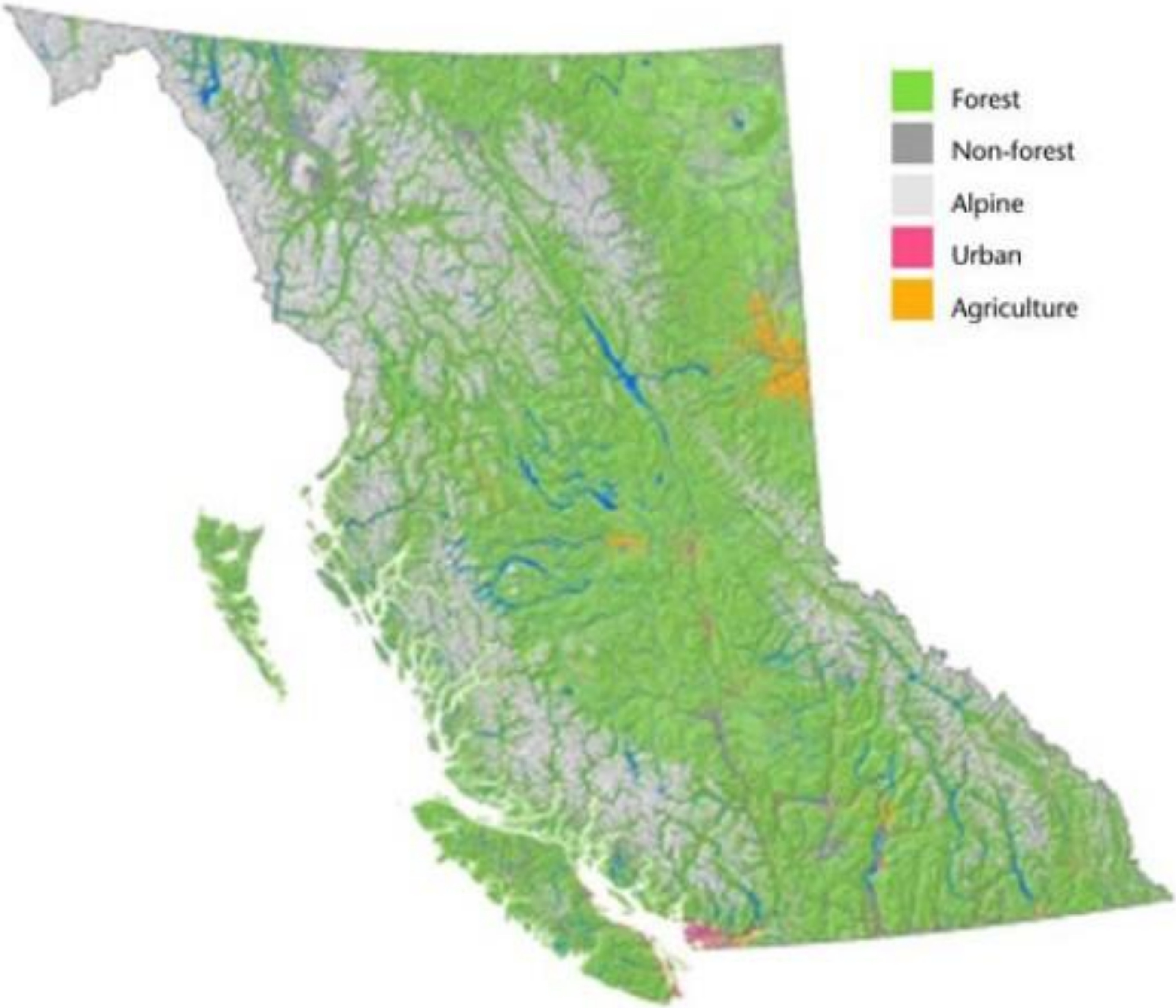
British Columbia Forest Inventory Review Panel Technical Background Report

December 2018



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Cover Map Source: The State of British Columbia's Forests – Third Edition. 2010. BC Ministry of Forests, Mines and Lands.

Acronyms Used

AAC	Allowable Annual Cut
ABCFP	Association of BC Forest Professionals
ALS	Airborne Laser Scanning (also referred to as LiDAR)
BC	British Columbia
BCGW	BC Geographic Warehouse
BCLCC	BC Land Cover Classification
BCTS	BC Timber Sales
BEC	Biogeoclimatic Ecosystem Classification system
CDC	Conservation Data Centre
CFS	Canadian Forestry Service
CMI	Change Monitoring Inventory
CWD	Coarse woody debris
DAPs	Digital Aerial Photos
DBH	diameter at breast height
DCS	Digital Camera System
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EFI	Enhanced Forest Inventory
EPs	Experimental Plots
FAIB	[FLNR] Forest Analysis and Inventory Branch
FC	Forest Cover (inventory protocol; see note at bottom)
FIZ	Forest Inventory Zones
FLNR	BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development
FPB	Forest Practices Board
FREP	Forest and Range Evaluation Program
FRPA	*Forest and Range Practices Act*
FVS	[USDA Forest Service] Forest Vegetation Simulator
GIS	Geographic Information Systems
GPS	Global Positioning System
GY	Growth and yield
IDF	Interior Douglas-fir BEC zone
IT	[Computer based] Information Technology
LiDAR	Light Detection and Ranging
LEFI	LiDAR Enhanced Forest Inventory
LSP	Large Scale Photo
LVI	Landscape Vegetation Inventory
MoU	Memorandum of Understanding
MPB	Mountain pine beetle
NASA	[United States] National Aeronautics and Space Administration
NFI	National Forest Inventory
NRM	Natural Resource Management
NVAF	Net Volume Adjustment Factor

OAFs	Operational Adjustment Factors (applied to TIPSY)
OGSI	Old Growth Site Index
PEM	Predictive Ecosystem Mapping
PPSWR	Probability Proportional to [Polygon] Size with replacement plot location
PSPs	Permanent Sample Plots
QC	Quality Control
RESULTS	Reporting Silviculture Updates and Land Status Tracking System
RIC	Resource Inventory Committee
RPF	Registered Professional Forester
SI	Site Index
SIBEC	Site Index by BEC Site Series
SMR	Soil Moisture Regime
SNR	Soil Nutrient Regime
TASS	Tree and Stand Simulator
TEM	Terrestrial Ecosystem Mapping
TFL	Tree Farm Licence
TIPSY	Table Interpolation Program for Stand Yields
TRIM	Terrain Resource Information Management
TSA	Timber Supply Area
TSPs	Temporary Sample Plots
UAV	Unmanned Aerial Vehicle
UBC	University of British Columbia
USDA	United States Department of Agriculture
VDYP	Variable Density Yield Projection
VRI	Vegetation Resource Inventory
VRIMS	Vegetation Resource Inventory Management System
YSM	Young Stand Monitoring

Note: Forest Cover (when capitalized), or Forest Cover inventory, or FC or FC inventory all refer to the pre-VRI forest inventory protocol. On occasion the term “forest cover inventory” (all lower case) is used to refer generally to forest inventory and not specifically to any one standard. In most cases this has been avoided by simply referring to “forest inventory.” On occasion reference is also made to “forest type(s)” or “forest inventory type(s).” These are used to indicate differences in forest characteristics in general and are not to be confused with formal definitions of “Inventory Type Groups” in relation to any given inventory standard. “Forest crown cover” (with or without a capital F) is used when specifically referring to crown cover percent.

Summary of Key Messages from the Review and Recommendations

The British Columbia (BC) Forests, Lands, Natural Resources Operations and Rural Development (FLNR) Minister Doug Donaldson announced in February 2018 that a Panel would review the BC Forest Inventory Program. Panel members are Dr. Bill Bourgeois (Panel chair), RPF (Ret); Dr. Clark Binkley; Dr. Valerie LeMay, RPF; Dr. Ian Moss, RPF; and Nick Reynolds, RPF.

The Panel reviewed the Inventory Program between April and September 2018. This included reviewing the existing program, requesting and evaluating written submissions, interviewing key users and developers, and assessing programs in other jurisdictions. This Technical Background Report presents the Panel's findings and provides recommendations on possible improvements to the Inventory Program. The Panel acknowledges and thanks the numerous individuals and organizations listed in Appendix I who provided feedback and ideas. A separate Summary Report prepared by the Panel highlights key findings and recommendations.

Key Messages from the Review

Government asserts BC is a world leader in sustainable forest management with leading-edge environmental practices. Fundamental to this claim is the ability to demonstrate the forest inventory is appropriate for supporting this statement. The review of the current BC Forest Inventory Program concluded:

- The **FAIB staff should be commended** for their efforts in meeting the needs of forest inventory users and working toward having an inventory program that will support well-managed forests. Their efforts are particularly commendable in light of the declining and now very low levels of financial and other support they receive.
- The ministry needs to move toward each component and project demonstrating how it contributes to the integrated **"forest inventory system."**
- The **forest inventory is widely used in decision-making**, not only within the FLNR but by other resource ministries, Crown corporations, non-governmental organizations, First Nations, and the forest industry.
- Based on the Panel's criteria for assessing the current Forest Inventory Program from the perspective of supporting well-managed forests, **having the lowest funding allocation per cubic metre logged among the provinces** (i.e., $0.16/m^3$) **is the major limiting factor** in:
    - Moving away from FAIB having to adopt a crisis management approach in responding to user needs, including those of government,
    - Providing the foundation for establishing effective forest management policies, guidelines, and practices which support the claim of being a world leader in forest management,
    - Meeting user needs for economic, environmental and social values decision-making,
    - Maintaining the forest inventory asset,
    - Being able to predict and respond to current and future conditions affecting the forest, and
    - Capitalizing on innovation and new technologies.

- The Panel is **confident FAIB will be able to generate the innovation to overcome the deficiencies** in an efficient and cost-effective manner to support well-managed forests, if provided with adequate resourcing and direction.
    - The analysis supporting AAC determinations in BC is essentially the same, if not more complex, than that used to develop long-term forest management plans for industrial and institutional timberland owners in North America. BC's expenditure on inventory is less than one tenth of that of these other organizations yet the cost of poor decisions is likely to be much greater.

Panel Recommendations Resourcing

1) Provide adequate and sustainable funding to move toward a robust forest inventory system with the data and analysis to support decision-making for well-managed forests.
2) Maintain and increase qualified workforce in terms of both the number of people and their skill levels.
3) Establish an innovation fund within the FAIB annual budget.
4) Establish a Growth and Yield Partnership to build financial and collaborative support for a long-term and sustainable Growth and Yield program.
5) Provide independent IT resourcing to increase efficiency and expansion of data storage and analytical capacity.

Administration

6) Restore the Chief Forester's legislated responsibility for the forest inventory.
7) Establish a ministry policy to view all inventory project and program decisions from the perspective of contributing to the BC forest inventory system as a whole, not as separate projects.
8) Expand the mandate of the Forest Practices Board to include providing independent advice regarding delivery of the Forest Inventory Program.
9) Establish a Forest Inventory Technical Advisory Group.

Communications

10) Develop a robust inventory system communications program to support an informed base of professional users and public audience.

Inventory

11) Obtain full LiDAR coverage for BC.
12) Produce and maintain an up-to-date VRI rank-1 layer dataset throughout the entire Province of BC.
13) Utilize advanced forest inventory information, tools and processes to achieve additional information important for forest management planning and practices in prioritized areas of the province, particularly to support AAC determinations in areas where timber supply is constrained and/or contentious.

14) Investigate and implement methodologies to estimate inventory uncertainty to better underwrite evaluation of the potential for risk versus reward in forest estate management planning and decision making at the forest, landscape, and polygon scales.

Innovation

15) Establish three (or more) inventory system research, development, and implementation test sites within the province to ensure that any all new innovations will provide the information needed at an acceptable cost.

Growth and Yield

16. Develop Growth and Yield models that cover the main stand types and management regimes in BC.

Acknowledgments

The Panel acknowledges the openness and availability of Forest Analysis and Inventory Branch staff and other staff in the BC government in providing the needed information and for responding to Panel questions concerning details of the BC Forest Inventory Program. The Panel also sends great thanks to all those in other jurisdictions who took the time to respond to requests for feedback on their Forest Inventory Programs. Finally, the Panel is extremely grateful to all those who provided honest and open feedback on both the successes of the BC Forest Inventory Program and the concerns they have. The numerous individuals and organizations that kindly provided feedback and ideas are listed in Appendix 1.

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1.0 Introduction

1.1 Preface

Forests, Lands, Natural Resources and Rural Development Minister Doug Donaldson announced in February 2018 that a Panel would review British Columbia (BC) Forest Inventory Program. The announcement included the Panel members as Bill Bourgeois, Clark Binkley, Valerie LeMay, Ian Moss and Nick Reynolds.

Key functions of BC's Forest Inventory Program include:

- Undertaking new forest inventories to replace older ones
- Maintaining existing forest inventories through updates
- Ground sampling and re-measurement of natural (unmanaged) stands
- Monitoring the post-harvest growth of managed stands
- Providing models to project stand development and future yield.

The BC Forest Inventory Panel undertook a review of the Forest Inventory Program between April and September 2018. The Panel's work included reviewing the existing program, requesting and then evaluating written submissions, interviewing key users and developers, and assessing programs in other provinces and jurisdictions. This report summarizes the Panel's findings and provides recommendations on possible improvements to the BC Forest Inventory Program.

The Panel heard from numerous organizations and individuals through submissions and/or interviews about how the BC Forest Inventory Program could be improved. The Panel appreciates the time and effort they spent on providing feedback and acknowledges those who provided input in Appendix 1.

1.2 Purpose of the Panel Review

Forests, Lands, Natural Resources and Rural Development (FLNR) Minister Doug Donaldson announced in February 2018 that the Panel would review British Columbia's (BC's) Forest Inventory Program.

"We have a robust Forest Inventory Program, but it's been 10 years since the program has been last reviewed, and since that time, we've seen significant changes to our forests, most notably from the mountain pine beetle epidemic and wildfires." Donaldson said. "Having a reliable inventory is important to garner public trust in how we manage our public forests."

Given FLNR's current Forest Inventory Program priorities, direction, resourcing, available technologies, and the social license required to manage BC's forest resources, the purpose of the review is to determine:

- If the Forest Inventory Program is meeting the current and future needs of users
- And, if not, what recommended changes can be made to optimize the program to meet those needs.

The inventory supports a variety of users including decision-makers. The users often utilize other information to support the tasks or decisions they make. The Panel was not asked to review the methods applied by users of the inventory (e.g., AAC determinations), but did assess the adequacy of the inventory in supporting user needs.

1.3 Motivation for the Review

The BC Forest Inventory forms the basis for all management of forest resources of BC. A reliable inventory is essential for making all forest stewardship decisions and investment assessments. With the 2000-2015 mountain pine beetle (MPB) epidemic and extensive wildfires in 2003 (265,000 ha burned and $375 million in fire-fighting costs), and again more recently in 2017 (1.2 million ha burned and $568 million in fire-fighting costs) and 2018 (1.3 million ha burned), concerns have been raised about the accuracy of the inventory for assessing existing and future mid-term timber supply – particularly where these assessments are critical to forest dependent communities. Anticipation of potential epidemics from other disturbance agents such as the spruce beetle and Douglas-fir beetle have increased the concerns that the timber supply may not meet demands. Many professional foresters are now asking – where is the wood that AAC determinations say is available? Are our projections on the performance of young stands following harvest and natural disturbances accurate? At the same time, there are concerns about species at risk under this changing landscape. Having an accurate and up-to-date forest inventory, as well as having the ability to accurately forecast future growth and yield, is critical to forest management of BC, especially with increasing uncertainties.

Adding to the need for a reliable forest inventory is the recent increased investments in a variety of land uses and interests. As well as timber industries, oil and gas industries are now key developments in northeast BC and elsewhere. Resource professionals and the general public have expressed growing concerns about species at risk, uncertainties concerning aboriginal rights and titles, and urban expansion. Cumulative, overlapping interests are all impacted by climate change that may precipitate the frequency and impacts of catastrophic events such as wildfires, floods, and droughts. Can future forests adapt to a changing climate? There is increasing anxiety among resource practitioners that we may not have information that is sufficiently reliable to meet professional practice obligations.

At the same time, recent, rapid technological advancements in remote sensing data alternatives including LiDAR and high resolution imagery, along with analytical tools are being tested for improving forest inventories. Forest licensees and resource practitioners have begun to implement some of these tools and this potentially different forest inventory information may lead to different conclusions than those based on the use of the existing BC forest inventory. There is concern that the steward of the BC's extensive public forest lands – the province of BC - may not have the best available information or forest attributes about its forests for some areas.

Resource practitioners express increasing needs for a forest inventory that not only supports strategic decisions such as allowable annual cut (AAC) determinations for larger spatial scales, but also is useful at smaller spatial scales, including at polygon levels, for operational and spatially explicit applications such as harvest scheduling, silviculture impact assessments, and species at risk management. The question is, can government meet these increasing information needs? Advancements using emerging technologies may provide the key to having a forest inventory that is scalable for strategic and operational applications.

In this context of the rapidly changing forests, overlapping interests, and emerging technologies, the Panel conducted a review of the BC Forest Inventory Program.

2.0 Process Used by the Panel

In April 2018, the Panel met with Forest Analysis and Inventory Branch (FAIB) staff of FLNR. FAIB presented information on the current BC Forest Inventory Program and provided a number of overview documents. Anticipated future changes to the Program and tests using emerging technologies that are already underway were stated. This information and further questions forwarded to FAIB staff provided the Panel's understanding of the BC Forest Inventory Program used in this review.

The Panel then listed the main uses of the BC Forest Inventory including:

- Analysis of fibre supply (i.e., timber supply review, AAC determinations);
- Evaluation of tenure options and business opportunities (e.g., forest companies, community forests);
- Simulation of forest carbon dynamics (e.g., BC's Forest Carbon Initiative);
- Design of silviculture regimen (e.g., by forest companies, BC Timber Sales, Forests for Tomorrow, Forest Enhancement Society of BC, Integrated Stewardship Strategies formerly called Integrated Silviculture Strategies, integrated investment planning);
- Timber harvest planning (e.g., forest stewardship plans and site plans);
- Habitat mapping (e.g., species at risk, regionally and culturally significant wildlife like moose and caribou);
- Wildfire risk assessment (e.g., Community Resiliency Investment Program - formerly called the Strategic Wildfire Prevention Initiative);
- Biodiversity assessment (e.g., old growth conservation efforts by environmental organizations, and old growth management areas designated by government);
- Impacts of changes in forest crown cover on water supplies and watershed dynamics; and
- Many other uses (e.g., Forest Consultation and Revenue Sharing agreement calculations, cumulative effects assessment, fostering ecological resilience as a climate change adaptation strategy).

The Panel identified four key questions for the interviews:

- Does the existing BC Forest Inventory Program, including growth and yield models, provide suitable and reliable information to support decisions required for sustainable, well-managed forests?
- What is working well? What is not working well?
- How can the forest inventory be improved to provide more useful and reliable information?
- What benefits would be achieved with the suggested improvements to the forest inventory?

In May 2018, a BC Forest Inventory Panel Update was prepared that provided the context for the review, raised these key questions, and outlined the Panel process for undertaking the review.

As well as an open call for submissions, the Panel identified organizations and individuals to contact as representatives of users or providers of BC Forest Inventory data. In late May 2018, the Panel contacted about 160 organizations and individuals, provided them with the Panel Update, and encouraged them to provide confidential submissions by June 30, 2018. This included provincial government (operations and headquarters), federal government, First Nations, major forest licensees, Woodlot Licensees and Community Forest Agreement holders, academia, consultants, and non-government organizations.

The Panel also undertook interviews with organizations and individuals to get feedback on how the BC Forest Inventory Program could be improved. An initial round of interviews occurred in May to pilot test the process, a second round in June, and a third and final round in July and August 2018 were held.

In early July, the Panel met to discuss the review process including submissions received. The Panel concluded there were gaps in submissions in the areas of comments from First Nations, environmental organizations, and from a wildlife habitat perspective. The Panel contacted organizations and individuals who could fill those gaps asking for a submission by July 20th – this included reminders to those already contacted as well as contacting 21 additional organizations and individuals who could fill those gaps.

