density, tree size, crown class, branch size, height to live crown, crown diameter, and visible defect. Following the development of predictive models, and a subsequent change in company ownership (to West Fraser Timber), the project was suspended. More recently, Alberta Sustainable Resource Development (ASRD) acquired full airborne LiDAR (A-LiDAR) coverage (1 pt/m^2) of Alberta's Foothills region, including all of the above-sampled stands. Whitehead and Stewart are currently working with specialists from the CFS-PFC (Mike Wulder) and University of British Columbia (UBC; Nicholas Coops) to develop partnerships with West Fraser and ASRD to: 1) evaluate LiDAR-derived estimates of stand parameters as predictors of fibre quality in large-scale inventories, and 2) improve stand descriptions to allow the addition of biomass estimates and carbon stocks to inventory. Long-term research installations in the Foothills region and BC interior are being proposed as validation sites.

Given the rather large existing data set (wood quality attributes—tree/stand/site relationships and A-LiDAR), the proposed work has strong potential to make significant and immediate contributions to the Correlation output (Fig. 1), advancements in the use of A-LiDAR for the description of vertical and horizontal structure as they relate to product potential and value, model refinements for the prediction of wood quality (e.g., with Tree and Stand Simulator [TASS]), and DSS enhancements for optimizing value (e.g., Silviculture, Yield, Lumber, Value, Economic Return [SYLVER]). Collaborators in the full research effort being proposed would include West Fraser Timber, Tembec, Foothills Growth and Yield Association, ASRD, UBC, British Columbia Ministry of Forests and Range (BCMoFR), CFS-PFC, and FPInnovations (Paprican, Forintek, and FERIC Divisions).

Manitoba: Chao Li (CWFC-NFC)

Li presented his ideas for models aimed at adding value attributes to existing forest inventories. He described a modeling framework that will use inventory data to predict the potential value of various end products (e.g., lumber, panels, OSB, pulp and paper, biomass, carbon, etc.) as inputs to a DSS that will conduct economic, cost–benefit analyses. Data have been acquired from various sources and sites from BC and model development and testing are underway. While this effort may serve the prediction aspects of the Inventory Tools output, it appears to have a good fit within requirements of the Valuation output (Fig. 1). Collaborations are under way for data sharing and modeling with CFS Fire and Carbon projects, Manitoba Conservation, ASRD, BCMoFR, Saskatchewan Environment and Resource Management (SERM), Tembec, Simon Fraser University Department of Biological Sciences, and UBC.

Ontario: Murray Woods (OMNR), Don Leckie (CFS-PFC), François Gougeon (CFS-PFC), Paul Treitz (Queen's University), Al Stinson (OMNR/CEC-FRP), and Doug Pitt (CWFC)

Through very successful engagement with the Canadian Ecology Centre – Forestry Research Partnership (CEC-FRP), the Advanced Forest Resource Inventory Technologies (AFRIT-ON) component is a well-established, ongoing research program that is now in its third year of CWFC funding. The component is well aligned with the CWFC's Inventory Tools output (Fig. 1) in that it aims to develop applications that will support and contribute to value chain optimization. To date, the component has made tangible progress towards operational implementation of A-LiDAR and semi-automated image interpretation of multi-spectral imagery for the purposes of adding tree and/or stand-level detail to existing inventories of a range of forest types. Results have demonstrated the potential for delivering more objective and accurate spatial quantifications of species composition, tree size and size distribution, horizontal and vertical structure, and biomass/volume than obtained through conventional manual interpretation in a Forest Resource Inventory (FRI) context. Either SoftCopy manual image interpretation or semi-automated computer interpretation, which isolates and predicts the species of tree crowns (ITCs), are used to stratify polygons and allow more accurate application of A-LiDAR-based predictions of stand attributes. Woods stated that during its first 2 years, the component research has determined that acceptable precision for the prediction of stand height, volume, basal area, density, quadratic mean DBH, and biomass can be achieved with low density A-LiDAR

(0.5 pt/m^2), and that increasing point density (and cost) does not appreciably increase stand-level estimation precision. While current emphasis is on enhancing stand-level accuracy, ongoing enhancements to ITC software are enabling better tree crown segmentation, which should lead to the ability to characterize and quantify individual trees, ultimately enabling the production of an inventory that uses the tree as its smallest unit of resolution.