The results of the BC Forest Inventory Panel's outreach efforts included:

- Contacting 181 organizations and individuals and asking for submissions;
- Evaluating 58 submissions that were sent in confidence to the Panel; and
- Undertaking 25 interviews with individuals who use the inventory.

In addition to Panel outreach efforts via submissions and interviews, the Panel also:

- Examined the inventory programs in other jurisdictions and ownerships, particularly other provinces, in terms of their level of effort and approach;
- Reviewed key literature on the current BC Forest Inventory Program and recent world-wide forest inventory innovations; and
- Utilized the within Panel expertise about the forest inventory to help evaluate the inventory program.

3.0 BC Forest Inventory System: Background

This section seeks to answer three questions: What is a forest inventory system? Why does BC need one? And how much should BC spend on this activity?

Conventionally, "forest inventory" is understood to be a snapshot-in-time description of a forest. That simple and intuitive definition belies a lot of complications. Hence, the focus on the idea of a forest inventory as a system. The "system" includes not just data but also the data-collection protocols as well as the models and the computer hardware and software necessary to maintain, update and project those data, and, of course, the people involved. It turns out that a "forest inventory system" defined this way has components scattered across the provincial government and does not just reside in FAIB alone.

Why does BC need a forest inventory system? The requirement is implied in provincial legislation, but that legislative requirement simply articulates the fact that good decisions require good information. Decisions requiring forest inventory information include the Chief Forester's AAC determinations but do not end there. A wide range of Ministries, Crown Corporations, companies and others in the forest sector use forest inventory as part of their activities.

Finally, how much should BC spend on forest inventory? Expenditures on information are capital expenditures: the upfront costs, plus "maintenance costs" should be expected to provide a stream of benefits that more than offsets the costs. What are those benefits? This is a difficult question to answer, but conventional economic theory provides some suggestions as does the benchmarking reported in Section 5 and the user feedback reported in Section 6.

3.1 What is a 'Forest Inventory System'?

The term "forest inventory system" refers to the process used to obtain a quantitative description of forest conditions on a specified land base at a fixed point in time. In so-called traditional forest inventory, "forest conditions" referred to the quantity of merchantable timber (perhaps by species and log type) available to harvest from a forest stand, management unit or region. As societal concerns related to other forest outputs—e.g., wildlife and biodiversity more generally; water; carbon stocks—have grown and broadened, the definition of "forest conditions" has evolved as well. Nonetheless, the principles remain the same even if the specific empirical needs have expanded dramatically as a focus on timber has been supplemented with these additional values.

A forest inventory described this way generally requires two separate activities: (i) measuring the forest conditions of interest; and (ii) projecting them forward in time conditional on specified management activities and future conditions. These two steps are required whether the objective is to know present forest conditions or to project them into the future. The latter proposition is obvious, but the former is perhaps more subtle.

On a land base of any size, it is extremely difficult if not impossible actually to measure forest conditions at a specific point in time. That is the case because it takes time to measure trees at a sample of ground plots, and ground data and any associated remote sensing imagery is out of date very shortly after it is collected. A typical practice is to take actual measurements over a period of time (e.g., sample ground plots on one tenth of a forest every year so the average age of the data is five years). As a result, only some of the information is "current" and the rest must be updated based on projections of forest growth and depletion associated with harvesting, administrative withdrawals and disturbances from such factors as insect outbreaks, fires and storms. In other words, inventories are maintained as being "current" through use of a combination of: (1) measurements and/or assessments, (2) methods of accounting for locations, extents, and impacts of disturbances as they occur, and (3) application of a system of forecasting to project forest (and potentially non forest) attributes to a current date.

Knowing forest conditions at the current moment is of interest for some uses, but many uses require forecasting the forest conditions into the future. Such forecasts are necessarily conditional on a specific set of management actions. The set of management actions might include the "no action" alternative of doing nothing as is the case in most parks and protected areas. Forecasts underlie such decisions as determining long-term sustainable harvest levels, projecting forest carbon stocks over time, or describing the area of suitable habitat for one or more species of interest.

A good forest inventory system is dynamically updated. That is, any disturbance causing major changes such as timber harvest and fire are reflected in the data, and forest conditions are projected to current date and into the future (as described above). With time, the quality of the base data used to underwrite the inventory tends to depreciate and errors associated with various updates and estimations to accumulate to a point that new information is required. This new information both helps to reset what are then-initial conditions and can be used to test whether or not the earlier projection is sound. For example, each year timber is harvested. For each harvest unit, the quantity of timber harvested may either be cruised in advance or scaled after the timber is removed. Scaled harvest volumes (normal production and avoidable) provide a census of the tree volumes removed in a harvest unit. Good practice regularly compares the cruised or scaled volume with the volumes predicted from the inventory system. Rarely if ever will the two numbers be exactly the same. However, over a large number of harvest units the average deviation should be zero and the variation should be within a range specified in the design of the inventory system. If either of these conditions is not met, then there could be trouble in the inventory system that requires attention to fix. The Panel recognizes that there may be operational and organizational impediments to matching harvest volumes with inventory estimates, but we believe the Ministry needs to overcome these to support a forest inventory system that invites confidence of users and the public.

BC faces one of the most daunting forest inventory challenges that exists anywhere in the developed world:

- The forested area is large with much of it remote from convenient access;
- The forests are quite diverse: many species, age classes, and ecological and management conditions; and
- The ministry is responsible not only for such government oversight functions as general monitoring of forests conditions, but also for making long-term forest management decisions such as AAC determinations and short-term allocations of quota to quota holders. In other jurisdictions these latter functions are more generally relegated to operating entities.

This latter factor is especially important in understanding our perspective on the extant inventory system. Consider the situation in other developed countries. In the United States, USDA Forest Service Forest Inventory and Analysis unit performs the government oversight function of the ministry. However, the long-term forest management/sustainability planning functions reside in the forest industry (e.g., Weyerhaeuser, Rayonier, Potlatch) or with institutional managers (e.g., Brookfield, the Hancock Timber Resource Group). The governmental forest inventory units of Sweden and Finland are organized similarly—the national forest inventory is used for government oversight purposes and those responsible for actual forest management planning use separate and far more detailed forest inventory systems. BC's dual government oversight and operational planning responsibilities place an especially and unusually heavy burden on its forest inventory system.

Other Canadian provinces share BC's broad responsibility, but the scale and diversity of the forests distinguish BC even in the Canadian context.

Because the forest inventory needs are so different for different parts of the BC land base, it makes sense to separate (i) the general government oversight needs for inventory on the entire 60 million hectares of forest land from (ii) the forest management needs on the 25 million hectares of the timber harvesting land base with 71 distinct land management units on which AACs are determined. Following the discussion above, the former is more similar to national forest inventories of Sweden, Finland and the US while the latter is more similar to the large corporate and institutional timberland owners (See Section 5 for more discussion on benchmarking).

Sometimes these distinctions are described as "strategic" "tactical" and "operational" and this report uses that language while acknowledging the difficulties with these terms. A key concern is this: if a "strategic" inventory is deemed unfit for operational planning, then the province is at risk of having a "strategic" level plan that is out of step with operational realities. If that occurs, then there is little assurance that the outcomes from the "strategic" plan will actually eventuate. Progress toward planned outcomes is monitored imperfectly and those responsible have little empirical basis for claiming that a plan and the associated course of action are "sustainable," especially when licensees ask "where is the wood?" that the "strategic" plan says is available.

If "strategic" decisions are not implemented on the ground there can be no assurance and little comfort the desired and modelled strategic outcomes will take place. Ideally, the best way to be sure the operational actions are consistent with a strategic plan is to base the activities on an operational-level inventory. However, the practicality of doing this across the BC forest land base is daunting and costly. BC needs to have one inventory that bests meets the needs at strategic, tactical and operational levels while working within practical constraints associated with available resources.

Throughout BC there is a need for an inventory that provides data and information for strategic decision-making. However, it is recognized there a certain landscape areas and/or forest management units within the province requiring additional information as a means of better ensuring sustainable forest management plans and practices. This is especially true for the inventory and analysis that underlies AAC determinations in places where timber supply is known to be tight and contentious. The BC forest inventory must contain properties and processes that provide this flexibility. The Panel has provided a practical solution outlined in Section 7.3.2 and Recommendations 13 and 14 to address acquiring this balance.

While these unique challenges have remained constant for many years, changes in the forest and in societal expectations have broadened and sharpened the needs for good information. "Good information" in this context has several dimensions, including: (1) the kinds of attributes that are represented (e.g. tree and stand, and/or habitat kinds of attributes), (2) the highest level of resolution that can be accessed (e.g. grid cell at 20m x 20m scale versus VRI polygon), (3) how reliable the data is (with what levels of precision and bias), (4) whether the information can be reasonably forecasted into the future or from the past, and (5) with what kinds of flexibility can the data be interpreted (the ability to select appropriate attributes, scale, and levels of aggregation) to underwrite the intended set of applications and/or needs (assessments, valuations, strategic and operational kinds of decisions). Industrial capacity has steadily grown just as insect attacks, fires and withdrawals of the timber-harvesting land base for other uses have reduced timber supply. Slack in the system, once considerable, no longer exists, particularly in some areas (e.g., the Cariboo-Chilcotin). The people of BC expect ecological outcomes as well as economic ones. These changes mean that the costs of decision errors associated with poor information have grown. As a result, it is logical that the value of good information has increased and, with it, a requirement for improved inventory.

3.2 Why Should BC Invest in a Forest Inventory System?

As a general matter, information is valuable only insofar as it affects decisions: If the decision remains the same despite the data, why spend scarce resource on collecting the data? If the decisions are trivial or if the consequences of errors are low, then why collect information? The value of the information can be measured by the losses avoided by poor decisions. The losses in turn depend on the *scale* and *importance* of the decisions. In BC, both the scale and importance of the decisions are quite large. Respecting this fact, the need for forest inventory is implied, but not stated, in key provincial guidance legislation.

3.2.1 Forests are an important provincial asset

"Scale" can be measured in many ways. BC's forests comprise some 60 million ha, over two thirds of the province's land base. The 25 million ha "timber harvest land base" exceeds the area of industrial and institutional timberland in the US by a considerable margin. The value of BC's forest land base is commonly estimated at $3 trillion.

The value of manufacturing shipments from the forest sector amounted to $15.9 billion in 2017. The forest sector provides 32% of the Provincial exports and directly supports 7,000 businesses employing 57,000 people. It provides nearly $1 billion in government revenue. And, this is just the trees.

However, the importance of BC's forest lands transcends mere economics.

- All of BC's potable water arises directly or indirectly from forested watersheds,
- BC's forests are home to many plants and animals, common but interesting, threatened or at risk,
- The forests support BC's recreational, artistic and spiritual lives, and
- Thousands of people, including many First Nations, call these forests "home."

Based on the economic, ecological and social importance of BC forests and the central role of government in managing them, it would make sense for the BC government to support a forest inventory system equivalent to, if not better than, the best in the world.

3.2.2 Decisions about forests have important consequences

The most immediate and obvious use of forest inventory information relates to management of the Province's forests. Key decisions include those related to:

- Determining land use—boundaries, restrictions, regulations, permits;
- Setting harvest levels and management direction, including managing wildfire and insect/disease outbreaks; and
- Monitoring sustainability.

These are both "top down" and "bottom up" activities. For example, the Chief Forester relies on forest inventory data and analysis based on those data in determining AAC levels for individual land management units. Licensees then use forest inventory data (provincial data perhaps supplemented with their own) to support annual harvest plans, including road construction and subsequent silvicultural activities. Good management practice includes monitoring actual activities against planned ones to be sure that plans are actually being executed—if not then the outcomes anticipated in the plans are unlikely to be achieved. The "top-down" then "bottom up" cycle closes the control loop in guiding forests to their desired condition.

The BC forest inventory supports decisions that go far beyond the Chief Forester's realm (See Appendix 2 for more details and how this relates to need for long-term sustainable forest inventory funding). The uses range from strategic to tactical to operational, addressing such decisions as:

- Investments in new primary and secondary manufacturing facilities (Ministries of Jobs, Trade & Technology; Finance);
- Management of protected areas, wilderness tourism, recreational fish and wildlife (Ministry of Tourism, Arts & Culture, Ministry of Environment and Climate Change);
- Range management (FLNR; Ministry of Agriculture);
- Managing the cumulative impacts of oil and gas extraction (Oil and Gas Commission);
- Reconciliation of First Nations issues (Ministry of Indigenous Relations & Reconciliation);
- Management of "Species at Risk" e.g., caribou (Ministry of Environment & Climate Change); and
- Projecting and monitoring carbon stocks (Ministry of Environment & Climate Change; Canadian Forest Service; Environment and Climate Change Canada).

This list is neither intended to be, nor is likely to be, comprehensive relative to the decisions supported by the forest inventory system. Rather, it simply shows the breadth of demands on the forest inventory system, and the opportunity for broad support within the government and a variety of stakeholders.

Given this large and broad scale of use, it is not surprising that BC's legislation indirectly requires a forest inventory system. However, extant legislative language is not explicit enough to reflect the needs or importance of the forest inventory system.

3.2.3 BC's laws require forest inventory

The key pieces of legislation that underwrite the need for reliable forest inventory are several:

- The purpose of the Ministry is specified in Section 4 of the *Ministry of Forests and Range Act*[1]:

  The purposes and functions of the ministry are, under the direction of the minister, to do the following:

  - *(a) encourage maximum productivity of the forest and range resources in British Columbia;*
  - *(b) manage, protect and conserve the forest and range resources of the government, having regard to the immediate and long term economic and social benefits they may confer on British Columbia;*
  - *(c) plan the use of the forest and range resources of the government, so that the production of timber and forage, the harvesting of timber, the grazing of livestock and the realization of fisheries, wildlife, water, outdoor recreation and other natural resource values are coordinated and integrated, in consultation and cooperation with other ministries and agencies of the government and with the private sector;*
  - *(d) encourage a vigorous, efficient and world competitive timber processing industry, and ranching sector in British Columbia;*
  - *(e) assert the financial interest of the government in its forest and range resources in a systematic and equitable manner.*

[1] http://www.bclaws.ca/civix/document/id/complete/statreg/96300_01

- Under the *Forest Act* the Chief Forester is assigned the task of determining Allowable Annual Cuts and is directed under Section 8 to take the following information into account:

  (a) *the rate of timber production that may be sustained on the area, taking into account*

  (i) the composition of the forest and its expected rate of growth on the area,

  (ii) the expected time that it will take the forest to become re-established on the area following denudation,

  (iii) silviculture treatments to be applied to the area,

  (iv) the standard of timber utilization and the allowance for decay, waste and breakage expected to be applied with respect to timber harvesting on the area,

  (v) the constraints on the amount of timber produced from the area that reasonably can be expected by use of the area for purposes other than timber production, and

  (vi) any other information that, in the chief forester's opinion, relates to the capability of the area to produce timber,

  (b) *the short and long term implications to British Columbia of alternative rates of timber harvesting from the area,*
  (c) *[Repealed 2003-31-2.]*
  (d) *the economic and social objectives of the government, as expressed by the minister, for the area, for the general region and for British Columbia, and*
  (e) *abnormal infestations in and devastations of, and major salvage programs planned for, timber on the area.*

- Section 35.1 of the *Forest Act* addresses Tree Farm License holder requirements for a sufficient forest inventory to support Management Plans.

- Under the *Forest and Range Practices Act*, Division 1 licensees are directed to prepare Forest Stewardship Plans that under Section 5 must:

  (1) (a) include a map that
  (2) uses a scale and format satisfactory to the minister, and
  (3) shows the boundaries of all forest development units,
  (b) specify intended results or strategies, each in relation to
  (1) objectives set by government, and
  (2) other objectives that are established under this Act and that pertain to all or part of the area subject to the plan, and
  (c) conform to prescribed requirements.

(1.1) The results and strategies referred to in subsection (1) (b) must be consistent to the prescribed extent with objectives set by government and with the other objectives referred to in subsection (1) (b) (ii).

(2) A forest stewardship plan must be consistent with timber harvesting rights granted by the government for any of the following to which the plan applies:

(a) the timber supply area;

(b) the community forest agreement area;

(c) the tree farm license area;

(d) the pulpwood area.

(3) A forest stewardship plan or an amendment to a forest stewardship plan must be signed by the person required to prepare the plan, if an individual or, if a corporation, by an individual or the individuals authorized to sign on behalf of the corporation.

- The FLNR either benefits or can benefit from forest inventory information under its Forest and Range Evaluation Program (FREP)[2] with the mission to:
  - Collect and communicate the best available natural resource monitoring information to inform decision making, improve resource management outcomes and provide evidence of government's commitment to environmental sustainability.

… and the objectives to:

- Assess the impacts of forest and range development on the 11 FRPA resource values to determine if on-the-ground results are sustainable
- Identify resource value status, trends and causal factors, and
- Identify opportunities for continued improvement of practices, policies and legislation.

The specific resource values of concern cited under FREP are the 11 FRPA values:

- Biodiversity
- Cultural heritage
- Fish/Riparian and Fish/Watershed
- Forage & Associated Plant Communities
- Recreation
- Resource Features (e.g., karst, culturally modified trees, wildlife trees)
- Soils
- Timber
- Visual Quality
- Water Quality
- Wildlife

One of the challenges in forest management is to assess the potential and probable impacts of forest practices on forest, landscape, and watershed level attributes and scales. Such assessments frequently extend beyond impacts observed at specific locations and times, requiring an

[2] https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/integrated-resource-monitoring/forest-range-evaluation-program

understanding of the broader context in which certain impacts have been observed. Examples of the kinds of questions that can arise are: Are the impacts positive or negative? What is the level of impact? How much time will it take for the forest to respond or recover and to what degree? How will the answer change in response to different kinds of treatment? Knowledge of the forest inventory can be central to the provision of reasonable answers to these kinds of questions. Examples of applications include estimating impacts of roads, harvesting, and natural disturbance events on watershed and habitat characteristics, potential for further damage by various agents, and quality and quantity of timber supplies.

Consequently, the requirement for a robust forest inventory system is *implied* by several core pieces of BC provincial legislation, but an inventory itself may not *per se* be deemed necessary under current practice.

3.3 How Much Should BC Invest in a Forest Inventory System?

The forest inventory system is a provincial asset used by many organizations. As with any asset, it needs to be maintained, updated and improved to realize a continued stream of benefits. Failure to do so results in deterioration of the asset and loss of value in its use. In the case of the forest inventory, a degraded system would have major negative consequences for a wide range of economic, environmental and social values in BC.

The BC forest inventory has been repeatedly highlighted as a critical need for all aspects of resources management in BC. In spite of this, resources allocated to inventory have been limited, and for the most part have also declined, as shown in Figure 3.1a and 3.1b. As shown in Figure 3.1b the real budget has fallen just over 5% per year on average since 1990. This raises the question: Is the asset being maintained at a level sufficient to underwrite reasonably reliable decision-making? As a starting point, the inventory reviews previously undertaken on behalf the ABCFP (Moss, et al. 2006; Moss, 2011) identified 15 million per annum as being a reasonable figure for completing Vegetation Resource Inventories on Province-wide basis on a 10-year cycle. This is consistent with recent internal budget estimates that would include increasing staff to 45 Full Time Equivalents (FTEs, pers. comm. FAIB Staff, 2018).

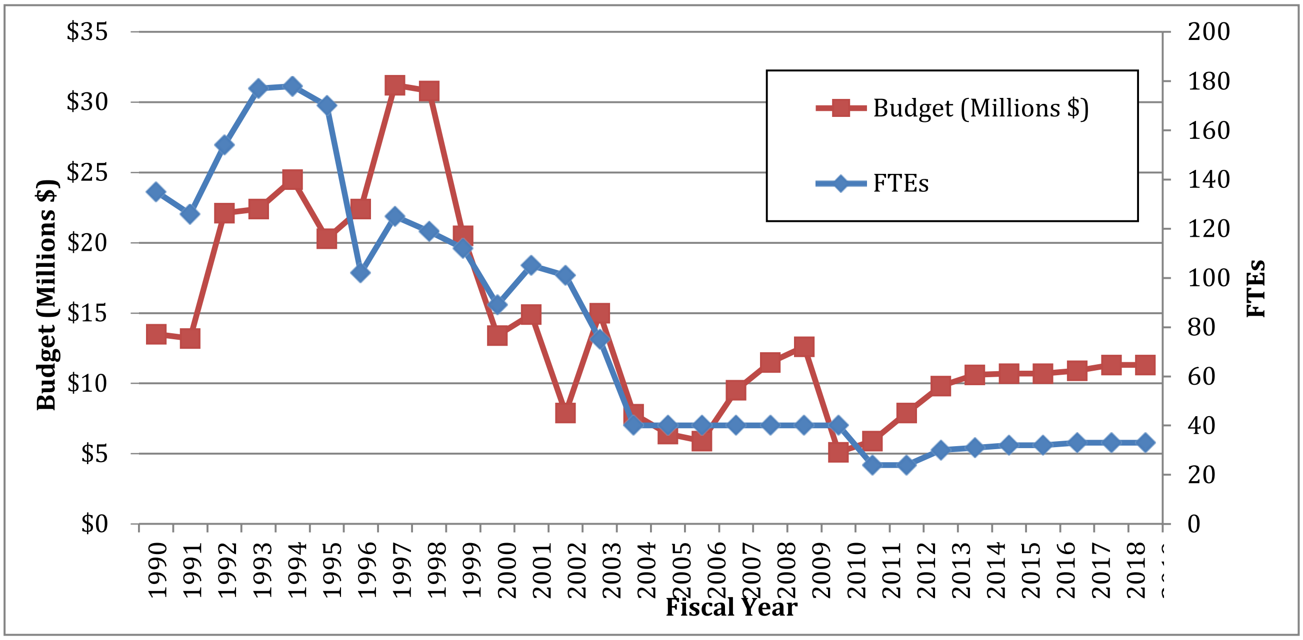

Figure 3.1a. BC forest inventory budget and Full Time Equivalent (FTE) personnel over time (nominal dollars not adjusted for inflation)

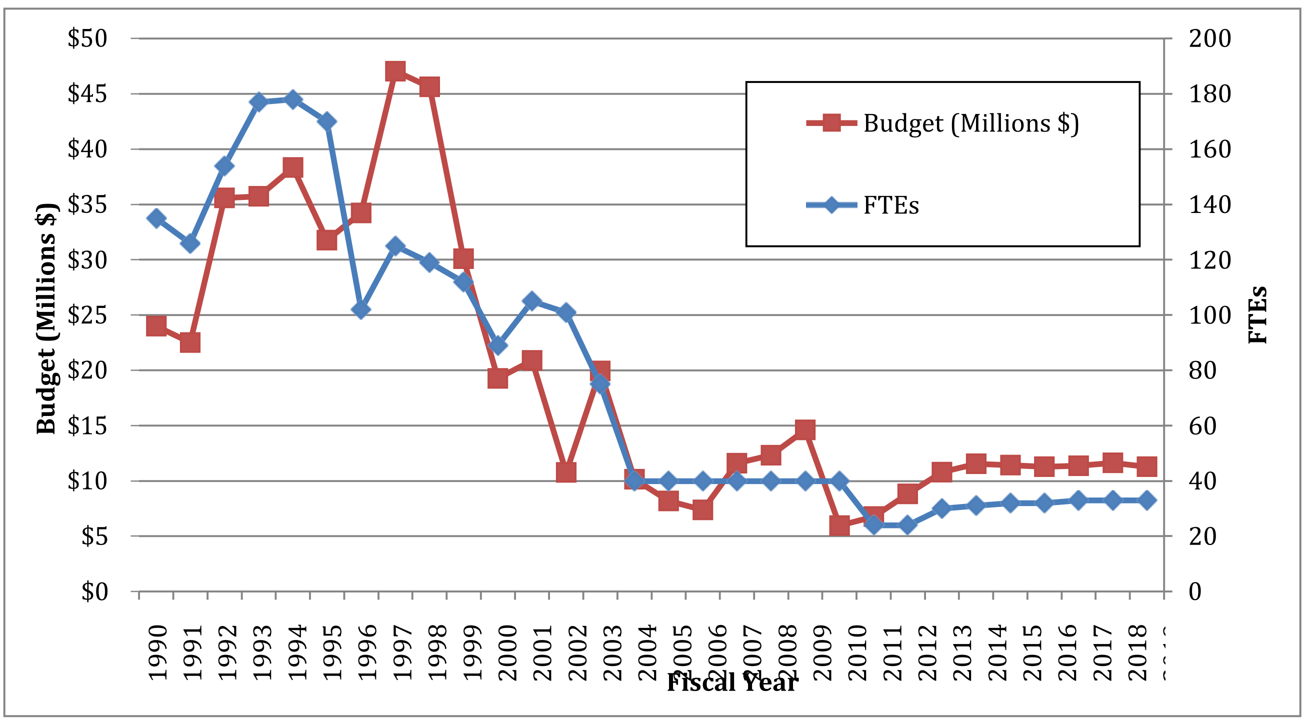

Figure 3.1b. BC forest inventory budget and Full Time Equivalent (FTE) personnel over time (real, inflation-adjusted dollars, based year 2018)

Like any investment, the objective of an investment in forest inventory is to create value over time that exceeds the cost of the investment. The costs include one-time capital investments (e.g. computer systems) along with ongoing "maintenance" costs to sustain the system—including re-measurement of plots and updating software. The benefits are far harder to define as they mostly derive from avoiding poor decisions. There is an academic literature on this subject, both the general case of the value of information (Cochran, 1963) and the specific applications to forestry (Borders et al., 2008; Robinson et al., 2016).

Borders et al. (2008) well summarized the conclusions of this literature:

> *Clearly, relatively large [Net Present Value] losses can result from the use of timber management plans developed with timber inventory data of poor quality* (p. 2288)

Regrettably none of this interesting and useful literature is directly relevant to the situation in BC and the questions at hand (but see Appendix 3, "Assessing the Optimal Level of Expenditure on Forest Inventory" suggests how this analytical approach might be applied to the situation in BC, a task that was beyond the scope of the Panel's remit). The work of Borders et al. (2008) in particular is identified herein as a prime example of how to go about assessing the true costs and benefits associated with forest inventory, and the potential benefits that can be accrued by way of additional expenditures to improve the quality of the information therein. It provides a basic economic framework that can be applied in British Columbia as well as in other jurisdictions.

The Panel recognizes that government and senior decision makers must have a means to determine the allocation of resources adequate to meet the current and future needs of the forest inventory system. The focus of such an allocation decision should be on meeting the criteria for a forest inventory system to achieve the goal of supporting well-managed forests, outlined in Section 5. The Panel identified two measures of how well BC achieves this objective. The first is to compare what BC does in relation to other jurisdictions facing similar decisions. The second is to consult users and other interested parties. That analysis is reported in Section 6 of this report.

4.0 BC Forest Inventory: History, Current Inventory, and Innovations

4.1 History of Forest Inventory in BC

4.11 Overview

The BC Forest Inventory has had an enduring role in developing forest management policies and managing BC's forests. The forest vegetation inventory information resides within a broader framework of information needs including topography, land cover, ecological classifications (e.g., Biogeoclimatic Ecosystem Classification system (BEC)), hydrological systems, road systems, and land survey and ownership, as well as human demographics and societal demands for various land uses, products, and ecosystem services (e.g., agriculture, timber, water, recreation, and cultural values). Collectively, this forest information provides a critical link between strategic, tactical, and operational decision-making, and is a foundation for establishing effective forest management policies, guidelines, and practices. Information needs for the current state of the forest and developments over time have changed with the particular forest management paradigm of that time, including Economic Development, Environmental Protection, Multiple Use Resource Management, Integrated Resource Management, Sustainability, and Ecosystem Based Management paradigms. An overview of the changes in the BC Forest Inventory since 1900 is presented in this section, along with some commentary on the motivations for these changes. A separate overview of growth and yield models for forecasting stands is presented as these play vital roles in using the forest inventory for forest management. Finally, information on resources allocated for the BC Forest Inventory over time, as well as the increasing information needs and challenges, is presented.

4.1.2 Early 1900s: Aerial photography and the need for forest information

Although ground measures of trees and stands were common for centuries prior to 1900, the use of analog aerial photographs began in the 1900s, as noted in the very popular textbook "Forest Mensuration" (Kershaw et al. 2017, Chapter 13, page 431):

> *Experimentation with the potential uses of aerial photography began within two decades of the first heavier than air flight by the Wright brothers in 1903, though initial work was focused primarily on the opportunities and challenges for mapping that arose during the First World War (e.g., see MacLeod, 1919; Whitlock et al., 1919). During the 1920s, aerial photography became an operational part of the forest inventory and mapping toolkit, but was not universally used, and methods for stock mapping and cover typing tended to be qualitative rather than quantitative (e.g., see Robbins, 1929; Parsons, 1930).*

During this time, ground measures commonly using "strip surveys" (i.e., systematic strip sampling) were the primary vehicle for determining forest attributes needed to buy and sell timber in particular.

In BC, the first BC Forest Resource Commission (Fulton et al., 1910) noted that inflated estimates of timber supply can lead to careless waste and "…distorted theories of annual destruction, by fire and lumbering, enable alarmists to harm the common-sense campaign for conservation by their exaggerations." This produces uncertainty in the business world and makes the government's task of "creating sound forest policies" more difficult. The commissioners recommended that all provincial government agencies dealing with forestry be consolidated into a Department of Forests, headed by a Chief Forester. In response to this, the BC Forest Branch was created in accordance with the new Forest Act (Forest Act, 1912), and Harvey R. MacMillan was appointed as the first Chief Forester. Under his direction, forest reconnaissance surveys were undertaken including information on topography, soil, climate, agricultural and grazing potential, known mineral resources, settlement history, and transportation infrastructure. Forest information included descriptions of forest types with associated areas, estimated merchantable volumes, and other characteristics. During these early years in the BC forest policy development, areas were classified into: i) statutory timberland (i.e., legally defined in 1896 as 8,000 board feet (fbm) per acre on the West Coast, and 5,000 fbm per acre in the Interior); ii) other forest land (mature stands with less volume or immature stands); iii) agriculture; iv) burned over; v) barren (usually alpine); or vi) other cover (wetlands or lakes).

In the 1930's, Mulholland, head of the Forest Survey Division, directed the completion of forest surveys at various locations in the province on a systematic basis. He contrasted a "cruise" from "forest survey" as follows (Mulholland, 1931, as cited in Parminter, 2000, page 185):

> *A timber cruise, however detailed and thorough is simply a crop survey; how much wood? How and at what cost can it be moved to the manufacturing plant? A forest survey is an economic survey, concerned with all branches of forestry;*

policy, management, silviculture, regulation of the cut, utilization, [and] protection. Its ultimate object is to provide information to enable a forest to be administered for permanent wood production.

Mulholland expressed concerns about extreme overcutting on the BC Coast, along with the need for better regulation of harvesting in the interior; in the latter case, he indicated a need for more complete accounting for impacts of wildfire (as cited in Wilson, 1987).

Aerial photography began to be developed for forest inventory after WW 1. The first large scale, operational application was in the Manitoba Pulpwood Survey of 5.72 million hectares in the northern part of the Province in 1926-1927 (Honer and Heygi, 1990). The Okanagan forest survey of 1938 was the first project to use air photographic planimetry on a production scale, both in the office and the field, this being a product of technology development by G.S. Andrews, William Hall, and H.M. Pogue (Mahood and Drushka, 1990). By 1940, 10.8 million acres (4.37 million ha.) were covered by forest type maps prepared from aerial photos (Andrews, 1940).

During World War II, Andrews was deployed using his knowledge of aerial photography, and later joined by Hall, to map approaches (depth of water) to Normandy in preparation for D-day (Sherwood, 2012). The government had done almost no aerial photography during these years except for the Alaska Highway so "… there was a grievous backlog of mapping BC's rugged terrain and stock-taking of her natural resources, which had been at a standstill during six long war years" (Sherwood, 2012, p. 136). "Aerial photography had improved considerably during the war years. There were better optics and cameras. New airplane models enabled the camera to take better quality photographs. In BC improved airfields had been constructed in many locations around the province to accommodate the larger, more powerful airplanes that replaced float planes for most of the aerial photography work."

After the war, Andrews was appointed as leader of Air Surveys Division reporting to the Surveyor General. Prior to that appointment, the Forestry Branch still viewed aerial photography as no more than, "… a minor adjunct to the old time forest survey," according to a letter written by Andrews (Sherwood, 2012, p. 133), but that was soon to change. Ultimately the decision to undertake aerial surveys was, in Andrews' words, "… imperative for modern land, forest, geological, hydrological development. Every effort is being made to keep the standards as high as any in the world through the use of the best instruments by the best-trained men."

4.1.3 Post 2nd World War: Forest inventory maps from aerial photographs, Sloan Commission

In the mid-1940s following the 2nd World War, a rapid growth in the use of aerial photos for topographic surveys (Sherwood, 2012; Kershaw et al. 2017, page 431) spurred an increase in use for creating forest inventory maps using photo-interpreters. Ground plots provided additional attributes, resulting in sufficient information to underwrite broad-scale forest management decisions. The use of aerial survey became fully operational on Canada-wide scale after the second world war following the establishment of the Canada Forestry Act of 1949 (Honer and Heygi, 1990; Thrower, 1992; Parminter, 2000). At the same time, the operational "cruise" remained as the mainstay for operational harvest planning and road development. While photo-interpretation was quickly becoming the foundation for forest inventory (aka "survey" as termed by Mulholland), the notion of sustained yield was introduced into BC forest legislation, as recommended in the 1945 Sloan Commission (Sloan, 1946). This policy required that there be a more complete accounting of the rates of forest growth, resultant yield, and the depletion amounts in each forest management unit over time. Given the absence of permanent sample plots for growth and yield measured over time, normalized (i.e., average stocking) yield tables by forest type were developed using temporary ground plots and assuming that a "substitution of space for time" would indicate yields over time. Collectively, these changes and forest inventory information products were motivated by the rapid expansion of the provincial infrastructure including the forest industry following the 2^{nd} World War.

4.1.4 1960s and 1970s: Industry expansion and increasing public concerns

In the 1960s and into the 70s, forest industry expansion was greatest in the interior, having already taken place on the Coast, and included new pulp mills and pulpwood agreements, along with a change from intermediate to close utilization standards by reducing the minimum diameter limit, resulting in increased AAC determinations (Pearse, 1976a and 1976b; see Griffin, 2016). Lodgepole pine was also becoming a much more viable, large-scale, commercial species.

Past policies on deliberately liquidating old growth timber led to expressed concerns that wood supply shortages were imminent. Regenerating stocks were not sufficient to sustain harvest rates. At the same time, commentary on conflicting land uses was becoming more vocal. For example, concerns were raised about impacts of driving logs down-river on fish spawning, reproduction and survival (Rajala, 2016a). This practice ended in the 70s, and attention turned to steep slope logging on what was later identified as unstable terrain (See Rajala, 2016b). These kinds of issues triggered the beginning of a more organized approach to dealing with environmental concerns amongst public interest groups, including the expansion of the Sierra Club into British Columbia[3], and the formation of Greenpeace (Montgomery, 2015; also see Wilson, 1987 for more comprehensive overview).

The BC forest inventory served a critical role in conflict resolution, possible compensation, and valuation of timber rights and lands. Forest management concerns and conflicts were frequently negotiated using references to the BC Forest Inventory. Arguments for and against certain practices usually at a specific location, included discussion on the value of the timber involved, the cost of production, and whether the supplies were sufficient to sustain forest operations if the given site were to be excluded from harvest. The inventory, including GY models, was used in determining whether all interests could be accommodated, or if accommodating one party's interests would compromise other interests. The quality of the inventory often came into question, particularly when one party had something to lose. The Inventory was sometimes used in determining compensation where the government wished to buy their way out of certain obligations, or where licensees were seen in breach of contract or operating outside the law. As well, the inventory was used as a basis for valuation of forestry operations to underwrite loans and property transfers, in juxtaposition to property rights, to gain access to timber, and to secure a social license to operate. While the inventory may not have seemed to be relevant in relation to the primary concern to start with, it quickly became a serious consideration from a broader landscape and forest-level decision-making perspective.

The first Continuous Forest Inventory of British Columbia was published in 1958 with subsequent revisions in ensuing years (Pearce, 1976b, p. D 5). This was developed using aerial photography in combination with ground sampling (Thrower, 1992). The stated objective of the inventory was

[3] https://sierraclub.bc.ca/about/history/ [Accessed September 9, 2018]

to provide estimates of total volume to a precision of ± 10% (within 2 standard errors) for major species in each Forest Inventory Zone (FIZ), and for all species at the subzone level. The FIZ were similar but not the same as currently defined. In 1963 the B.C. Forest Service Inventory Division introduced growth curves using a graphical technique to show the relationship between stand volume for 17 type groups, 7 inventory zones, and 4 site classes. By 1976 there were 1500 growth curves produced for the Province based on 48,000 ground samples

In June 1975, forest management concerns led to the Forestry Commission Review of Timber Rights and Timber Policy led by Pearse (1976a and 1976b). In his report, Pearce indicated that the underlying problem leading to these concerns and conflicts was the need to better account for land use effects on timber supply estimates. He recommended separating forest lands into land-use types as: primary timber production; multiple use; protected areas; or special management zones where the land use objectives and associated forest practices needed further clarification. He indicated the inventory at that time was adequate, albeit somewhat dated; the problem lay with interpretation and having the appropriate information on hand to use the inventory appropriately. Overall, he emphasized the need to clearly identify what was in, versus out of the timber harvesting land base.

4.1.5 1980s: Forest Inventory Program and multiple use information needs

A new forest inventory protocol was introduced starting in 1978 and it contained several significant changes (Thrower, 1992). "These were precipitated largely from a need for more detailed information about forest resources. However, a major factor in the development of the inventory methods in this period was a change in philosophy in the Forest Service of what was needed from the inventory and how the information was to be used. The former inventory was designed to estimate averages of groupings of similar forest types, thus could not provide estimates at the stand level. Consequently, a new sampling methodology was required to supply the information for more stringent demands. This motivated significant changes in classification, sampling, data storage, compilation, and the method for estimating volumes for individual stands." This new standard became known as the Forest Cover (FC) inventory protocol.

The new multi-phase forest inventory divided the province into 12 Forest Inventory Zones (FIZ) based on a combination of forest ecological zones identified by Krajina and administration boundaries. The "Forest Cover" inventory standard of the first phase provided forest inventory type maps using photo-interpretation of analog aerial photographs viewed as stereoscopic images (e.g., color IR stereo-pairs, 1:10,000 to 1:15,000 scale). These forest inventory maps showed stand delineations along with forest attributes (i.e., crown closure, species composition, height class, age class, site index class) and were stored as physical mylar (i.e., plastic) maps that could be overlaid with other mylar maps. The second phase involved selection and measurement of ground samples (i.e., tree list of species, diameter at breast height (DBH), height and other measures), supplemented by Large Scale Photo (LSP) plots (i.e., high-resolution analog 3D stereo-pair aerial photographs on which a tree list of species, crown area, and height of each tree was obtained) to reduce access costs in remote areas. These ground, and LSP plots summaries were used to improve photo-interpreted attributes for each stand in forest inventory maps. With the advent of reliable database software, attribute data for each forest stand were stored electronically with cross-references to analog spatial data stored as mylar inventory maps. Also, models using regression methods were used to relate ground (or LSP) plot attributes such as volume per ha to inventory type attributes (i.e., species composition, age class, height class, and crown closure class) for each FIZ.

Other inventory improvements took place in the 1980s. Whole-tree volume models had been developed in the late 1970s, along with decay, waste, and breakage estimates using data from a wide-scale collection of destructive tree data. In the 1980s, more emphasis was placed on tree taper models that were being researched at UBC by Kozak (e.g., Kozak, 1988) and others using these destructive tree data. With the increasing availability of permanent sample plot data, new growth and yield models were being developed to forecast volume per ha yields over time using forest inventory attributes as inputs, as described later. Site index models were also developed to indicate site productivity of the dominant species, again using destructively sampled tree data. The BEC system was also released and began to be used for a multitude of purposes including in the BC Forest Inventory (Pojar et al., 1987).