Through collaboration with Queens University, this component is also exploring the role of multi-spectral imagery and A-LiDAR in generating data that will feed predictive ecosite models. This work is currently only being applied to the Petawawa Research Forest as a pilot project, but could pave the way for more much-needed research in this area. Collaboration with the Inventory Correlations output (Fig. 1) and proposed integration with FPInnovations – FERIC Division's FPInterface software foreshadow real potential for AFRIT-ON research to facilitate the mapping of fibre attributes and value, within a cost framework that is not substantially greater than that of Ontario's current FRI. Woods said that the component is poised in its third and fourth year to apply and demonstrate application of the new methodologies in an operational setting.

The AFRIT-ON component is linked to and feeding procedures and applications to the Eastern Hardwood Initiative and to the inventory research component that is currently being initiated in Newfoundland. FPInnovations – Paprican and Forintek Divisions are involved to a limited extent where detailed fibre attribute data are available for ground-truth data sets being used in the study. FPInnovations – FERIC Division will be involved in the evaluation of FPInterface predictions from enhanced inventory data. The component leverages significant resources from the Ontario Ministry of Natural Resources (OMNR), Tembec, Ontario Centres of Excellence, CFS-PFC, and Queen's University.

Quebec: Chhun-Huor Ung (CWFC – Laurentian Forestry Centre [LFC]), Richard Fournier (Sherbrooke University), Anick Patry (Ministère des Ressources naturelles et de la Faune du Québec [MRNF-QC]), and Andre Beaudoin (CFS-LFC)

The Enhanced Forest Inventory (EFI-QC) component is another established, ongoing research component that is now in its second year of CWFC funding. Like AFRIT-ON, the component is well aligned with the CWFC's Inventory Tools output (Fig. 1) in that it aims to develop applications that will support and contribute to value chain optimization. While the end goals of EFI-QC appear to be similar to AFRIT-ON's, some of the tools and approaches being used are quite different. For example, terrestrial LiDAR (T-LiDAR) is being used in this component to quantify individual tree geometry and architecture (taper, deformities, branchiness) and relate these aspects to fibre and product attributes. A-LiDAR and digital aerial photographs are being used at the pixel scale for calibrating spatially explicit prediction models of forest stand attributes. Stand delineation and quantification are being conducted through post-stratification and the K-Nearest Neighbours (K-NN) approach that uses ground-truth information to identify and characterize adjacent sampling units (pixels) that have similar stand structure characteristics. Regardless, both QC and ON components are striving to develop statistical relationships between A-LiDAR stand structure and fibre quality attributes so that these may be mapped. Ultimately, the best approach may consist of a mix of the QC and ON approaches.

Ung said that EFI-QC is linked with and feeding procedures and applications to the Eastern Hardwood Initiative. The component involves the active participation of end-users and leverages resources from MRNF-QC and from FQRNT (Fonds québécois de la recherche sur la nature et les technologies) (2009–2012), and involves Université Laval, UQAM (Université du Québec à Montréal), Sherbrooke University, and CFS-LFC. FPInnovations – Forintek Division is involved in linking T-LiDAR data to Optitek sawmill optimization software, and FPInnovations – FERIC Division will test enhanced inventory data with FPInterface harvest planning software.