Although extensive advances were taking place in forest inventory methods in the 1980s, at the same time, the need for more extensive forest information increased. Demands increased for the use of forests for purposes other than timber production, including: water, recreation, wildlife habitat, cultural values, old growth, and protected areas for ecosystem representation, parks and wilderness. In the mid-1970s, the BC Forest Service had already made efforts to accommodate these demands via more integrated forest management. Using the mylar forest inventory maps, along with base and topography maps as mylar overlays, termed “folios” or “folio systems”, areas of conflict could be identified, allowing decisions to be made that, as much as possible, respected all values and interests, prompting changes in road and timber development as needed. However, in spite of these analyses, there was growing frustration that non-timber demands were not being heard or were not being listened to in a meaningful way. By the end of the 1980s, protests and blockades were becoming a more regular occurrence.

4.1.6 1990s and early 2000s: Adoption of Geographic Information Systems, the Forest Resources Commission, and Vegetation Resources Inventory

Land information capture methods advanced greatly in the 1990s with the development of digital spatial Geographic Information Systems (GIS) that replaced physical maps, stored as analog mylar sheets used to create paper maps (The conversion of hand drafted maps into a digital form had already started in 1979 (Beinhauer, 2011). Two schools of thought developed in GIS circles: 1) polygon-based GIS systems with irregularly shaped objects, better related to differences in forest conditions, roads, land-use, and other maps; versus 2) raster-based GIS systems using square pixels as objects, which better related to advancing remote sensing technologies such as Landsat data. Digital photography became available, and advanced to higher resolutions during this decade. Further research advances in taper models, decay models, and GY models also took place, including further development of tree-level and process growth and yield models as later described.

In BC, the Forest Resources Commission was called into action in 1990 to find a solution to the problems occurring from multiple, conflicting demands on forest lands: How could the myriad of demands that seemed to vary from one region to the next be addressed? In the final report (Peel, 1991), ***the Commission stated that a forest vegetation inventory to underwrite the management of all forest resources, not just timber, was the primary area that needed improvement***. They also emphasized the need to develop regional and local-level land use plans with extensive public consultation. Collectively, the Commission believed that these were the two main solutions for resolving the manifold conflicts that had arisen in various regions of the province.

In response to the Commission's report, the Resource Inventory Committee (RIC) was struck to review the development of a multitude of resources values, with a special task force within RIC commissioned to review the forest vegetation inventory. The forest Vegetation Inventory Task Force completed their work in 1995, with the specifications for a new Vegetation Resource Inventory (VRI; Vegetation Inventory Working Group, 1995). The Task Force emphasized that VRI was developed with the intent of addressing all resource values, albeit with a focus on all aspects of vegetation (e.g., attributes for all vegetation layers, BEC site series), and including provisions for evaluating surficial organic matter (including LFH layers and coarse woody debris), and for soils as part of the ground sampling process. Many of the ecological attributes that were included in the original sample design were, within a few years, dropped from the program.

As with the Forest Inventory Program in the 1980s, VRI was multi-phase design:

- Phase I (aka, Phase 1 in some documents): Forest inventory maps via interpretation of analog (or digital) photographs, with greater spatial (e.g., smaller polygons) and attribute details (e.g., up to four structural layers) than the former Forest Cover (FC) inventory, using ground "calibration plots"), and air calls (i.e., observations made in fly-overs) to improve their forest inventory maps.
- Phase II (aka, Phase 2): Ground sampling using unequal probability selection of plots (i.e., probability proportional to polygon size) and a cluster of ground plots at each selected sample location. These ground plots were used to obtain design-based estimates of volume per ha and other attributes for subsets of the forest land area, and also used to adjust photo- interpreted attributes in forest inventory maps for consistency between design-based ground estimates and photo-based estimates.
- Phase III (aka, Net Volume and Adjustment, NVAF): Destructive sampling of trees within Phase II ground plots. These data were used to adjust individual tree merchantable volume estimates to net volumes using localized tree volume and decay measures.

The expectation of most resource professionals was that the VRI protocols would be implemented for all forest lands of BC and completed within 10 years. However, a number of events precluded this from happening, including a recession in 2000, several reorganizations of BC Ministries, and changes in legislation. In 2001, the responsibility for the vegetation inventory was transferred to the Ministry of Sustainable Resource Management, and the Forest Act was amended, removing responsibility for management of the inventory from the Chief Forester. In 2005, the inventory was reassigned to the Ministry of Forests. However, restoring the Chief Forester's legislated responsibility for inventory was not viewed as necessary for managing forests in a way that fulfills provincial obligations.

As well as the need for improved vegetation leading to RIC and the VRI design, 1990 Forest Resource Commission had recommended developing regional and local-level land use plans with extensive public consultation. Progress was made in the 1990s with Regional Land Use Plans in high conflict areas through the Commission on Resources and Environment (CORE) process. Land and Resource Management Plans (LRMPs) were developed for most of BC. These plans took several years to develop and represented a substantial investment in both volunteer and paid professional time. Implementing and monitoring progress on these plans requires high-quality forest inventory information. Since 2001, very little has been done in this regard due to priorities identified by the BC government.

In 2006, the Association of BC Professional Foresters (ABCPF; now Association of BC Forest Professionals, ABCFP) commissioned a review of the BC Forest Inventory based on members' concerns. Moss et al. (2006) first listed the criteria for a good forest inventory with regards to: i) currency; ii) coverage and sufficiency; iii) forecasting and linking historical and spatial data; scalability; and reliability. They then assessed the BC Forest Inventory relative to this list. Many recommendations were made in regards to the administration of the inventory, including stable and adequate funding, clear lines of responsibility, accessibility of data and products, reporting, and support of innovation and research. One recommendation of note was that the restoration of the legislative responsibility for BC Forest Inventory to the Chief Forester.

4.1.7 2010s: Further inventory evolution and the BC Auditor General's report

In very recent history, forest inventory innovations have continued. Notably, the acquisition of ground measures improved given the general availability of laser and ultrasound emitting devices to improve tree height and distance measures, along with Global Positioning System (GPS) hand-held devices; with access to sub-metre precision enabled by President Clinton in 1996, and made available officially in 2000; Rankin, 2016). Increased use of remote sensing data outside of digital aerial photos has also taken place, notably the use of Landsat data for updating inventory for natural disturbance events. The possible uses of other remote sensing data are in active research, including some operational trials. As well, LiDAR data continue to evolve with increasing spatial and spectral resolutions, and lower acquisition and processing costs. These LiDAR data are particularly useful for high quality terrain information (i.e., DTMs and DEMs); as a result, these DTMs and DEMs are highly sought after for forest operations and forest hydrology at the local scale. There has also been continued development of the Tree and Stand Simulator (TASS) GY model, particularly for expanding the model for more mixed-species stands, along with other active research (See Section 4.3 for more on innovations).

At the same time as these innovations in forest inventory methods, reviews of the forest inventory and the state of forests took place. Moss (2011) produced an update of the Moss et al. (2006) report for the ABCFP. The report indicated that progress had been made in addressing the list of issues noted in the 2006 review, including increased coverage and currency, via a number of changes in methods. However, it also emphasized that funding was not sufficient to adequately meet information needs. The 2012 BC Special Committee on Timber Supply recognized the importance of the need to update forest inventories in the post-MPB era and with special recognition of the opportunity to further develop the BC bio-economy. In 2013, the BC Auditor General's office published a review of the Forest, Lands, and Natural Resources Operations (FLNR) Ministry (now Forest, Lands, Natural Resources Operations, and Rural Development) management of timber resources (Auditor General of BC, 2013). Concerns were raised that long-term timber supply objectives were not being met with adequate investment in silviculture practices, and adequate restocking of harvested areas. FLNR responded with commitments to periodically conduct a re-inventory with assurances that the evaluation of post-free growing stand attribution would be updated. Recommendations were also made regarding young stand growth and yield monitoring.

4.1.8 Forecasting future timber: Brief history of BC growth and yield models

As noted, early yield tables were derived using temporary sample plots (TSPs) measured once since there was an absence of permanent sample plots, resulting in normalized (i.e., average stocking) yield tables by forest type (See Tesch, 1981). The assumption behind developing these tables was that one could "connect the dots" between temporary plots at different ages in a "space for time substitution", as long as these were carefully stratified by species and site characteristics, and "average stocking" plots. However, these yield tables tended to reach a maximum too early and the maximal values were low relative to actual yield trends in time measured by permanent sample plots (Clutter et al. 1983, pages 45 and 46).

Given the problems with yield tables resulting from using temporary plots, permanent sample plots (PSPs) were established across BC forests beginning in the late 1950s/early 1960s. Purposive sampling was used to select a matrix of locations representing a wide variety of stand types at different ages, species compositions, densities, ecological types, and site productivities. Since establishment, most of the PSPs have been measured on more than two occasions.

Using the PSP and other data, alternatives to the early normalized yield tables using TSPs were developed. The first of these was the Variable Density Yield Projection (VDPY) system developed to forecast existing stands (so-called "natural" stands). In this model, stand-level yields (i.e., merchantable volume, basal area per ha, stems per ha) could be forecasted over time as a function of available forest inventory type attributes (i.e., crown closure, species composition, height class, age class, and SI class). Over time, VDYP has undergone a series of changes to the current VDYP7 described in Section 4.2.

As well as VDYP, The Tree and Stand Simulator (TASS; Stand Development Modelling Group, 2017) was developed to model individual tree growth post-harvest (i.e., so-called "managed stands"). TASS was based on the fundamental work by Mitchell (1975) for even-aged, Coastal Douglas-fir trees based on photosynthetic capacity in tree crowns. Mitchell's goal was to be able to model growth for all major commercial species in BC. Over time, TASS (now referred to as TASS II) to include more species, particularly coastal species, and a variety of silvicultural regimes (e.g., improved genetic stocks, spacing, thinning, variable retention harvests, etc.). For this development, PSP, and Experimental Plots (EP) along with destructive sampling for detailed stem and crown attribute modeling were fundamental sources of data. . EP data are from formally designed field experiments of alternative silvicultural regimes including different genetic stocks, fertilization and/or thinning trials, and mixed-species trials; many of these field experiments were established more than 25 years ago, and re-measured over time. Since TASS was fundamentally designed as a research model, the meta-model (See Garcia 2005 for more on GY meta-models) called the Table Interpolation Program for Stand Yields (TIPSY) was developed later on to provide single-cohort monoculture stand-level yields over time.

Although only the TASS program (including TIPSY) and the VDYP program are currently supported by the Ministry, the development of other GY models have been supported by the Ministry in the past. These include: i) SORTIE-ND, a semi-process-based individual tree growth model that uses light interception for regeneration and growth, based on work by Canham and then in BC by Coates (e.g., Canham et al., 2004); and ii) Prognosis^{BC} that forecasts individual trees in mixed-species, complex structured forests under complete or partial harvests, based on early work by Stage (1973)[4]. The motivation behind these other models was to provide forecast models for a wider amplitude of BC forest types and silvicultural systems. However, these models are not currently supported because of budget constraints and other considerations.

Other GY models have been developed for BC forests outside of the BC government (e.g., the stock and stand projection model by Jang et al., 2018). Perhaps most notable in this regard is the Mixedwood Growth Model (MGM) that has been developed and maintained at the University of Alberta, Faculty of Agriculture and Life Sciences (see Bokalo et al. 2013).

Both TASS and VDYP are currently developed and maintained within FAIB with support from the Resource Practices Branch who manage the EP program. As supported models, both TIPSY and VDYP are made available for public use with a Graphic User Interface or batch processing. Although not currently supported by the Ministry, Prognosis^{BC} continues to be supported by ESSA, a consulting firm, and was made available for use for silvicultural gaming and to develop yield tables for mixed-species, complex structured stands[5].

Of great concern for continued improvement of GY models, irregular and often inadequate funding of the BC Forest Inventory Program over time has resulted in legacy PSPs being dropped and others not measured or maintained for long periods. Since these data represent very long time series critical for accurate and realistic models of growth and yield trends, there are no substitutes for these PSPs in building and improving GY models. In more recent years the program has received stable funding and been managed in a way that is sensitive to this issue. The goal here is to underline the importance of stable and adequate funding for the PSP program.

Finally, an important note is that the development of TASS and VDYP has historically not been the responsibility of one group of GY modelling experts. TASS was developed within the Research Branch of the Ministry of Forests, with consultants and university experts for some aspects, until the Branch was dismantled in 2011. VDYP was developed as an inventory tool within the former Resources Inventory Branch. Prognosis^{BC} and other models including SortieND were developed using experts from the former Research Branch, the ESSA consulting firm, former Silviculture Branch, and universities (i.e., UBC and UNBC).

4.1.9 Overall trends in BC Forest Inventory Program history: Increasing information needs, decreasing budgets, making efficiencies

Throughout the history of the BC Forest Inventory Program, concerns have been expressed by information users regarding the available forest resource information versus information needs. These resource information needs have been steadily increasing over time, but this trend has accelerated in the last 15 years. At the same time, the resources allocated to this program have decreased (Figure 3.1) with a notable decline in 2010. This has challenged the Ministry staff to meet base information needs while responding to urgent needs. Of note, the major MPB and fire disturbances have necessitated the diversion of resources to update forest inventory information for the large land areas and adjacent communities affected.

A notable change over time is the reduction in dependence on ground-based sample plots in the process for constructing the BC Forest Inventory. To reduce this gap between information needs

[4] See https://www.for.gov.bc.ca/hfp/silviculture/Prognosis.htm. [Accessed September 12, 2018].
[5] See https://essa.com/?viba_portfolio=fvs-prognosis. [Accessed September 12, 2018]

and available resources, emerging technologies and associated reductions in ground information were deployed. This began with early adoption of aerial photography, and became more apparent in the late 80's after abandoning ground sampling within a multiphase design due to difficulties in implementation and technical problems involving the use of 70 mm aerial photography (Thrower, 1998). Each potential technology has required development of appropriate methods using data to reliably and efficiently provide the needed information, along with staff training. The methods have become more complex in time, also, corresponding with the use of ever-increasing multi-source data. This is becoming increasingly apparent in the transition from analogue photogrammetric techniques combined with extensive use of human intervention for purposes of interpretation. There is a strong movement into a digital world with increasing kinds and numbers of sensors, kinds of techniques for processing the resultant data, and kinds of associated statistical techniques for relating either ground or photo plot sample data to imagery and other kinds of attributes and indices. These techniques significantly extend the range of possibilities for how forest inventory can be advanced into the future and has the potential to change the nature of the skills necessary to do it.

Another notable change over time is the increased interest of a variety of professionals and public groups, for larger spatial extents, and for a greater range of resources. The focus in early history was mostly on timber information by those directly involved with the timber industry, that later extended to include better accounting for habitat, water, and other resources over time. The advent of the internet and then social media has greatly increased the number of people in BC and worldwide expressing concerns about forest lands of BC.

Overall, this gap in needs versus resourcing has been a concern throughout history. Periodic outbursts of conflict and concern for sustainability of forest resources has drawn attention to this gap and has often been accompanied with added resources in the short-term, but not sustained over the longer-term. The most recent cycle in these events was initiated with the 1990 Forest Resources Commission. In spite of efficiencies made in using emerging technologies, the increased information needs versus decreased resourcing has led to great concerns by resource professionals and public groups.

4.2 Current BC Forest Inventory Program

4.2.1 Overview

The BC Forest Inventory Program provides a strategic, rather than an operational inventory, at the management unit level (e.g., District, Timber Supply Area (TSA) or Tree Farm License (TFL). The current BC Forest Inventory System uses a mixture of primary data from aerial photographs (aka air photos), Landsat and other remotely sensed data (e.g., LiDAR, SPOT, MODIS, large-scale photo-plots, etc.), ground plots (i.e., temporary and permanent plots), and destructive sampling of trees. Other spatial coverage information is also used, in particular, base maps and topography data (e.g., DataBC for Geospatial data).

Collectively, this information is used to provide the main products of forest inventories, namely:
i) land cover classification and forest inventory type maps updated to current dates; iii) forest attributes for each stand in the forest inventory type maps; and ii) growth and yield models to forecast the future forest under different management scenarios. Ancillary products critical for forest inventory are also produced, in particular: i) site productivity maps and models; and ii) individual tree volume, taper, decay (waste and breakage), and biomass models. As well, all

primary data and derived data (e.g., summary of ground plots, forest inventory maps, growth and yield models, etc.) are products in themselves used for a variety of purposes, including informing re-inventories. The approaches to gather and use the primary data in producing forest inventory products have changed over time in BC, as noted in Section 4.1 of this report. The approaches also vary among jurisdictions in Canada and elsewhere, as noted in Section 5.2. However, the underlying concepts and forest inventory products have been relatively consistent over time and worldwide.

4.2.2 Forest inventory map and attribute information

The current BC Forest Inventory system is illustrated in Figure 4.1. The forest inventory information (aka "stand map", "forest polygons") varies by the year when information was first acquired (Figure 4.2; Reference Date). Also, this information is currently based on one of three protocols depending on the location in the province, namely, Vegetation Resources Inventory (VRI) Phase I, (referred to as the "V" standard where there is complete Phase I photo-attribution), Forest Cover (FC) protocols ("F" standard) and a third standard where incomplete VRI attribution is applied (the "I" standard; see Figure 4.3). The "I" standard is applied in situations where limited information may be available. It tends to occur sporadically within a map and never constitutes the majority of a map sheet (pers. comm. FAIB Staff, 2018). The Landscape Vegetation Inventory (LVI) is one means of meeting the "I" standard with a primary focus on describing stands in terms of layer 1 attributes. Consideration is being given to creating separate "LVI" and "LEFI" standards in addition to those that already exist (pers. comm. FAIB Staff, 2018). The large Cassiar Timber Supply Area in the northwest corner of the province, indicated as being of 1970 to 1979 vintage (Figure 4.3), is currently being updated using the LVI protocol and expected to be completed by the end of this fiscal-year.

Areas with the oldest Reference Date were based on FC inventory protocols from the 1984 forest inventory and are found primarily in the northwest parts of BC with very limited road access (Figures 4. 2 and 4.3). The area under FC inventory has been decreasing, particularly since this was one of the objectives of the 2012-2022 Strategic Plan (FLNR, 2013).

For approximately half of BC forests, forest inventory information is based on VRI protocols implemented in 1994 (FAIB Staff, 2018; Figure 4.4). Areas are prioritized for VRI Phase I inventory (or re-inventory) based on greatest need (FLNR, 2013). Recent re-inventory projects include MPB- affected areas (FAIB, 2015a) and other special coastal areas high priority areas (FAIB, 2015b) scheduled for completion in 2018. VRI forest inventory data are stored, displayed and updated (later described) using the Vegetation Resource Inventory Management System (VRIMS) database (FAIB, 2015c); VRIMS was developed for data submission and quality control.

In the VRI Phase I protocols, forest inventory data are provided by photo-interpreters who use softcopy (digital) air photos (spatial resolution of ~ 25 cm Ground Surface Distance (GSD) for a ~1:15,000 scale; red, green, blue and near infrared bands (RGBIR); overlapping photos for stereo (i.e., 3D) viewing) in a multistep approach:

1) Forested areas are first separated from non-forest lands using BC Land Cover Classification (BCLCC) protocols (*Vegetation Resources Inventory: Photo Interpretation* Procedures, FAIB, 2017c).

2) Forested areas are then delineated into reasonably homogenous polygons (minimum of 0.5 ha in size).

3) Forest attributes, including both vegetation and non-vegetation characteristics, are estimated (note heights of individual trees are sometimes “measured” using stereo pair imagery as basis for making such estimates) or interpreted (estimated in accordance with photo interpreter knowledge and experience) for each delineated stand. To interpret these attributes, interpreters use their experience, as well as variety of information sources including: field checks by interpreters; available cruise and other ground plot data; historic data (e.g., prior forest inventory field data; information in the RESULTS (REporting Silviculture Updates and Land status Tracking System) database; and local information provided by Ministry and other forest professionals.