Newfoundland: Joan Luther (CFS – Atlantic Forestry Centre [AFC]), Richard Fournier (Sherbrooke University), and Jean-François Côté (Sherbrooke University)

Luther described a new initiative that is currently being launched in Newfoundland, aimed at mapping fibre properties from forest inventory and environmental variables. For the boreal forests that dominate the island, this component aims to 1) quantify relationships among available forest, environmental, and fibre attributes at tree, stand, and forest levels; 2) enhance measurement of forest structure at tree and stand scales to improve fibre attribute predictions; and 3) improve mapping of forest attributes at landscape scales using enhanced databases of fibre properties. The component will achieve these 3 objectives in an incremental fashion by starting with available inventory data to seek ecological relationships between existing inventory parameters and fibre attributes (Phase I), testing new technologies (e.g., A- and T-LiDAR) for their ability to improve these relationships (Phase II), and then exploring means of enhancing the spatial prediction of key attributes through new sampling "scaling-up" strategies and data bases/models for enhanced forest management planning (Phase III). An extensive network of PSPs, currently being measured by the province and augmented with fibre-attribute data, will serve as the fundamental unit for model development and validation in the study.

This component builds on an extensive partnership surrounding an Atlantic Innovation Fund Initiative led by Corner Brook Pulp and Paper (CBPP, 2008–2011), which is designed to maintain and increase competitiveness of the Newfoundland and Labrador forest industry by making better use of wood and fibre resources. Under this initiative, samples collected by the province during their routine inventory sampling are being analyzed by FPInnovations – Paprican Division for fibre attributes, including wood density, modulus of elasticity (MOE), fibre length, coarseness, and cross-sectional dimensions, MFA, and decay content. FPInnovations will determine what fibre properties are of industrial significance to CBPP. These properties will be linked to the site information provided by the province in order to aid the mill in planning activities.

The NL component will expand on these results using enhanced geospatial technologies to develop new and improved methods for mapping fibre attributes of forest stands. Through an extended partnership effort with the

Sherbrooke University, Sir Wilfred Grenfell College, Newfoundland and Labrador Department of Natural Resources, Atlantic Canada Opportunities Agency and FPInnovations – Paprican Division, terrestrial and airborne LiDAR, combined with high-resolution optical imagery, will be used to supplement traditional measurements from ground inventory and supply a new series of structural metrics. These enhanced datasets will be the base from which new models and mapping capabilities for wood and fibre properties will be developed.

The NL component has strong linkages with the Correlations output (Fig. 1) and the EFI-QC component through work relating wood and fibre attributes crown measures and T-LiDAR-based tree architectural models, respectively. The component is connected to AFRIT-ON in the use of semi-automated interpretation (ITC) on optical imagery and the use of A-LiDAR for the quantification of vertical and horizontal stand structure. It is further linked with FPInnovations – Paprican Division linking wood and fibre attributes to pulp and paper quality. The NL component is thus well positioned to incorporate and apply approaches and results from Paprican and the ON and QC initiatives to support optimal utilization of fibre resources in NL.

Linkages: Inventory Correlations output, Art Groot (CWFC–Great Lakes Forestry Centre [GLFC])

Groot gave a thorough overview of the Inventory Correlations output, emphasizing the critical role that this output plays in concert with the Inventory Tools output to deliver the overall Inventory project outcomes (Fig. 1). Augmenting existing inventory data with fibre attribute information is important for strategic wood supply planning and marketing, operational or tactical planning, and wood allocation, harvest scheduling, and product segregation. Ultimately, the landowner is the only party with an interest in creating value in the forest and thus is the party that bears responsibility for inventorying value. The broad attributes felt to convey value include species, size (DBH, height), taper, defect, and site, with more product-specific attributes that include branchiness, wood density, cell-wall thickness, and MFA.