4) Existing site index and growth and yield models (e.g., VDYP later described) are used to obtain estimates of site index, volume per ha, and other attributes from interpreted attributes.

Interpreters may divide structurally complex stands into a maximum of nine layers, but in practice the maximum is observed to be three, with layer 1 representing the top of canopy trees. With respect to silviculture the maximum number of layers is four when using a multi-story survey: mature (silviculture layer 1; ≥ 12.5 cm dbh), pole (SL 2; 7.5 to 12.49 cm dbh), sapling (SL 3, 1.3 m in height to 7.49 cm dbh), and regeneration (SL 4; < 1.3 m in height; Resource Practices Branch, 2016).

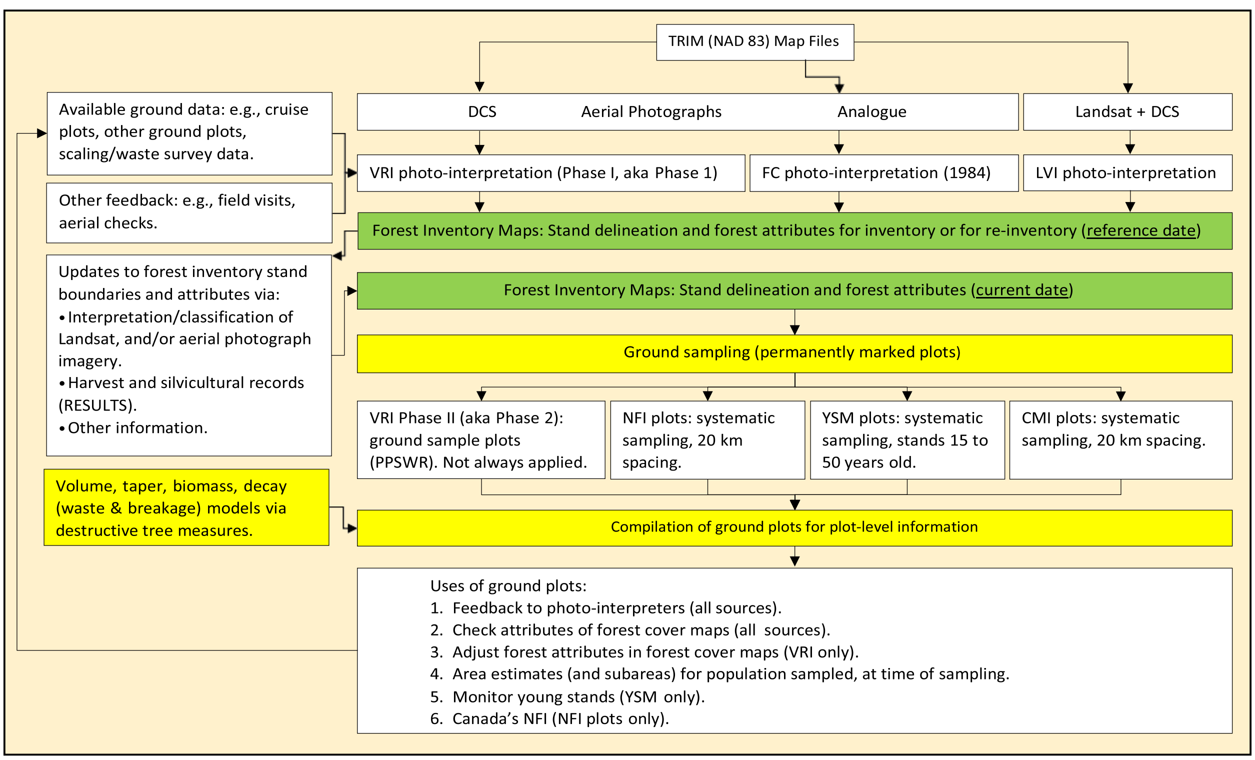

Figure 4.1. BC Forest Inventory system. Green highlights indicate critical forest inventory products, whereas yellow highlights indicate essential ancillary products.

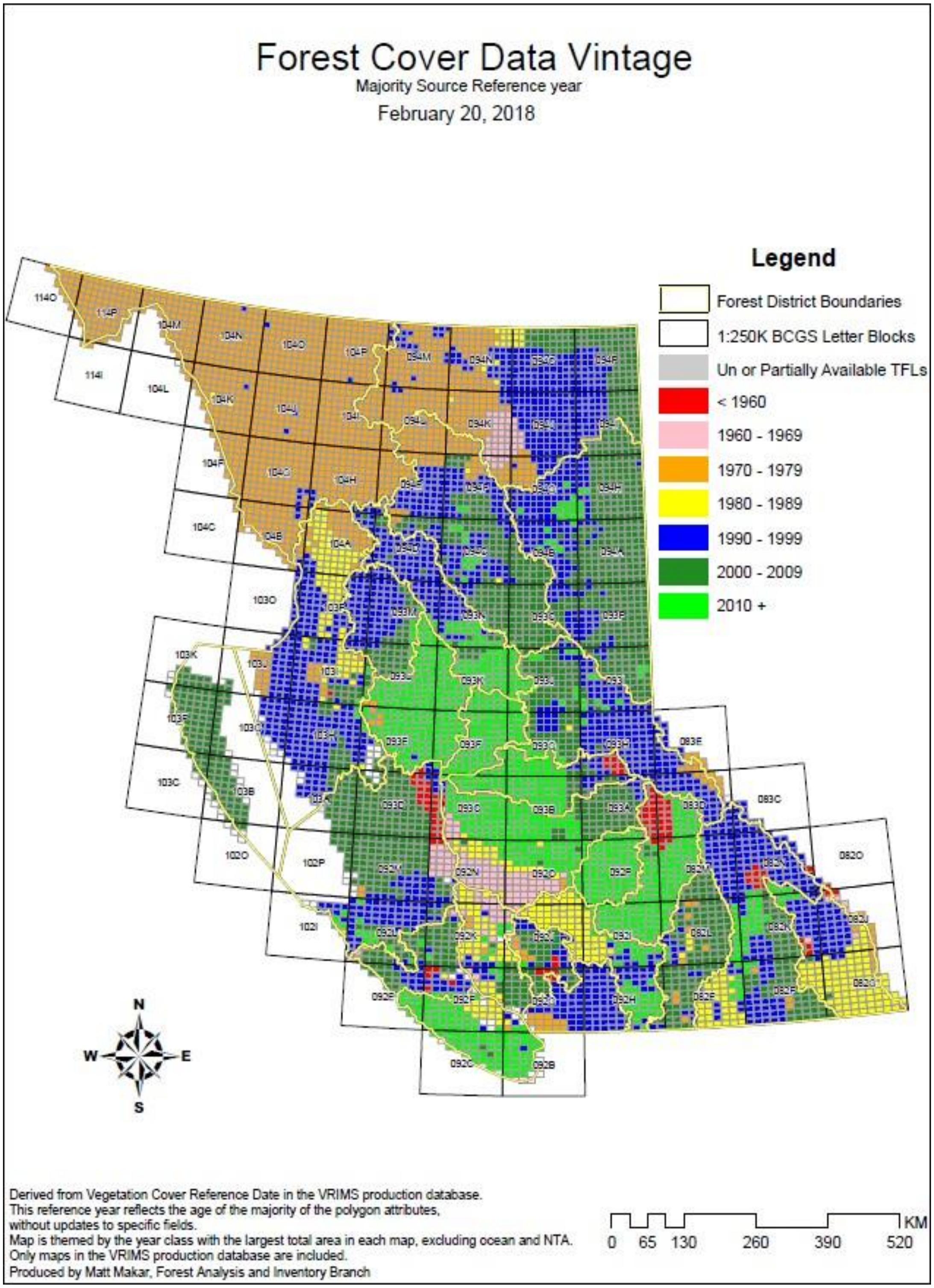

Figure 4.2 BC Forest Inventory dates of last inventory (i.e., Reference Date).

Yellow lines indicate Timber Supply Areas (Source: Presentation by FAIB Staff to the Blue Ribbon Panel, April, 2018; yellow lines delineate Timber Supply Areas). NOTE: VRI protocols were released in 1994.

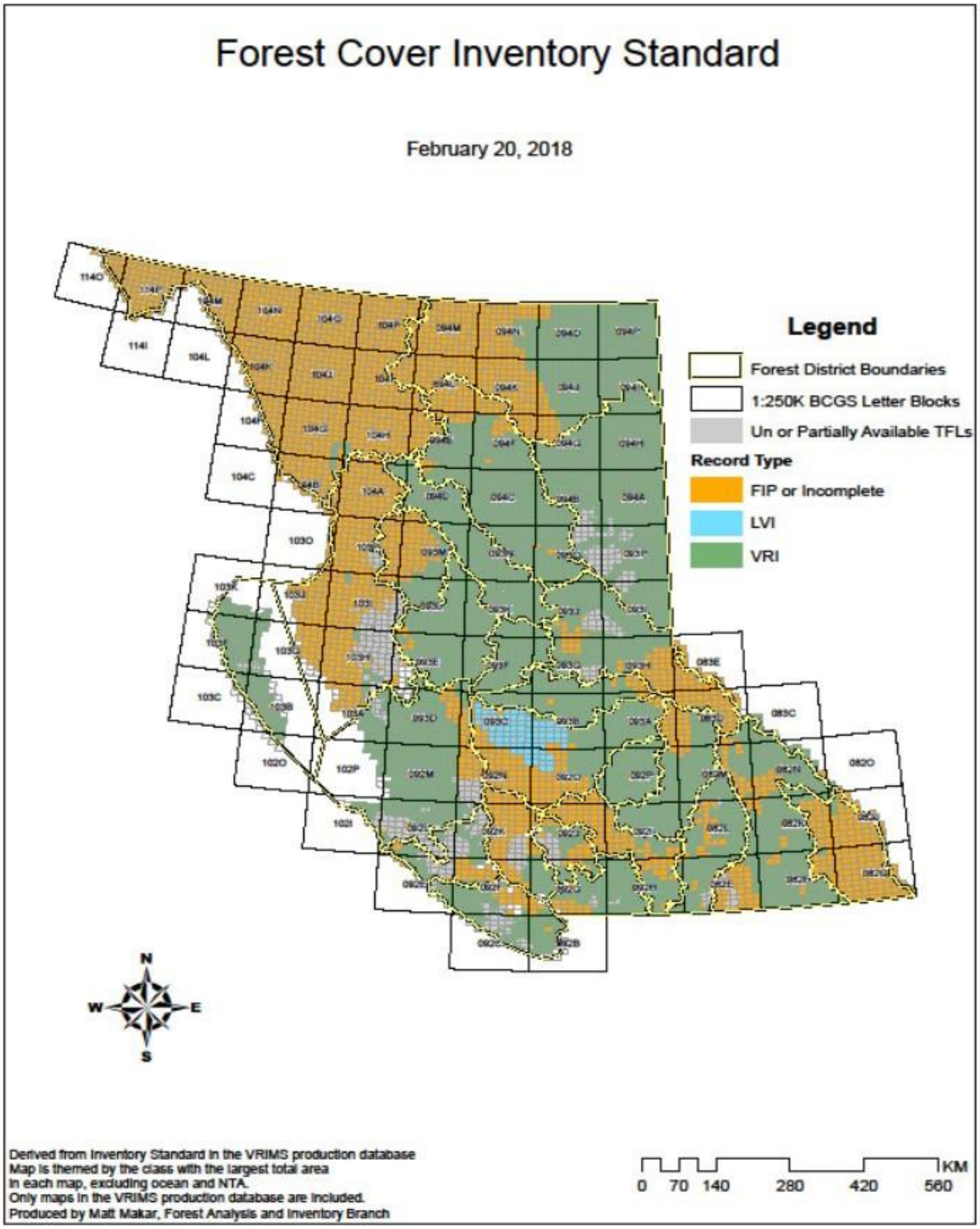

Figure 4.3 BC Forest Inventory forest inventory mapping coverage by inventory standard (FAIB Staff, 2018). NOTE: FC was the Forest Cover inventory standard prior to the VRI protocols in 1994, and LVI is a simplified protocol relative to VRI Phase I.

Of note, recent changes to the VRI Phase I photo-interpretation protocols have included protocols for interpreting attributes of dead trees, particularly in MPB-impacted areas (FAIB 2017c).

All VRI Phase I projects are subject to internal Quality Control (QC) procedures as applied by contractors when undertaking field and/or photo interpretation work. Quality Assurance (QA) is completed by independent parties at the direction of FAIB and in accordance with published VRI QA standards. QA is a more comprehensive set of procedures when compared with QC.

Using the two recent projects as a basis (FAIB 2015a in BC Interior and 2015b in BC Coast), the total cost of obtaining VRI Phase I maps (spatial and attribute data) is about $1.50/ha for aerial photo interpretation including field checks by interpreters and built-in QC costs. Added to this is the cost imagery acquisition of $0.40/ha for a total $1.90/ha.

Forest inventory information, particularly, layer 1, is made available for public use on a website. This information is very frequently downloaded (FAIB Staff, 2018).

The use of LVI protocols as an alternative to VRI Phase I is relatively recent (Penner, 2014a; FAIB Staff, 2018). LVI uses Landsat data along with a systematic sample of aerial photos (DAPs) in a model-based approach to obtain a forest inventory map. LVI is lower cost than VRI (approximately $0.12/ha for LVI, including photo acquisition and aerial photo interpretation, plus $0.26/ha for audit plots, for a total of $0.36/ha, producing a savings of around $1.54/ha) and reduces the workload of photo-interpreters, but does not provide the same forest inventory details as VRI Phase I. However, this level of forest inventory information is sufficient for areas that are utilized to a small extent, and or managed with low intensity, or for consideration of management decisions on broader scales. It may be as good as VRI for purposes of "broad strategic planning" but is likely to be less reliable for "operational decision-making." The introduction of LVI is contributed toward the goals of complete coverage of BC's forests as stated in the 2012-2022 Strategic Plan (FAIB, 2018a).

4.2.3 Updating forest inventory information to Current Date

Although the reference dates of the forest inventory maps vary over the province (Figure 4.3), all forest inventory maps are regularly updated for natural and human disturbances using a variety of information sources, along with undisturbed areas projected forward to the Current Date (Figure 4.1). Wildfires, particularly larger areas (e.g. > 100 ha) are mapped using Landsat based severity mapping. In some cases, particularly where large areas are impacted, the Landsat disturbance severity mapping may (later) be supplemented with vegetation resource re-inventory using aerial photography. Recent disturbances due to insects (e.g. MPB) and other damage agents are evaluated on a Province-wide basis using Forest Health Aerial Overview flight surveys generally carried out between early July and late August of each year (Resources Practices Branch, 2000). Data from these surveys are maintained separately from the Vegetation Resource Inventory, but are generally considered when undertaking a Timber Supply Review. Depending on the cumulative severity and extent of damage with time, a re-inventory may be instituted. Harvest information provided by licensees and forest professionals is another source of update information that is supplied through the RESULTS database. Only data, as it pertains to forest inventory, is directly transferred from RESULTS into the forest inventory system through VRIMS (FAIB Staff, 2018)

Under the current BC Forest Inventory Program budget (See Figure 4.1), there is a backlog of areas that require updating (FAIB Staff, 2018). In some cases, information on harvest, silvicultural activities, and other disturbance updates are available, but have not yet been transferred to the forest inventory database. In other cases, information is not yet available. The current update cycle for disturbance and regeneration is to be completed every year after the May 31 reporting deadline for licensees (pers. comm.,FAIB Staff, 2018). The update team is to process all new disturbances and regeneration surveys reported by TSA prior to making the projected inventory available to the public. This means the currently available public inventory is at most 18 months out of date and at best 6 months (all of this work being done currently by 3 staff). There is currently a small backlog of approximately 30,000 Free Growing openings that still need to be integrated into the Provincial inventory. These are currently being processed and prepared for integration into the forest inventory.

4.2.4 Ground Plots

As noted, available ground data (including available cruise plots, permanent plots, etc.) and field checks ("ground calls") by interpreters are used in the VRI Phase I process. The BC forest inventory system utilizes a variety of ground plot data to modify and audit forest inventory maps (Figure 4.1, Ground Sampling). These plots are compiled to obtain plot-level data from tree-level data using volume, taper, decay, and biomass models developed from a database of historic and new destructively-sampled individual trees (i.e., felled and segmented). Since these plots can be drawn from a variety of programs where ground plots are collected for the specific use of that program of a specific government agency, variations in how these plots are compiled to the plot level exist (e.g., different taper/volume/biomass/decay models used for cruise plots versus YSM, NFI, etc.). Inconsistencies amongst the programs make it more difficult to use different sources of information, be that for model development, imputation, or verification, testing, and validation purposes.

In the original VRI protocols, VRI Phase II ground plots were selected using an Ordered Systematic (OS) protocol, otherwise referred to as being based on systematic sample starting with a sorted list. This was subsequently changed using a multistage design with probability proportional to polygon size with replacement (PPSWR). At each sample point, a cluster of variable-radius ground plots was located. The VRI Phase II ground plots were the primary focus of the original VRI design since they could be summarized using *design-based estimators* (i.e., known sampling probabilities are used) to obtain unbiased estimates of forest areas. These ground plots were also used to adjust attributes of the VRI Phase I maps using *model-assisted estimators* (i.e., using the known sampling probabilities as weights in building models). Further, some trees on these ground plots were destructively sampled and used to obtain local volume, taper, and decay (and waste) information, termed Net Volume Adjustment Factoring (NVAF sampling; Phase III).

However, in the current Forest Inventory system, the VRI Phase II ground plots are not commonly used for adjustment. They continue to be used along with CMI and YSM plots for purposes of audit. Within the context of the original VRI design, NVAF sampling has been temporarily put on hold while the process for data collection and analyses is under review (FAIB Staff, 2018).

The original VRI sample design is undergoing change as follows: Instead of VRI Phase II ground samples, a combination of National Forest Inventory (NFI) plots that contribute to Canada's forest inventory (CFS, 2018), along with the BC Change Monitoring Inventory (CMI), and Young Stand Monitoring (YSM) plots are increasingly being used to audit the Phase I information and may be used to adjust the associated inventory attributes (Figure 4.1, Ground Sampling). All of these protocols include tagging of trees at the time of plot establishment. Systematic sampling (i.e., equal probability sampling) is based on use of a grid (the NFI grid in the case of CMI plots) to select plot locations and establish fixed-area plots (single or nested plots) at each location. Within this framework there may still be need for additional ground plots that in turn may be established within a more intensive grid, or alternatively following the Phase II sampling design with PPSWR. The NVAF program is being reviewed in part, to better determine where and how it should be implemented in combination with CMI plots in lieu of these changes.

In the NFI, photo-plots are located over a very widely spaced grid (20 X 20 km) and a subset of these is selected for ground sampling. CMI uses the same spacing as NFI; ground plots are established at many locations in forested lands in particular. Narrower spacing is used for YSM and Audit Plots (FAIB Staff, 2018; see also FAIB, 2018a). The intent is that at least some of these CMI ground plots will be periodically re-measured; therefore, these plots (and trees, in some cases) are permanently marked (FAIB, 2018a). Re-measurement of the CMI plots has already begun. The goal continues to be to obtain more complete CMI plot ground representation of NFI plots across the province, particularly in forested areas, and to then focus on re-measurement thereafter.

For the BC forest inventory, these systematically sampled ground plots serve a variety of purposes, in particular:

1) YSM provides a design-based check on management plan assumptions used in TSR (to help evaluate if second growth stands are meeting timber supply expectations) and to serve as an independent source of data for implementing site index adjustments.

2) To assess the accuracy of the Current Date forest inventory maps and/or make inventory adjustments. VRI Phase II (audit) plots, perhaps including YSM, NFI, and/or CMI data, and to produce a wide variety of *model-assisted* or *model-based estimators* of forest and non-forest attributes (i.e., sampling probabilities are not used/needed for building models);

3) To contribute to Canada's NFI (NFI plots with or without the use of CMI plot data);

4) To possibly modify the Current Date key tree cover attributes; and

5) To obtain unbiased estimates of forest area attributes using audit plots and design- based estimators assuming equal probabilities for the systematically located plots.