Groot identified 2 general approaches that may be taken to adding fibre attribute data to the inventory. The first involves establishing statistical relationships between data collected in the inventory at the forest or stand scales (including forest or stand descriptors, remotely sensed data, and site information) and the fibre quality attributes of interest. The AB, ON, QC, and NL inventory components are or will be using this approach to varying degrees. The second approach is to more directly establish functionally or structurally based statistical relationships between individual tree measures that are undertaken in an enhanced inventory and the fibre quality attributes themselves, so that value information may be rolled up to different scales from the individual tree level. For example, remote sensing tools are quickly evolving to support the resolution of individual tree crowns, allowing us to accurately identify species, measure crown diameter or area, and tree and crown height. This second approach therefore involves relating these individual tree measures to the fibre attributes of interest so that these may be predicted and mapped across areas of interest. Developing these relationships is the goal of the Inventory Correlations output, largely driven by the Crown–Fibre Attribute Relationships (CFAR) component.

There are currently 14 hypotheses being tested under the CFAR component using data from silvicultural experiments across Canada. The partnership for this work is broad, involving CWFC researchers across the country, as well as FPInnovations – Paprican and Forintek Divisions, industry (Tembec and Corner Brook Pulp and Paper), and several universities (UQAM, University of Toronto, UBC, and Nipissing University). Inventory Tools components in AB, ON, QC, and NL are involved heavily in this work, both in feeding data to the construction and validation of these relationships, and applying these relationships in an inventory context. It is likely that a combination of the stand/forest level and individual tree-level approaches will ultimately be used to ascribe various fibre attributes to forest inventories of the future.

Linkages: National Forest Inventory, Mark Gillis (CFS-PFC)

The National Forest Inventory (NFI) consists of an extensive network of photo and ground samples drawn from a systematic 20 km × 20 km grid across the entire country. At each grid point intersection resides a 2 km × 2 km photographic plot, amounting to a total of 18 950 plots across the country. From the grid-point intersections that exist in forested conditions, a random subset are sampled on the ground using circular, nested plots for quantifying large trees (400 m^2), ecological characteristics (400 m^2), small trees (50 m^2), woody debris (2 transects), ground vegetation (4 × 1 m^2), and soils (1 pit). A total of 1150 of these ground plots exist, with a minimum of 50 in each of Canada's ecozones. Data are collected under a common set of standards according to a national monitoring framework. Growth data from increment cores have been archived and are available for anyone to use. All NFI data are available on a user-friendly interface at https://nfi.nfis.org that permits individual plot data to be downloaded or collated and summarized in a multitude of different ways.

Gillis stated that NFI's goal is to maintain a 10-year remeasurement cycle, with a 5-year reporting cycle based on statistical estimates of change. Like any undertaking this size, sustainability is a serious issue in the face of increasing pressure to reduce budgets. There are several opportunities for CWFC research efforts to partner with NFI for mutual benefit. For example, semi-automated image interpretation research results could make NFI photo plot updates more effective and cost-efficient. There are also opportunities for data and model-sharing between NFI partners and CWFC researchers. Gillis suggested that the NFI Web site could be an ideal platform for rolling out fibre attribute and product value data. There exists good provincial buy-in, involvement, and participation in NFI that might be used to foster technology transfer and uptake of CWFC research.

How Well is the CWFC Doing?

The general consensus of the group was that the CWFC-funded research components collectively contain the building blocks of a comprehensive national research program that appears poised to offer sound regional delivery. Some comments that were conveyed in discussions at the workshop include:

- “There seems to be good cooperation and collaboration between FPI, CWFC, CFS, and the provinces.”
- “Most of the right players appear to be engaged.”
- “The existing program seems to consist of complementary research with surprisingly little duplication/redundancy and strong potential to improve our understanding. Any duplication that exists involves testing in different forest types, and the provision of ‘replication’ in the experimental sense.”
- “There is good work going on in Ontario and Quebec that is being synthesised and applied in Newfoundland—this latter component is, in many ways, an semi-operational extension of the ON and QC research, with many of the same players involved.” While regionally focussed, each of the components offer national applicability.
- “There appears to be adequate focus on the correct technologies and tools, including A-LiDAR, T-LiDAR, ITC, and semi-automated polygon interpretation and delineation.”
- “The program seems to be doing a good job of building on existing inventory data and systems (things that we’ve spent a lot of money on already).”
- “There appears to be good movement towards operational implementation.”
- “The direct inventory side is covered fairly well, but the program may be weak on the predictive side.”

In general, the existing CWFC research program appears to have direct forest inventory research needs fairly well addressed (Table 2). The overall research thrust reflects the CWFC’s goal of enhancing abilities to map value, with 5 of the 6 research components directly focusing on increased tree- and stand-level detail for key attributes that are known to contribute substantively to this objective: species, tree size and size distribution, horizontal distribution (site occupancy), and site quality. These enhancements are largely being driven through the use of multispectral optical imagery and A-LiDAR. All of the research components are or will be delving deeper into adding more specific fibre quality attributes to the inventory, such as branch size and distribution, bole taper, wood density, and MFA, through component-specific evaluations and linkages with the Inventory Correlations output (Fig. 1). For these fibre quality attributes, a combination of approaches is being used, including the establishment of relationships driven by individual crown measures derived from multispectral imagery and A-LiDAR, tree geometry assessed

Table 2. Research needs versus the degree to which each are addressed by CWFC-funded Components. (AB, MB, ON, QC, and NL are the Components being led out of Alberta, Manitoba, Ontario, Quebec, and Newfoundland, respectively; Corr references the Inventory Correlations Output).

Research needs	AB	MB	ON	QC	NL	Corr
Produce existing data faster, cheaper	Red	Red	Green	Green	Green	Red
Extract more information from existing inventory/remote sensing	Blue	Green	Blue	Green	Green	Green
Increase tree- and stand-level detail on:						
Species	Green	Yellow	Green	Green	Green	Green
Diameter distribution	Green	Yellow	Green	Green	Green	Green
Height distribution	Green	Yellow	Green	Green	Green	Green
Horizontal distribution	Green	Yellow	Green	Green	Green	Green
Site/ecosite	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Specific attributes of fibre quality	Green	Green	Green	Green	Green	Green
Inventory of young/regenerating stands; SEM	Red	Blue	Blue	Blue	Blue	Blue
Statistical confidence of estimates	Green	Red	Green	Green	Green	Green
Quantify existing inventory accuracy	Yellow	Yellow	Blue	Yellow	Yellow	Red
Develop predictive models for:						
Spatial extrapolation	Yellow	Yellow	Green	Green	Green	Yellow
Predicting ecosite	Blue	Red	Yellow	Yellow	Red	Red
Forecasting through time	Blue	Blue	Red	Blue	Red	Red
Systems to incorporate existing data	Red	Red	Red	Red	Red	Red
Practical sampling systems	Yellow	Blue	Yellow	Yellow	Yellow	Red
Automation of:						
Image processing	Red	Red	Green	Yellow	Yellow	Red
Interpretation of species	Red	Red	Green	Blue	Yellow	Red
Interpretation of site	Red	Red	Green	Blue	Yellow	Red
Polygon delineation	Red	Red	Green	Blue	Yellow	Red
“Package” applications / create “tool kits”	Red	Yellow	Green	Yellow	Blue	Red
Identification of value-added opportunities	Red	Red	Yellow	Yellow	Yellow	Red
Operational extension/application	Blue	Blue	Green	Green	Blue	Blue
Web based availability	Red	Red	Yellow	Yellow	Red	Red
Cost-benefit analyses	Blue	Blue	Blue	Blue	Blue	Blue

Green: Being addressed directly by research
Yellow: Being addressed indirectly/in part by research
Blue: Potential to be addressed with additional resources
Red: Currently not being addressed – potential research gap

from T-LiDAR, and multivariate statistical relationships based on a variety of inventory parameters. Inherent in this work is the development of models for the spatial extrapolation of these relationships over broader forest areas through one or more forms of remote sensing within a sampling design framework.