The systematically established plots are specifically not currently used to assist in the process of VRI Phase I photo interpretation as a result of being used for purposes of audit. There are currently 2,414 NFI photo plots established on a 20 km x 20 km grid. Of these, 268 are ground sampled using the full NFI ground plot measurement protocols (FAIB, 2018c). An additional 549 CMI plots have also been established on this same grid, with 497 of these contained within the south and central portions of interior BC. The number of CMI plots is expected to increase in years in coming years to obtain more complete coverage of the province as a whole.

The rationale for the YSM program was outlined by FAIB (2011) in a report entitled, "Why we need to monitor change in our managed forests." The concept grew out of deliberations of a Growth and Yield Monitoring Task Force in 1996 that culminated in the design of the CMI protocol. With respect to YSM, Associated Strategic Consulting Experts Ltd (2016) reported on the results of having established 452 YSM plots in ESSF, ICH, IDF, MS, SBPS, and SBS Biogeoclimatic Zones in Interior TSAs.. An additional 43 ground plots were subsequently established and measured in Haida Gwaii in the CWH biogeoclimatic zone (FAIB, 2017e).

As well as these ground-sampling programs within the Forest Inventory Program, other ground data can be used by photo-interpreters, including:

1) Purposively-selected Permanent Sample Plots (PSPs; see Omule, 2015) to support growth and yield modelling (described next);
2) Operational cruise plots on areas that are planned for imminent harvest to support the Timber Appraisal System (i.e., cruise or scale-based sales)[6].
3) Ground plots of silvicultural surveys (e.g., stocking and free-to-grow surveys);
4) Stand Development Monitoring (SDM; see Snetsinger, 2011; and Ken, 2014) plots on harvested areas i.e., similar to the YSM program, but with different outcomes (McWilliams, 2015);
5) Experimental Plots as part of designed-experiments, also used to support growth and yield modelling;
6) Ground plots to support LiDAR Enhanced Forest Inventory (LEFI; described in Section 4.3 on innovations; FAIB, 2016) research and operational trials; and
7) Research plots which vary greatly in coverage, how they are located, the type of plot, and what is measured depending upon the research objectives.

Most of these plots have unknown sampling probabilities, including large LiDAR plots (other than those that are CMI Plots) and PSPs. Known probabilities are not of concern when the plots are used for purposes of photo calibration. Operational cruise plots are located using design-based sampling protocols with known probabilities; however, the population covered is planned harvest areas. Given that these plots generally do not have known sampling probabilities, to use these alone or in combination with the CMI, NFI, and YSM ground plots (that do have known probabilities), is to require *model-based estimators* (as opposed to *design-based* estimators) that assume the model is correct, as is commonly done in LEFI.

4.2.5 Re-inventory

Even though forest inventory information is regularly updated to Current Date, re-inventory is eventually needed. The timing of re-inventory varies, since the urgency depends on the levels of natural and human disturbances since the last inventory. For example, recent re-inventories include MPB-affected areas in the Fort St. James District (FAIB, 2015a) as well as other special, high priority South Vancouver Island areas (FAIB, 2015b) that are scheduled for completion in 2018. For re-inventory, the existing forest cover information is used as one source of data for photo-interpreters. Also, stakeholders are consulted with regards to particular forest inventory map issues of concern. For the Fort St. James project, stakeholders were particularly concerned about information on dead trees. The VRI Phase I standards were updated in 2017 and now include enhanced protocols for dead trees that will be used in this re-inventory project. Since there is a very limited budget for the BC Forest Inventory Program, resources allocated to re-inventory

[6] See https://www2.gov.bc.ca/gov/content/industry/forestry/competitive-forest-industry/timber-pricing/timber-cruising/timber-cruising-manual [Accessed September 13, 2018]

projects must be balanced with inventory projects (i.e., covered by FC inventory protocols not VRI), and innovative projects on forest inventory enhancements.

4.2.6 Forecasting future forests using Growth and Yield Models

Growth and yield (GY) models are vital tools for forecasting future forests under different management regimes. They can also be used to update stand attributes in forest inventory type maps to Current Date (See Section 4.2). As a result, GY models must: i) cover all forest types in BC; ii) forecast a wide variety of harvest/silvicultural options; and iii) be accurate, including providing biologically possible outcomes, and realistically representing growth trends over time. Further, it must be possible to connect these GY models to the forest inventory information; inputs needed to drive the GY models must be available directly as attributes for each forest inventory type polygon or available indirectly via models between ground measured and photo-measured attributes.

The BC Forest Inventory Program includes the development of GY models that connect to the forest inventory information to forecast future forests. As noted in Section 4.1, several GY models have been supported by the Ministry in the past, but only VDYP and TASS /TIPSY are currently supported (Figure 4.4).

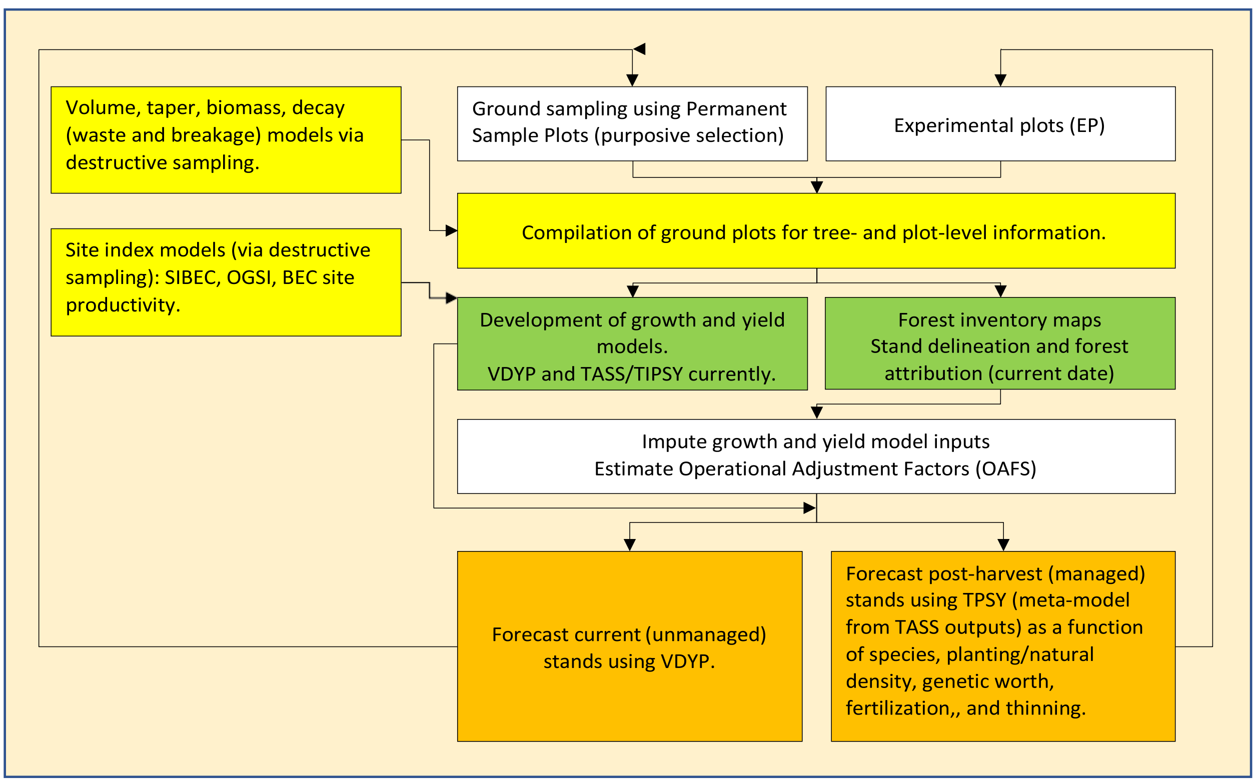

Figure 4.4 Forecasting future forests using growth and yield models.

VDYP

VDYP is a stand-level model that uses the attributes for existing stands at the time of the inventory (i.e., termed *natural or unmanaged stands*) of the forest inventory database to forecast future stands under no human and no natural epidemic disturbances. The current version is VDYP7, which differs from prior version, in that the underlying models are both growth and yield models (Flewelling, 2007). Previous versions were developed to estimate yields with respect to changes in height without accounting for changes observed by way of plot re-measurement (i.e. growth). Since the VDYP model inputs are available as forest inventory attributes, VDYP is routinely used to update the forest inventory and to forecast future timber supplies and future forest conditions (FAIB Staff, 2018).

VDYP7 is a growth model that uses average height, average age, site productivity, species composition, and basal area per ha as inputs; yields are obtained via aggregation of growth for each future year (Flewelling, 2007). These input variables are available in the VRI Forest Cover database for each stand. Unlike previous versions of VDYP that used forest crown cover percent as the measure of stocking, VDYP7 uses basal area per ha. This stocking measure is critical for yield forecasts, but basal area is difficult to reliably estimate using photo-interpretation. Interpreters must rely heavily on field visits, as well as available ground data and other information to obtain basal area estimates on each forest inventory polygon.

For mixed-species stands, VDYP7 forecasts the future stand under the assumption that the composition of the stand will remain the same for the forecast period; no successional changes in species are simulated. VDYP7 includes mortality due to competition and endemic natural disturbances as represented in the TSP and PSP data. To simulate unmanaged stand yields post-harvest or following epidemic disturbance (e.g., fire causing partial or complete stands removals), assumptions must be made regarding the attributes of the regenerating stand. For example, the new stand could have the same site productivity and species composition as the old stand, but the age, height and basal area per ha will be "reset" in time.

For timber supply and other analysis, a batch version of VDYP7 is used. VDYP7 is also used to estimate volume per ha and other forest attributes of each forest stand in the forest inventory information at the Reference Date and to forecast these attributes for the Current Date forest inventory information. As such, VDYP7 directly connects to the VRIMS database.

TASS/TIPSY

TASS is a single-tree, distance-dependent growth model that forecasts stands post-harvest (i.e., termed *managed stands*). As noted, TASS was developed as a research model following Mitchell (1975), originally designed to simulate even-aged white spruce stands. Over the approximate 40 years of development in BC, TASS was expanded to simulate a variety of BC Coastal species under thinning, fertilization, and improved genetic stocks. TASS does not explicitly model mixed-species stands nor partial harvests in irregular stand conditions. Post-harvest yields derived from different species, or cut versus uncut areas representing different cohorts, can be estimated using TIPSY, that in turn is constructed using TASS outputs. For example, a 50% Coastal Douglas-fir and 50% western hemlock post-harvest stand may be represented as two separate stands with each contributing ½ of the land area so as to represent a single stand. For variable retention harvesting, the area can be separated into uncut and cut areas, each with a different set of attributes. For example, the resultant conditions can be described as a combination of residual stand attributes (remaining trees or sets of trees to represent the estimated proportion of uncut area), and the expected regeneration outcomes (representing the estimated cut-over proportion of area). Each of these can be grown as separate cohorts and combined, or not, as deemed necessary to complete a process of simulating stand development with time. TASS (FAIB, 2018) was expanded to provide product mixtures as yield outputs, and financial analyses of costs and benefits (i.e., SYLVER/FAN$Y) (Stand Development Modelling Group, 2017). The current version of TASS II is not generally available for public use.

More recently, a new version of TASS III was distributed as an executable engine with a graphical user interface. It includes more realistic simulations of mixed species stands and cohorts and currently provides for two Interior BC species, white spruce and lodgepole pine. It is recommended for mixed species and partial harvests, because it simulates these dynamics more realistically by using light interception levels and species relative shade tolerances to govern crown recession and mortality.

As noted earlier, a meta-model was developed to access a database of TASS II outputs for different stands, termed TIPSY, and is used for post-harvest managed stands in timber supply and other analyses. TASS III outputs are also being made available through TIPSY. TIPSY uses stand-level input variables for post-harvest stands to forecast future yields. Silvicultural treatments including fertilization, thinning, and improved genetics stocks can be simulated, if available in the database of TASS runs. As well, the FAIB TASS group can simulate specific stand conditions required for timber supply analysis. Since TASS III includes only a limited number of mixed-species managed stand types, assumptions must be made in using TASS II to simulate most types of mixed-species managed stands of BC as already described above.

4.3 New Technologies and Innovation

4.3.1 Overview

Although forest inventory approaches have historically used remotely sensed data for about 100 years, the recent availability of a large variety of remotely sensed data has increased the interest in using more of these data sources to obtain forest inventory information. The main drivers for this interest are:

- Forest inventories for strategic analyses can be costly depending on the levels of accuracy required for in support of good decision-making. Careful use of remotely sensed data can reduce costs, while maintaining similar accuracies, spatial resolution, and kinds of attributes (see Snook et al., 1987, Morgan et al., 2010, and White at al., 2016 for further discussion on this topic). Thompson et al., 2007 discusses what to use and how are best established according to prior successes and the results of recent research projects in decision-making. The discussion includes accuracy assessments of given products, and also further consideration to the implications with respect to intended applications. A reduction in the cost of forest inventory can translate into better coverage in BC that includes more current information (e.g., LVI now used for some areas of BC).
- LiDAR data can be used as part of a multi-source data, forest inventory system to provide information at a higher spatial resolution. Accurate DEM/DTM can be produced using LiDAR data and these more accurate data DEMs can vastly improve harvest and road engineering. As a result, for forest areas under active harvest, the cost of LiDAR for forest

inventory use is often considered a “free” added-on benefit of LiDAR acquisition for other purposes.
- As well as LiDAR data, digital aerial photos (DAPs) viewed in 3D have seen a resurgence in literature for providing within-stand details (e.g. see St-Onge et al., 2015).
- Research and limited trials using new technologies have shown that reasonably accurate operational-level forest inventories (i.e. fit for operational application(s) at finer spatial scales (i.e. at high resolution) can be achieved at comparable or lower costs using model-based approaches and a mixture of remotely sensed data (e.g. see Uddin et al. 2015).
- New technologies are being actively developed including unmanned aerial vehicles (UAVs) and citizen science data collection. These are very new technologies that are just now being researched for potential uses in obtaining forest inventory and habitat information at lower costs.

There are also increasing pressures for improved GY models. The main driver is the need for more detailed within-stand information forecasted in time, including:
- Stand and stock tables showing tree and species distributions of stems and volume per ha, for product analyses, value analyses, species diversity, and habitat analyses.
- Dead trees and coarse woody debris needed for habitat analyses, fire risk analyses near communities, and carbon accounting, as well as for valuing stands for products that may utilize these materials including biofuels.
- Growth and yield under different climate scenarios.
- Growth and yield responses to disturbance agents (e.g., rusts, insects, etc.)
- Growth and yield responses to a wide variety of harvest/silvicultural regimes, such as variable retention harvests, patch cuts, single-tree harvests, improved genetic stocks, species mixtures, fertilization, etc.

A complete review of the uses of new remote-sensing technologies, including large variety of model-based approaches, as well GY innovations is beyond the scope of this report. Some brief statements on the use of the multitude of remote sensing data types for forest inventory are presented first. Then, examples of operational trials and use of new technologies in BC are given. A few examples of very recent research that and emerging technologies that show promise for implementation are given. For a more complete views of some of these innovations see: i) White et al. (2016) on the use of LiDAR, terrestrial laser scanning, digital photography, and high spatial resolution imagery for enhanced forest inventory; ii) Wulder et al., 2016 for remote sensing data used for land cover; ii) Eskelson et al. (2009) and Chririci et al. (2016) for an overview of distribution free (aka, nonparametric in some papers) model-based approaches. Finally, some statements are made on GY innovations, particularly with regards to forecasting stands for large-scale analyses.

4.3.2 Remote sensing imagery for forestry

Remote sensing data available freely or for purchase has accelerated, increasing the spatial resolution, the spectral resolution (i.e., the range of wavelengths covered and the number of bands within this range), and the temporal resolution. As noted in the very popular and multiple edition “Forest Mensuration” textbook by Kershaw et al. (2017):

“In theory, the ideal remote sensing approach for forestry and forest ecology would be operated from a satellite, would provide frequent or on - demand coverage anywhere in

the world (with seamless, wall - to - wall coverage also available over large regions), and would use a combination of active and passive sensors (so that it could be operated at night, and so that in the daytime the imagery would be unaffected by nuisances such as terrain and solar angle). It would have very fine spatial resolution, high spectral resolution across a broad swath of the electromagnetic spectrum, and high dynamic range along with radiometric resolution and fidelity. It could be used not only for two dimensional mapping, but also for three - dimensional measurements such as ground elevation and tree height. Moreover, data could be acquired even through dust, smoke, or clouds. The data would be freely available and could be stored and processed using simple techniques using inexpensive computers or even handheld devices in the field. Of course, ***no such data exist or are likely to in the future****. Real data sources are associated with tradeoffs between coverage, availability, resolution, and other characteristics. All of these factors, plus cost (which includes both the cost of acquiring data and of processing it into useful form), interact with the intended use of the data to determine the "best" kind of remotely sensed data to use in any particular application."*

In the BC Forest Inventory, passive sensors were most commonly used in the past, using satellites (Landsat) along with fixed-wing aircrafts (aerial photos) and helicopters (e.g., LSP plots) as the platforms on which sensors were mounted. Some tests using radar as an active sensor to penetrate cloud cover for Coastal areas were done (e.g., Dr. Peter Murtha at UBC), but costs to acquire the imagery were high (See Holopainen et al., 2009, on use of radar for forest inventory applications). Increasingly, active sensors using light wavelengths are being used using near-earth platforms in BC and elsewhere. Of these active sensors, airborne LiDAR (aka ALS) have become the most popular for localize use in vegetation monitoring, and for broader scale creation of DEM/DTMs.

4.3.3 Remote sensing technologies used in BC

Given the diversity of possible remote sensing data, what data are being used and what innovations are possible in BC? As noted in the description of the current Forest Inventory, digital aerial photographs (DAPs) are the base information used in producing VRI Phase I, along with Landsat and other imagery for inventory updates for major disturbances. LVI uses Landsat and a systematic sample of DAPs in a model-based approach, as an alternative to VRI Phase I.

However, the 2012-2022 Strategic Plan (FLNR, 2013) highlighted the increasing information needs that require LiDAR and other data sources using complex approaches to combine data sources, stating:

"In recent years, new technologies and inventory methods have been developed. The newest digital air photos provide high resolution and may permit the automating of some photo-interpretation steps. With the emergence of LiDAR (Light Detection and Ranging) new approaches to forest inventory have developed. A common theme in current inventory research is the sophisticated combining of various data sources, including satellite imagery. To support new uses for forest fibre, the biomass in forest stands must be characterized in terms relevant to its use in bio-fuels, bio-energy, and bio-products. Given these changes, some components of the information technology infrastructure of the inventory program are outdated and require modernization. Opportunities exist to innovate and adopt new technology and methods in the provincial Forest Inventory Program."

As a step towards meeting these increasing information needs, some provinces in Canada have acquired LiDAR wall-to-wall (See Section 5b). In BC:

- FAIB has access to LiDAR coverage for only some of BC (FPInnovations, 2014), but has collaborated on up to 2.5 million hectares of operational trials as summarized in FAIB Staff (2018).
- FAIB has a target to complete 15 million hectares of innovative forest inventory in their 10-year strategic plan. To date 5.5 million hectares of innovative forest inventory projects have been completed (FAIB, 2018a). With the completion of the Cassiar LVI the current fiscal year, the total area of innovative forest inventory will significantly exceed the 15- million hectare target.
- BC Timber Sales (under FLNR) has over 5.2 million hectares of LiDAR[7], with 0.76 million hectares of enhanced forest inventory (EFI) products with undertaken in collaboration with FAIB.
- GeoBC, through the *Coordinated Free and Open LiDAR Program Initiative* has intellectual property rights for the distribution of up to 9.5 million hectares of LiDAR in BC[8]. Note that this initiative is not funded (e.g., no funds for LiDAR acquisition, rather custodianship).
- LiDAR acquisition standards have been developed by FLNR[9] (FLNR, 2017).
- FAIB is using LiDAR as one data source operationally in some projects. For example, LiDAR data collected by another agency is being used for habitat information on Vancouver Island (FAIB, 2015b).