Also fairly well addressed is the need for inventory automation. The AFRIT-ON component is focussed on increasing automation in image processing, species interpretation, and polygon delineation. This work is largely being driven through ITC classification of multispectral optical imagery. The addition of A-LiDAR data (canopy height model) to spectral-based ITC is enhancing individual tree crown segmentation and ground masking. The EFI-QC approach allows operational extrapolation of ground-based data and knowledge to areas lacking such data through the K-NN approach and is currently being tested in operational deployment. While these components are directed at similar objectives, the different approaches being taken are complementary and may ultimately suggest synergy through integration; the NL component, which will employ methodologies from both the ON and QC components, may serve as a testing ground for such integration. Across the components, a variety of different Canadian forest types are being examined, with the boreal being a common thread. As well, these new methodologies should all produce estimates that are associated with measures of statistical precision. Elements of the AFRIT-ON and EFI-QC components are focused on "packaging" tools for easy uptake and application by potential users (e.g., A-LiDAR Processing Tool Box). Given CWFC objectives, experts around the table felt that the research components were currently engaging the best-bet technologies (i.e., optical multi-spectral imagery, A-LiDAR, and T-LiDAR) and not ignoring any of the emerging tools such as RadarSat and IFSAR that are being touted for other applications.

As by-products of the research, efforts in ON, QC, and NL, have strong potential to more efficiently produce conventional inventory data. Components in MB, QC, NL, and in the Inventory Correlations output, will undoubtedly reveal means of predicting variables of interest with existing inventory data. Efforts in ON, QC, and NL will also identify and quantify value-added opportunities associated with the systems and tools being researched, such as accurate DEMs, hydrology and wetland features, and surficial geology.

All of the research components offer potential for wider spatial extrapolation and application that undoubtedly will be tested as the research matures. For example, AFRIT-ON is poised to deliver and validate an operational scale-up of an A-LiDAR-based inventory for 650 000 ha in the Romeo Malette Forest in 2010 and EFI-QC has moved towards testing operational application of the KNN methodology in QC. However, the existing research program is generally weak on the predictive modeling side, particularly in terms of predictive ecosite modeling and forecast modeling. It is fairly well known that site quality has a major influence on wood quality and, while most of the components are exploring site–wood value relationships to some extent, none are directly tackling the issue of predicting ecosite from inventory data on a large scale. A small project being conducted by Queens University is exploring ecosite prediction from multispectral imagery and A-LiDAR on the Petawawa Research Forest, and will hopefully serve as a catalyst for more work in this area. In addition, few of the current research efforts are directed at the forecasting of inventory data, an aspect that the provinces view as important for extending the life of their inventories and, thus, lowering costs. Arguably, such modeling efforts may best be applied once the "enhanced inventory" is defined, since the appropriate variables and data upon which the models should be built are somewhat unknown currently. Similarly, none of the research components are directed at developing systems for incorporating existing and historical data into predictive models and the inventory itself (e.g., StanForD-compatible *.STM files from harvesters, and scaling, G and Y, and NFI data). Issues surrounding the proprietary nature of some of these data may need to be resolved. The development of efficient sampling designs to better use existing inventory data and/or incorporate enhanced data will be addressed on a component-specific basis, although few of the components are currently explicitly addressing this need. In the EFI-QC component, the KNN method is being used as a fundamental basis for incorporating existing data, and may open the door to more work in this area. Like forecast modeling, in-depth research directed at sampling and sample design may naturally follow the development of enhanced tools. None of the research components are specifically addressing the inventory of young regenerating stands, or the issue of tackling SEM through remote sensing, and few are directly addressing the issue of quantifying the accuracy of existing inventory data as a baseline for comparison.

All of the existing research components are considering the operational extension of the systems and tools being researched; however, it is likely that the cost of this research extension is larger than the CWFC alone can bear, requiring increased collaboration and participation from the provinces when this work takes place. Likewise, all of the components are planning to undertake cost–benefit analyses; however, manpower and expertise may be required from outside the CWFC to properly address this work. Although AFRIT-ON and EFI-QC will test web-portals for viewing inventory data, none of the components are poised to deliver web-based inventory products, a need that the provinces are arguably in the best position to address.

Recommendations for Moving Forward

It is evident that the planning sessions that the CWFC has engaged in over the last 3 years, coupled with provincial/industry consultation sessions and input from the Divisional Steering Committee, have helped to align existing research components with forest inventory research needs. The current research program is well positioned to add value to existing inventory data by increasing tree- and stand-level detail that will not only facilitate better strategic and operational forest planning, but support an ability to map product potential and value, thereby facilitating value-chain optimization. During the next 2-year period, the research program should measurably contribute to inventory tool and system enhancements that will permit semi-automated interpretation and quantification of tree species, size and size distribution, horizontal distribution (site occupancy), and site quality. Operational extension and implementation of these enhancements should be feasible over the next 5-year period. The capability to map more specific fibre quality attributes, such as branch size and distribution, bole taper, wood density, and MFA. should also be well tested over this same period. To help ensure that these targets are met, the following recommendations stem from workshop discussions:

(1) There is a need for better and continued communication between research components to insure data-collection and analyses compatibility and enable the sharing of methods, models, and results. NFI may offer sound base standards to which all components should comply.

(2) Through this workshop, an important step has been taken to engage the provinces in the design and execution of the research that we are conducting. We should similarly be communicating and linking with other groups that have industrial links (e.g., Western Boreal Growth and Yield Cooperative [WESBOGY]; Foothills Growth and Yield Association; Mixedwood Management Association; Forest Ecosystem Science Cooperative; bioenergy/biomass groups; Centres of Excellence; CEC-FRP; K-NN Working Group) and to forest industry directly, including service providers and operational inventory personnel. For maximum data sharing, buy-in, and uptake, geographic alliances (e.g., boreal, Great Lakes – St. Lawrence, western coastal) may be better than strict provincial groups. The potential for non-traditional partners should also be recognized and further explored (e.g., hydro-electric, transportation, mining, and parks).

(3) There is a need to insure that we are building on the research that is being done elsewhere in the CFS. It was recommended that Don Leckie and Mark Gillis update their state-of-inventory synthesis document (Gillis and Leckie 1993).

(4) Technology-transfer resources should be proactively brought to bear on some or all of the inventory research components to facilitate and enable thorough and effective transfer and uptake of research results. Key decision and policy makers in both government and industry should be recognized as a primary audience for transfer activities.

The following recommendations are made to address outstanding research gaps:

(1) Following the first 2-year evaluation phase of direct inventory research, more resources need to be applied to the prediction aspects of forest inventory, including both predictive ecosite and forecast modeling. For the former, existing tools such as "SOLIM" (http://solim.geography.wisc.edu/) and the work of Danijela Puric-Mladenovic (OMNR) (Puric-Mladenovic, D., J. Buck, D. Bradley, R. Arends and S. Strobl 2008) should be considered. Modeling efforts may require the CWFC to engage additional personnel both inside and outside the organization.

(2) Existing data from harvesters, scaling, G and Y programs, NFI, and historical records contain a great deal of information that may bolster the detail and accuracy of a forest inventory. Developing systems to integrate these data with inventory data is a largely unaddressed research need. We should insure that this research need is addressed either in, or outside the CWFC. Expertise from FPInnovations – FERIC Division should be fully engaged to incorporate these aspects into FPInterface software.

(3) Following the development and testing of enhanced inventory tools and systems for "mature" stands, extension/adaptation should be made to young/regenerating stands. Such work should be of concern to the provinces, and research costs should be incurred accordingly.

(4) Partnerships with the provinces, forest industry, and service providers should continue to be developed, not only for knowledge transfer, but for cost-sharing in and validation of the operational extension and implementation of the research.

(5) Cost–benefit analyses associated with enhanced inventory systems are an essential part of the research being undertaken. The current research component partnerships need to be expanded to properly address this aspect of the work.