Further, since DAPs are the basis for producing forest inventory maps, and have seen a resurgence in recent literature, FAIB has begun looking at processes to improve training and speed up the processes of photo-interpreters. As noted, LVI is an example of this, but FAIB is also building a "photo-chip" library of different forest types.

4.3.4 Recent promising research using existing and emerging technologies

FAIB has supported some research projects using combinations of LiDAR, DAPs, and other remote sensing, including the development of LVI and also updating forest inventory maps using LiDAR and a temporal series of Landsat data in collaboration with CFS and UBC (Bolton et al. 2018). Because of the increasing need for land-based information world-wide, an extensive number of research projects have been done using multi-source data, including testing alternative model-based approaches. To indicate the amplitude of this research, here is a selection of recent papers that show promise for application.

1) Using LiDAR to enhance forest inventory: This has received great attention in recent literature as well as application for forest inventory with numerous publications in the last 10 years. A limited list of notable work in Canada includes:

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[7] Personal communication, Don Davis, LiDAR Specialist, BC Timber Sales. Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

[8] Personal communication, Nancy Liesch, Director, GeoBC. Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

[9] https://www2.gov.bc.ca/assets/gov/data/geographic/digital-imagery/geobc_LiDAR_specifications.pdf

2) White et al. (2017) provided a guide for enhanced forest inventory applications using airborne LiDAR.

3) Research by Penner, Pitt, and Woods (several references, not listed) tested the use of airborne LiDAR for enhanced forest inventory in Ontario.

4) Combining multisource data in model-based approaches for wall-to-wall estimates (i.e., by pixel):

5) Lochhead et al. (2018) showed that a number of forest attributes could be estimated wall-to wall for the boreal forest of Canada using the photo-plots of the NFI and Landsat data (i.e., no ground plots, as with LVI) in model-based approaches. The most promising model-based approach was applied to obtain attributes for the western boreal that could be used for macro-scale analysis, and demonstrated for use in strategic analyses.

6) Halperin et al. (2018) used Landsat 8 OLS and ground data a model-based approach to map forest inventory attributes for Zambia. The use of RapidEye was also tested, along with a wide variety of parametric and nonparametric model approaches.

7) Tree-lists (i.e., stems per has by species and DBH): Forest inventory specialists and users indicate that they would like to be able to obtain a tree-list using remote sensing data rather than ground plots, thereby decreasing costs and increasing the area on which this information is available. Tree lists are useful for habitat assessments and are the inputs required for single-tree GY models. Early work on this by Temesgen et al. (2003) used forest inventory maps and other available auxiliary data (e.g., slope) to estimate tree-lists measured on ground plots using nonparametric models. Since the development of LiDAR data, many attempts have been made to get accurate tree lists from these data. However, while LiDAR data provide very accurate DEM/DTM and canopy height profiles (i.e., CHM), there are difficulties in: i) segmenting these into trees; and ii) assigning species to each tree. Recent research to try to improve tree-list estimations include:

8) Kukkonen et al. (2018) combined LiDAR data with Landsat or other optimal data to improve species composition estimates.

9) Ayrey et al. (2016) proposed an algorithm to improve the segmentation of LiDAR data into trees

10) Other authors have recommended using DAPs since species can be identified in stereoscopic viewing and these data are less expensive than LiDAR. Some authors combined LiDAR with DAPs to obtain accurate height profiles and improve species composition.

11) Emerging technologies include automation of DAP point cloud data, and using UAV's with LiDAR or DAPs, for example Goodbody et al. (2017) for residual volumes, Goodbody et al.(2018a) for regeneration, and Goodbody et al. (2018c) for spruce budworm incidence.

Since there are potential opportunities for developing new products using emerging technologies for forest inventory as business ventures, the Ministry has occasionally been approached by vendors wishing to promote their particular products and services (FAIB, 2007).

One response was to develop a standardized approach to evaluating new technologies that could be used internally, as well as by independent evaluators, for ensuring fair and reasonable assessments of such claims, and do so in a transparent way (FAIB, 2007).

4.3.5 Growth and Yield innovations

In recent years, GY research has primarily focused on finer spatial scales at the tree or even sub-tree level (e.g., crowns and branches), as well as reporting impacts of silvicultural treatments using EPs. In BC, the Stand Development Modelling Group (2018) has been conducting this research for a limited number of BC tree species, primarily using EP data from the Forest Practices Branch. The EP data have become very valuable in that many of these plots have three or more measures. However, the goal expressed by Mitchell to have models for all commercial tree species of BC has not yet been achieved in the approximately 40 years of research. Further, stands are more complex than previously anticipated, both in terms of spatial distributions and in terms of species/size complexity. The research is very critical to understanding forests, but the goal of having models for all conditions appears to be far in the future.

Models that can forecast future forests for large landscapes, while providing acceptable accuracy for changes in stand components (e.g., shifting species, diameter distributions, etc.) are needed for analysis of forest lands. Further, these forecasts must be of acceptable accuracy under climate changes, a wide variety of management interventions, and natural disturbances. Recent research using cohorts of trees, rather than individuals, as was done in the past, shows promise for meeting this goal, particularly given recent remote sensing technologies. As an example, Jang et al., (2018) modelled stand tables over time for Douglas-fir. This type of GY model based on cohorts of trees increases the possibility of connecting GY models to large-scale stand-level inventories, since a cohort list is needed as input data, rather than a tree-list. However, with the exception of this paper and a few other papers, the research on using cohorts of trees is very dated. Further, there is little to no research on using remote sensing data sources to obtain cost-effective and accurate estimates of cohort-lists as inputs to GY cohort models.

While there are many opportunities to improve forest inventory using new technologies and to improve growth and yield forecasts for more complete coverage of stand types, management alternatives, climate changes, etc., there is perhaps a substantial opportunity to develop an integrated system. This integrated system could provide more comprehensive and realistic impact assessments related to disturbance agents (e.g., bark beetles, wildfire, harvesting, climate change) on vegetation, water resources, and wildlife habitats, as well as on socio-economic conditions (Shifley et al., 2017). To this end, there has been some efforts made to develop these integrated systems in research and in application e.g., Xiao et al., (2017).

4.4 Related Programs and Other Data Sources

Although the BC Forest Inventory is the responsibility of FAIB, as noted, data are used from other programs directly as part of the inventory system, as well as for particular analyses undertaken by FAIB depending on the information needs. These include:

- Silvicultural and harvest information, in particular:
    - The RESULTS database managed by Resource Practices Branch; and
    - The Stand Development Monitoring (SDM) program data managed by Forest Planning and Assessment Branch (it used to be managed by Resource Practices

Branch). These data have not been used by FAIB to date for purpose of forest inventory, but the program objectives are aligned with those defined under YSM.
    - YSM is managed by FAIB,
- Operational cruise data on areas scheduled for upcoming harvest.
- Base Mapping Information including:
    - Topography (e.g., TRIM data), hydrology, roads, human settlements, land classes, and other base GIS layers; and
    - Administration GIS layers, including land ownerships, Timber Supply Areas, Community Forests, land use zonation, planning maps, and other administration zones.
- BEC GIS layers, including PEM/TEM GIS layers maintained by the Ministry of Environment.
- Remotely sensed data collected by a variety of agencies including Landsat (NASA), and digital/analog aerial photographs (BC Ministries and other sources).
- Environmental data collected by BC government and Canadian government agencies, including the Conservation Data Centre (CDC) information regarding critical and endangered species.
- Research data collected by other government agencies, universities, and other private/public groups.
- Available LiDAR data, often with associated ground plots used to build models of forest attributes.
- Other GIS data including Google Earth data (used to check access), and maps.

Collectively, these data provide: i) the basis for forest inventory maps as noted earlier; ii) critical information for inventory updates on harvests: iii) critical information on updates for major natural disturbances; and iv) essential information for analysis by FAIB and other government and non-governmental groups for specific information needs.

The complexity of these multi-agency, land-based data present challenges to data storage, data use, and data sharing. As part of DataBC, a data-sharing warehouse called BC Geographic Warehouse (BCGW)[10] was established to facilitate sharing amongst government and non-governmental agencies, and the public. However:

- Not all data can be generally shared due to sensitivity of the information (e.g., timber sales data), as well as data ownership (e.g., Landsat data owned by NASA).
- Historic data may not be available in digital format, making storing and sharing very difficult.
- Since data are from multiple sources, data dictionaries are essential. However, often data dictionaries are not sufficient for using the data because of the extensive number of data nuances for each dataset (e.g., What kind of LiDAR data? How were ground plots selected? What was the minimum tree size? All species? Also dead trees? What volume/biomass functions for each tree? Were the data checked for errors? Were the ground crews well-trained? etc.).

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[10] See https://www2.gov.bc.ca/gov/content/data/geographic-data-services/bc-spatial-data-infrastructure/bc-geographic-warehouse [Accessed September 11, 2018; See also https://www2.gov.bc.ca/gov/content/data/geographic-data-services/web-based-mapping/imapbc for iMapBC

As a result, BCGW often provides linkages and contact information for a great deal of land-based information outside of this data warehouse (e.g., link to Landsat), rather than attempting to directly house these data.

To reduce costs of ground sampling, efforts have been made over the many years of the Forest Inventory to co-ordinate these activities. However, direct use of all ground data in inventory analyses is often not possible as these data are often tailored to the particular information need. As examples of this:

- Operational cruise data is collected only for areas scheduled for imminent harvest, using a design-based approach. However, the minimum tree size and species included in the cruise may exclude trees that would be including in a forest inventory plot. Further, variable radius plots are often used (aka, prism or relascope plots). While these plots could be measured repeatedly in time, the trees "in" and "out" of the plot change over time making it very difficult to use these data for GY models. Finally, these data may not be available outside of the forest company that collected the data.
- Silvicultural survey data is collected to meet regulatory requirements, including "stocking" and "free-to-grow" stands. As a result, the plot data collected is tailored to this information need, such as only measuring "well-spaced trees" rather than all trees in a plot, which makes these data very different than ground data needed for forest inventory (McWilliams and Goudie, 2015). It is to be noted that the Layer 1 inventory label representing regenerated stands is described in terms of ocular estimates of the following attributes: species, species percentages, average height of dominant plus codominant trees associated with the first two leading species, crown closure, age, total stems per hectare, site index (including method of determination), and year of survey (Forest Practices Branch, 2000, p. 117).
- Research data collected outside of the EP program and other innovations trials by FAIB, are collected for an extremely diverse set of research objectives. While these data are often sufficiently documented for use by the researcher, data dictionaries and other documentation (i.e., metadata including statements as to data accuracy) are not commonly available.

In spite of these many challenges, these ground plot data collected for other purposes are being used for some forest inventory purposes, notably:

- Photo-interpreters use a variety of summarized ground data information to "calibrate their eye" for each new project.
- Silvicultural/harvest data are summarized locally and provided to FAIB to update the forest inventory.
- In combination with LiDAR data, to fulfill operational data needs (e.g., improved TRIM data and resultant estimates of selected structural attributes), and to test future forest inventory innovations.
- NFI and YSM data are part of data used in inventory audits for accuracy.

Overall, data from other agencies are critical for FAIB analyses and to the BC Forest Inventory system. Efforts have been made to increase data sharing within the BC government, and to investigate other possibilities for decreasing costs.

5.0 Supporting Well Managed Forest Decisions

In previous sections what comprises a forest inventory system has been defined and how one might think about its adequacy. The BC's forest inventory system has been described—what it is now and how it got to be to its current condition. None of that analysis is adequate to answer the question of how well the current system serves BC's needs. This Section addresses that question indirectly. First the criteria that should be used to address adequacy are identified along with some benchmarks from Canada and elsewhere to assist in this evaluation.

5.1 Criteria for Evaluating Forest Inventory and Forest Inventory Practices[11]

The FAIB has the following vision for the BC Forest Inventory:

> *"The inventory of BC forests is sufficiently well developed and managed to support the design, development and implementation of timely, efficient and effective forest management practices necessary to produce desired strategic, tactical and operational outcomes and impacts, across large landscapes and areas of the province, in perpetuity."*

In particular, it should:

- Provide useful information as needed and on time, allowing managers and practitioners to make effective forest management decisions;
- Be supported with sufficient resources to be current, of known standards and degrees of reliability, and represent complete coverage for the forested lands of BC as a whole;
- Be continuously improved through investment in research, development and implementation of new technologies and techniques for data acquisition, organization, analyses and reporting of results;
- Be routinely assessed with reports made on the current state of the inventory, recent applications, and the progress being made in research, development, and adoption of new technologies and techniques; and
- Be guided by the development and implementation of a strategic plan, including a forecast of the resources necessary to achieve the plan, and annual assessments as to whether or not the plan is being met.

5.1.1 Criteria for Assessment of Effective and Efficient Forest Inventory Administration

The following are the criteria used by the Panel to assess the Forest Inventory Program:

1) Clear Lines of Responsibility
   a) The inventory is consolidated within a given agency with well-coordinated inputs from agencies and clear lines of responsibility for inventory function, use and maintenance.

2) Stable and Adequate Funding
   a) Forest inventory is viewed as a continual baseline process, not a campaign for periodic re-inventory. The development and maintenance of a provincial forest inventory requires consistent long-term baseline funding that includes the resources needed to complete updates related to major disturbance events.

[11] The ABCFP 2006 Inventory review (Moss et al. 2006) was used as a starting point for developing this document. There are some significant changes and extensions to that work herein.

3) Effective Quality Assurance System
   a) Forest inventory meets the ISO 9001:2015 Quality Management System Standard.
   b) The inventory database is periodically (e.g., every 5 years) checked for completeness, consistency among variables, etc. (See Table 5.1).
   c) Data provided by third parties are subjected to quality review and required to meet minimum standards established by FAIB in collaboration with inventory data users.
   d) All inventory models are validated using existing data sources.

4) Accessibility of Data and Products
   a) The sources of data and methods used to produce the data are well documented.
   b) The kinds of data used and produced are documented in a data dictionary.
   c) Forest inventory is easily accessed and used in accordance with well identified use cases.
   d) Training and supporting documentation are readily available and updated in support of key inventory applications.

Table 5.1. Information Quality Dimensions (adapted from Lee et al., 2002, p. 143).

IQ Dimension	Meaning
Accessibility	Information is quickly accessible when required.
Appropriate Amount	The amount of information is appropriate for the intended applications.
Believability	Information is trustworthy.
Completeness	Information has sufficient breadth and depth for the intended applications (is of an appropriate kind and includes all necessary values).
Concise Representation	Information is compact in the way it is presented.
Consistent Representation	Information is presented in the same format every time.
Ease of Operation	Information is easy to integrate with other information.
Free of Error	Information is accurate and reliable.
Interpretability	Information is easy to interpret.
Objectivity	The information presented is founded on: reliable and representative measures and compilations with specified levels of error of estimation.
Relevancy	Information is useful for (applicable to) the intended applications. It provides direct inferences with few or no assumptions, and so too, for indirect inferences supported by well documented assumptions, that are necessary and sufficient to support reliable decision making.
Reputation	The sources of information are reputable. e.g., The people who collected the data and compiled the information are trained and certified in data collection methods along with use of QC/QA protocols. The methods used are known to be reliable and “fit for purpose”.
Security	Access to information and (authority to manipulate data) is provided with appropriate levels of authorization and password protections.
Timeliness	Information is sufficiently up-to-date for the task and is available when needed.
Understandability	Information is easily interpreted and applied.

5) Reporting
   a) State of the forest inventory reporting is updated periodically (e.g., every 5-years) with an accounting for changes due to establishment, growth and depletion.
   b) Forest inventory attribute estimates are routinely reconciled relative to other sources of data collected in accordance with Provincial standards, particularly where those sources are influenced by, or by themselves influence, the way forest inventory is applied. The methods and results of these kinds of analyses are reported publicly.
   c) Forest growth and mortality forecasts are routinely compared with ground plot estimates, preferably including circumstances where the ground plots have been located and established to be representative of forest inventory polygon populations as a whole.
   d) Reports are publicly available.
6) Innovation and Research
   a) Baseline forest inventory is supported with research into the use of possible new technologies and methods to improve forest inventory procedures.

5.1.2 Criteria for Evaluating the Status of Forest Inventory

The following are suggested criteria for evaluating the status of the forest inventory:

1) Currency
   a) An up-to-date inventory is maintained along with periodic (1 to 5 year) accounting for changes due to establishment, growth and depletion.
   b) Forest re-inventory is applied to some, or all, of a forest management unit (e.g., TSA, TFL) where the impacts are difficult to characterize due to disturbances that have: a) manifested themselves over a long period of time (e.g., 10 to 15 years), b) generated stand conditions that are more variable in nature, and have done so over relatively large areas (potentially < 10 y), or c) both.
   c) Changes in the key stand attributes are accounted for in both space and time, including: species composition, crown closure, basal area, gross and net volume, and trees per hectare. It is desirable to also account for changes in diameter distribution.
   d) The accuracies of forest inventory and forest inventory updates are evaluated on a regular periodic basis.

2) Coverage and Sufficiency
   a) The provincial forest inventory covers the entire province to a common minimum standard.
   b) There may be locations where the minimum standard is exceeded and where additional attributes are available. These areas must provide the data required for populating forest inventory attributes in a format that is consistent with the minimum standard.
   c) There are regular, periodic reviews of forest information needs in relation to current inventory standards and procedures, to ensure the latter are necessary and sufficient to meet forest management objectives. These reviews are completed with consideration for expected future trends in environment, technology, and associated demands for forest resources and ecosystem services.
   d) The information is of a quality that fulfills the requirements listed in Table 5.1.

3) Forecasting and Linking Historical and Spatial Data
   a) There is one or more reliable and cross-validated method(s) for forecasting future forest and stand (and tree-level) conditions.

b) The inventory includes the key attributes necessary to support localized (stand-level) growth projections, including changes with respect to species composition, stand height, crown closure, basal area, gross and merchantable volume, and stems per hectare.
c) There is a program for establishing and re-measuring ground plots to support the development of growth and mortality forecast models and to monitor stand dynamics.
d) Historical data is routinely archived and properly documented.
e) Inventory data are provided in a format that can be easily connected with other sources of data relevant to management of a particular area and within a given period of time, including for example: ecosystem mapping, streams and water bodies, roads and other linear features.

4) Resolution, Scalability, Reliability, and Level of Detail
   a) There is a base inventory that is available province-wide that meets a common minimum standard with respect to the above-mentioned inventory characteristics: resolution, scalability, reliability, and level of detail.
   b) There is the ability to incorporate more reliable, higher resolution data into the inventory, particularly where there are: 1) significant competing/overlapping demands for forest resources and/or ecosystem services, and/or 2) forest and stand conditions that are complex with respect to the amount of change in space and/or time.
   c) There is the ability to incorporate additional attributes, beyond the minimum standard, as deemed necessary to underwrite strategic and operational decision-making within any given forest management unit.
   d) The reliability of inventory, and growth and yield attributes and forecasts are evaluated in terms of their impacts on forest and stand-level decision-making at the forest management unit scale, including for example: AAC determination, harvest scheduling, silviculture investment, habitat, watershed, and fire and bark beetle risk assessment, and investment in associated forest protection activities.

5.2 Comparisons with Forest Inventories in Other Jurisdictions

The Panel conducted a comparative review to benchmark BC's efforts with those of other well managed forests. The closest comparators were other Forest Inventory Programs in heavily forested provinces in Canada.

5.2.1 Other Canadian Provinces

The Panel interviewed and solicited written submissions from the Forest Inventory Programs[12] of Alberta, Saskatchewan, Ontario, Quebec and New Brunswick (referred to below as the 'units'). In addition, experts from Natural Resources Canada were able to provide input into several collaborative projects between provincial and federal governments.

Given the variety of forest inventory methods across the country, data on specific methodological comparisons was considered less useful than a generalized comparison approach. Provincial governments have the responsibility of sustainably managing forestry on 'crown' land, which makes up most provincial lands in the units reviewed (Table 5.2). There are however a multitude of forest tenure systems across Canada, conveying a variety of responsibilities to forest tenure holders to maintain forest inventory or growth and yield programs. Given these variabilities, it is

[12] Alberta: Ministry of Agriculture and Forestry, Forestry Division, Forest Management Branch.

difficult to provide a precise comparison on several aspects of Forest Inventory Programs. For example, some jurisdictions require industry to maintain change detections for harvest depletion, silviculture and/or natural disturbance. Likewise, some provinces (e.g., Alberta) rely significantly on industry to maintain permanent or temporary sample plots for supporting growth and yield projections. In many cases, there are distinct ecological/physiographical differences between jurisdictions.