This workshop made important strides towards enhancing communication within the CWFC and between CWFC researchers and the broader forest inventory research and operational community. For efficient and effective knowledge exchange and transfer of future CWFC research results, it is imperative that the discussion and knowledge exchange initiated among researchers and provincial inventory leaders at this workshop continue. Toward this end, it was suggested that the group reconvene, possibly in conjunction with an upcoming NFI Task Force annual meeting, to continue dialogue and knowledge exchange. It was further suggested that the group capitalize on existing knowledge exchange and technology transfer initiatives, such as the ongoing CIF/IFC electronic lecture series and *The Forestry Chronicle*. In the latter, a forest inventory theme issue will be undertaken within the next 2- to 5- year period, presenting peer-reviewed papers, editorials and synthesis articles.

Summary

Throughout Canada, overall forest management responsibility resides with the provinces and territories. Forest inventories are conducted to address this responsibility, with their derivation and production falling under the direct control and supervision of specific provincial ministries or agencies charged with land management responsibility. Typically, the detailed tasks of inventory data acquisition and compilation are undertaken by specialty contractors, with government personnel providing quality control audits on finished product. Current systems are usually designed and standardized to generate strategic, forest-level information for aspatial forecasts related to the supply of timber, habitat, and other values. However, changing strategic and operational planning needs, a new generation of spatial models, and an emerging desire to maximize forest value through better informed business decisions, are increasing the need for more tree- and stand-level detail and accuracy in forest inventory data. At the same time, constant pressure to reduce costs and hasten delivery is dictating the streamlining and automation of the inventory production process.

The enhancement of existing inventory tools and systems to enable the spatial identification and forecasting of value has become a priority research focus for the Canadian Wood

Fibre Centre (CWFC). On June 3–4, 2009, the CWFC invited lead inventory researchers, their collaborators, and provincial inventory managers and specialists from across the country to review inventory research needs and to ensure that current and future CWFC-funded research efforts are strategically aligned to make substantive progress towards addressing these needs during the next 2- to 5-year period.

Five planned and ongoing CWFC-funded inventory research components across Canada represent a complementary set of efforts that appear poised to offer sound regional delivery with national application in several priority research areas. Current efforts are well-focused on increasing tree- and stand-level detail that will not only facilitate better strategic and operational forest planning, but enhance the ability to map product potential and value. Over the next 2-year period, the program should measurably contribute to inventory tool and system enhancements that permit cost-effective, semi-automated interpretation and quantification of tree species, tree size and size distribution, and horizontal distribution (site occupancy). Efforts are also being directed at the addition of specific fibre quality attributes to the inventory, such as branch size and distribution, wood density, and microfibril angle (MFA), through work within the individual research components themselves and linkages with the CWFC's Inventory Correlations output. Inherent in this work is the development of models for the spatial extrapolation of these relationships over broader forest areas through one or more forms of remote sensing within a sampling design framework. Operational extension and implementation of these enhancements, coupled with cost–benefit analyses are planned within the next 5-year period.

The current CWFC research program does not address the need for predictive modeling, (ecosite and forecast modeling in particular), and the development of efficient sampling systems to integrate different scales of information (e.g., full-coverage remote sensing, more detailed remote sensing samples, and ground samples). Arguably, these research needs may best be met in a second phase of tools /systems development. There is also a need to develop systems that incorporate a variety of data from existing sources (e.g., harvest and scaling data) to improve and refine prediction accuracy and precision. Additional resources, or the redirection of this work to other agencies, will be required to fully address these gaps.

To ensure that the CWFC's existing research program advances in an efficient manner, it is essential that communication between research components and among other forest inventory interest groups (e.g., other researches, National Forest Inventory, provinces, industry, service providers) be strengthened. This is particularly true as we enter the phase of operational testing and cost–benefit analyses, where resources external to the CWFC will likely be required. Standardized data collection is recommended to facilitate data, model, and results-sharing. It is also essential that CWFC knowledge exchange personnel be proactively engaged at the individual research component level to facilitate and guarantee the effective transfer and uptake of research results.

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