Table 5.2. Percent of ownership, size and harvest activities on forestland in Canada

Unit	Provincial (%)[13]	Federal (%)[14]	Private (%)[14]	Forested land (millions ha)[14]	Timber harvesting Land Base (millions ha)[15]	Annual Harvest (m^3)[2]
British Columbia	95	1	4	60	25	67,970,000
Alberta	87	8	5	35.2	23.3	23,031,000
Saskatchewan	90	4	6	34	11.7	3,712,000
Ontario	91	1	7	71	27	15,829,000
Quebec	89	0	11	76	28.2	28,559,000
New Brunswick	48	2	50	6	3.3	9,363,000

Saskatchewan: Ministry of Energy and Resources, Forestry Development Branch.
Ontario: Ministry of Natural Resources and Forestry, Forest Management Unit
Quebec : Ministère des Forêts, de la Faune et des Parcs, Direction des inventaires forestiers
New Brunswick: Ministry of Energy and Resource Development, Forest Planning and Stewardship Branch

Considering these limitations, and the relative size of forestry activities across the units, the scope of the review considered certain key indicators, including:

- Funding- how much funding is available for inventory programming?
- Professionals- what is the size of staff and their credentials?
- Reliability- how often are inventories updated, and how is reliability measured?
- Innovation- what new innovative technologies have been explored or implemented?
- Communications- what process(s) are followed to communicate and provide data access to the public?
- Forest activity- how large is the forest managed land base and how does it contribute to the economy?

See Appendix 4 for details on inter-provincial inventory programs and innovations.

Similarities among inventory programs

Despite the differences between these jurisdictions, there remain a series of similarities in their Forest Inventory Programs. Some of these include:

- The use of manual interpretation of 3D digital aerial photogrammetry is consistent across all units. While some units have moved or are moving closer to model-assisted or model-

[13] (Canadian Forest Service, 2005)
[14] See Appendix 4 for a list of citations
[15] Crown lands only

based inventories, photo interpretation remains a key method for certain attributes (such as species and forest ages). Furthermore, aerial photogrammetric interpretation skills are limited, dominated by older cohorts of consultants with kills not really being currently taught in post-secondary schools.

- There are pressures on all programs to deliver tactical or operational scale forest inventory.
- All jurisdictions have challenges integrating new technologies with inventory standards and products.
- It is difficult to maintain, incorporate or report on reliability indicators (quality assurance) in a systematic fashion. All inventory programs rely in some form (some more subjectively then others) on user feedback.
- Data infrastructure/architecture/storage is a key challenge for all jurisdictions, particularly in keeping pace with technological advancements.

Resourcing

The forested area in the jurisdictions reviewed range from being much smaller (New Brunswick is about 10% the size of BC) to being somewhat larger than BC (Quebec's forested land is 27% larger). There is also a disparity in values realized from the forest sector across jurisdictions (e.g., softwood vs. hardwood markets), costs of operations (e.g., accessibility to markets) and differences in proportional rates of harvesting. Therefore, when comparing resource indicators, it is important to normalize data to provide a relative scale. Table 5.3 provides summary statistics on government resourcing of Forest Inventory Programs across the jurisdictions reviewed. See Appendix 4 for a listing of original data and sources.

Table 5.3. Summary of relative government resourcing of Forest Inventory Programs (arrows indicate BC as being above ↑ or below ↓ or consistent = with the Canadian average, interpreted as positive (green) or negative (red) to the BC's Forest Inventory Program)

	Above/ Below Average	BC	Alta	Sask	Ont	Que	NB
Domestic Economic Impact of Forestry as percent of GDP	↑	8%	2%	1%	2%	5%	13%
Government revenue ($) per m^3 logged	↑	12	7	3	6	11	9
Inventory budget ($) per m^3 logged	↓	0.16	0.37	0.27	0.59	0.70	0.25
% Inventory budget of Crown revenue from forestry	↓	1%	5%	10%	9%	7%	3%
Inventory budget ($) per km^2 of THLB	=	44	37	9	34	71	71
Staff per km^2 (000) of THLB	↑	0.13	0.04	0.06	0.1	0.27	0.39
Km^2 of THLB per ground plot	↓	63	259	138	37	24	2

Next to New Brunswick, BC's economy is most influenced by the forest sector out of the jurisdictions reviewed. BC's Domestic Economic Impact from forestry related goods is 8% of the provinces' GDP. While the BC government gets the highest return per cubic metre ($12/$m^3$) compared to other Canadian provinces it also spends the lowest amount in Canada relative to the provincial revenues directly sourced from forestry. Overall, BC spends approximately $44/km^2 of timber harvesting land base (THLB) on its Forest Inventory Program, which is 30% less then Quebec and New Brunswick, and about 35% more than Alberta.

Despite this relatively lower budget, BC maintains a higher ratio of ground plots per square kilometre of THLB, and a high ratio of inventory program staff per square kilometre, compared to some of the other jurisdictions. Forty five percent of the staff also have post-graduate degrees. Every jurisdiction in Canada also has a strategic target for a complete re-inventory of 10 years. BC has set a target of 10 years to have all inventory as being less than 30 years old (FLNR 2013).

A description of process to determine the necessary funding requirements is outlined in Appendix 3.

5.2.2 The United States

The forest management situation in the US differs markedly from that in Canada. The vast majority of the timber harvesting land base is privately owned. Public owners—including several branches of the federal government, the various states and local jurisdictions—may or may not manage their lands for timber production and the quality and type of timber inventory varies among these groups. The State of Washington appears to be representative of the more substantial state-level forest management activities. The practices of the large corporate holders (reported in Section 5.2.4, below) reflect the situation faced by BC in the timber harvesting land base.

US National Inventory—Forest Inventory and Analysis

The national forest inventory in the US, an inventory that covers the entire United States (forest and non-forest area) appears to be representative of BC's sovereign obligations on its entire land base.

The Forest Inventory and Analysis ("FIA") unit, located in the federal Department of Agriculture's Forest Service, has conducted surveys of all lands in the US for over 80 years (along with additional information on such matters as timber products removals and forest ownership).[16] This covers 905.6 million ha of land in the United States, (including Puerto Rico and territories). Of this, 328.4 million ha are classified as "forest land", only a small portion of which is actively used for timber production.

The inventory is conducted in two phases. The first is a "wall-to-wall" survey by remote sensing of land cover. Those data are used to stratify a grid-based sample of some 326,000 ground plots. There is roughly one plot for every 2,400 ha of forested land (one per 24 km^2). In 2016, 12.1% of the ground plots were re-measured (this is down from prior years due to a budget freeze). If this rate held steady, it would imply an average re-measurement interval of 8.3 years and an average age of the inventory slightly over four years.

FIA conducts its surveys in cooperation with other organizations. Some states contribute additional money and resources to produce a more intensive sample. FIA uses a variety of collaborators, including universities, tribes and NGOs, to produce the information. In 2016, the total budget was $112 million (USD 86.1 million), including both federal appropriations and

[16] This account is drawn from USDA Forest Service. 2017. Forest Inventory and Analysis Fiscal Year 2016 Business Report. FS 1075. August. Dr. Greg Reams provided most helpful responses to the Panel's questions.

contributions from states. Staffing included 353 federal FTEs and 213 FTEs from collaborators. Table 5.4 below provides some analysis of these data.

Table 5.4. US FIA Expenditures and Staffing

EXPENDITURES	
$/total sq km	$12.40
$/forested ha	$34.10
$/plot, total area	$343.00
$/plot, re-measured	$7,822.00
STAFFING	
Square km/staff	16,000
Square km forested area/staff	5,805
Staff per thousand sq. km of forested area	0.17

A state example: State of Washington Department of Natural Resources

The State of Washington Department of Natural Resources (DNR) manages approximately 850,000 hectares of state trust lands, and in 2017 had a harvest level of approximately 2,189,607m^3 (DNR, 2017)[17]. In the same period, state revenues directly related to DNR's forestry operations were approximately $191 million, providing the highest return on cubic metres logged than any other jurisdiction reviewed ($87 in state revenues/m^3). Its forest inventory is used for planning, executing and monitoring forest management operations. The system utilizes a pixel (raster) based inventory with a base-layer (particularly for species) built from photo interpreted aerial imagery (vintages ranging from 1990's to 2013). The program maintains approximately 11,800 permanent sample plots (one plot/4.7km^2). These plots are used to calibrate growth and yield models supporting a "Sustainable Harvest Calculation". The harvest levels are authorized by the Board of Natural Resources, made up of elected and appointed representatives from government and academia. Silviculture records are used to inform re-inventory updates on two-year cycles. The DNR maintains 10 staff, including 3 with post-graduate education, dedicated to forest inventory and growth and yield with an annual budget of approximately $1.3 million (the budget equates to 0.46/m^3 or $118/ km^{2}km^2). While the budget is much higher per square km of managed forest, it is less than 1% of the government revenues sourced from DNR operations. Access to digital forest inventory spatial data is restricted to government use, however hardcopy forest maps are available for a fee. All LiDAR data is freely available and downloadable.

Washington's DNR is approaching 100% LiDAR coverage for their forest lands. The unit collaborates with the USDA National Agriculture Imagery Program to aid in the acquisition of imagery which has helped the entire inventory to be built using remotely sensed data. LiDAR is generally only used to characterize the ground surface (DTMs), and the state has been using Digital Aerial Photogrammetry (DAP) since 2013 to acquire point clouds and derive model-based forest attributes. The inventory department has been testing multi-spectral photography for species attribution, but currently still relies on manual interpretation (photos/plots) for species attribution.

Their program includes the measurement of between 500-1000 validation plots every two years to validate and improve the remotely sensed inventory. Cruise plot volumes (approximately 1000 plots per year) are compared with model-based inventories to help evaluate inventory estimates to

[17] Volume conversions from mbf to m^3 based on (Stone, Phelps, & Samson, 2002)

harvest. UAVs are used opportunistically for projects needing high resolution imagery, such as to determine the efficacy of herbicide applications or to conduct stocking surveys.

5.2.3 Other Countries--Nordic countries

The following is a brief history of forest inventories in Nordic countries, along with a summary of the implementation of certain innovative practices.

Aerial photographs have been used at least since the 1940's for stand delineation and visual interpretation in Nordic countries. From the early 1980s and until airborne lasers took over around 2002, manual assessments and measurements in photogrammetric work stations constituted the main method in Norway, and stereo observations and measurements guided determination of all needed stand variables, at least in mature forests (Næsset, 2014). Assessments in photogrammetric work stations with a minimum of field checks were also used in Sweden from the 1980s until laser scanning took over three decades later.

Aerial images are still used for stand delineation in all countries. In Denmark and Sweden, currently, most forest management plans are made by combining field work and interpretation of digital orthophotos. Since 2010s, laser scanning, combined with ground plot data, have been the main data sources for FMI inventory and for stand delineation in both Finland and Norway (Naesset, 2007, 2014; Maltamo and Packalen, 2015). Finland has also included the use of digital aerial imagery as a basis for imputing species-specific stand attributes.

In Denmark and Sweden, to an increasing degree, map products from laser scanning are being used in producing the inventory data by complimenting it with additional data. In both countries, nationwide raster databases with estimated forest variables have been produced using ALS data and field reference plots from NFI are freely available over the internet (Nilsson et al. 2017; Nord-Larsen et al. 2017). Furthermore, in Denmark laser scanning point cloud data, digital terrain model (DTM), and crown height model (CHM) are freely available. In Sweden, several of the large forest companies have also made, or ordered, their own products from laser scanning data and have their own field plots in the same way as in Norway and Finland.

In Sweden, Lantmäteriet [18] has, in 2016, started to produce 3D point clouds from digital photography on a regular basis, which could be an aid to delineation of forest stands, estimates of growth on a grid cell, and automated estimates.

Denmark was the first country producing a nationwide forest resource map based on laser scanning (collected in 2006-2007) and trained with National Forest Inventory data (Nord-Larsen and Schumacher 2012). The use of photogrammetric point clouds for mapping and estimation purposes were started in Norway in the 2010s (Briedenbach and Astrup, 2012).

In Norway, the plots are set out in a systematic fashion, but in the other Nordic countries, a systematic cluster sampling design is used (See Table 5.5 below).

Finland is moving to have all forest inventory data in raster format and freely available to the public. Currently, the data are updated based on forest owners informing the forestry centre about their plans to harvest, but new updating procedures are being developed. If the developed methods

[18] Sweden's mapping, cadastral and land registration authority.

prove to be feasible, harvesting will be updated in the database using information from forestry operators and Remote Sensing change detection.

Norway will be testing sensor fusion, with 3D ALS or photogrammetric data combined with hyper- and/or multi-spectral data.

Table 5.5. Current NFI design in the Nordic Countries versus Canada's NFI plots in BC

Country	Area (km^2)	Method	N-Strata	Cycle (Y)	N-Plots (y^{-1})
Denmark	43,094	CS	-	5	8600
Finland	338,145	SCS	6	PS-5**	15000
Norway	103,000	SSS	4	PS-5	4400
Sweden	323,802	SCS	5	PS-5	10000
BC***	944,735	20 km Grid	-	5	498

*CS: Cluster Sampling, SCS: Stratified Cluster Sampling, SSS Stratified Systematic Sampling
** Panel System of 5-years
*** This includes Canada's NFI data in BC only. Crude Approximation. A presumed 5-year cycle annual re-measurement based on plots established on 20km grid with 2491 plots in total (FAIB, 2008). Among the 2491 photo plots, there are 268 NFI ground plots located in forested areas. There are currently 549 additional CMI ground plots established on the NFI grid and new plots are to be added in the future.
**** In reality a 10-year ground and photo plot re-measurement cycle is more realistic (see https://nfi.nfis.org/en/faq).

Table 5.6. Current Forest Management Inventory organization in the Nordic countries

Country	Method*	Who Pays**	Subsidies	Coordination
Denmark	VA & FM	FO	No	No
Finland	ABLS	G	Yes (100%)	Yes***
Norway	VA or ABLS	FO	Yes (57%)	Yes****
Sweden	VA	FO	No	No

* VA: Visual assessment using aerial photographs. FM: Field measurements. ABLS: Area based laser scanning (including ground plots).
** FO: Forest owner, or G: Government. The latter also provides computer suggested treatments. The FO still pays for the forest management plan.
*** Centralized data collection.
**** Region forester assists with coordinating land owners.

5.2.4 Industrial and Institutional Lands in North America

Industrial and institutional timberland owners comprise the majority of the large, non-public forests in North America. They include such familiar names as Weyerhaeuser, Rayonier and Potlatch—all publicly traded real estate investment trusts. A newer and less-well known group are the "TIMOs"—timberland investment management organizations. TIMOs manage timberland holdings on behalf of institutional investors, including pension plans, endowments, insurance companies and the like. The larger TIMOs include Brookfield Asset Management in Canada and the Hancock Timber Resource Group in the US (owned by the Canadian insurance company Manulife). Some institutional investors hold large areas of timberland directly; this is the case for the two large private holdings on Vancouver Island, owned by the BC Investment Management Corporation and other Canadian pension plans.

Managers for these lands face essentially the same problem that BC does in managing the "timber harvesting land base" and the 71 land management units for which AAC are determined. The core management challenge is to determine long-term sustainable harvest levels that are consistent with forest practice regulations along with near-term harvest opportunities. Meeting that challenge includes monitoring annual activities and harvest volumes against plans which depend on information from a forest inventory system as defined in this report.

In all of these cases the manager, whether a public company or a TIMO, has a fiduciary obligation to their underlying investors. This obligation has serious legal implications for those managers. Although the instances are not publicized, investors have fired TIMOs when they find large discrepancies between volumes actually harvested that the quantities carried in their forest inventories, or between actual re-inventories and inventories that have been updated using harvest records and modelled growth estimates.

One quite public case of the outcome from poor forest inventory took place in 2014. Rayonier had to restate its financial statements for the first half of that year due to a large discrepancy in the volume estimates for their lands in the state of Washington.[19] As a result, the company reduced harvest levels, and cut the dividend by 17%. On announcement of the error, the value of the stock fell, several senior executives were fired and a group of shareholders sued the company.[20]

As a result, managers of large industrial and institutional properties take forest inventory seriously. A typical practice [21] is to conduct a "wall-to-wall" survey of forest inventory characteristics, including stand mapping using remote sensing (most typically aerial photography but increasingly satellite imagery and LiDAR). Then inventory information is collected for individual stands with systematic sampling of ground plots. The sample of ground plots are re-measured on a recurring basis—typical practice might be as short as every seven years in the US South where timber rotations are short to every 10 years in the Pacific Northwest where rotations are longer. Every year the plots that are not re-measured are updated on the basis of harvest records, growth models and surveys of depletion from insects, diseases, storms and fire.

The objective of these forest inventory systems is principally to estimate and predict merchantable harvest volumes broken out by log grade—at a minimum pulp logs versus sawlogs, but in some cases the distribution of log types within a stand. As a result, typical good practice for well-

[19] https://www.wsj.com/articles/rayonier-realigns-strategy-restates-results-1415624304

[20] https://www.nipimpressions.com/shareholders-say-they-took-hit-over-rayonier-timber-inventory-mistake-file-lawsuit-cms-3181

[21] The Panel contacted inventory experts in companies, TIMOs and the consultants who serve both to collect information on forest inventory practices. We sought detailed, quantitative information on inventory standards and practices. Most were reluctant to respond. As a result, this narrative is drawn from a series of interviews and is not as precise as we would have liked. Nevertheless, we believe this is an accurate account of typical practice in North American industrial and institutional forest owners.

managed forests includes regularly monitoring actual scaled harvest volumes against the volumes predicted by the forest inventory system.

Although our data cannot be considered comprehensive, they are representative. The annual cost of inventory for these ownerships appears to be in the range of $2 to $6/ha/year (or $200 to $600/km^2/year). Sampling intensity appears to be in the range of 1 to 10 plots per ha).

6.0 What the Panel Heard

6.1 Context of Input

The information received by the Panel needs to be put into context. The Panel views the Forest Inventory Program as a system. This was perhaps not considered by many, if not all, the people providing input. The input tended to be focused on the expertise of the individual or their role in the organization in utilizing the inventory information. Seldom was the comment made in consideration of the resources available to FAIB. Consequently, the input may not consider the requirements of a system or a reflection of what FAIB may or may not be doing or the constraints to which they are confronted. Some examples of these issues are included in Appendix 8.

This Section is intended to report what the Panel received under these conditions. It is not necessarily an accurate reflection of what is actually being provided by FAIB by way of forest inventory or what may indeed be needed for a system to support well-managed forests. Comments regarding these aspects are reflected in Sections 7 and 8.

6.2 Summary of Panel Outreach and Feedback

Table 6.1 provides a summary of Panel outreach and feedback by target group. Some organizations or individuals provided a submission and were interviewed – so the column at far right summarizes feedback from distinct sources by removing that overlap. Also, there were some submissions from individuals who were not on the target group list but heard about the opportunity to provide feedback.

Table 6.1: Summary of Panel outreach and feedback by organization

Target Group	Contacted	Submission Received	Interviewed	**Submission or Interview** (minus overlap)
Provincial Government - Headquarters	25	13	5	18
Provincial Government - Operations	50	8	1	9
Federal Government	5	3	3	4
Major Licensees/Associations	8	3	3	5
Woodlots and Community Forests/Associations	6	2	0	2
Academia	25	2	4	6
Consultants	19	7	3	9
First Nations	23	2	2	4
ENGOs	7	2	1	3

Other	13	6	3	7
Not Target Group	0	10	0	10
Total	**181**	**58**	**25**	**77**

Table 6.2 summarizes feedback received by the Panel by region.

Table 6.2: Summary of Panel feedback by region

Location	Number of Submissions and Interviews
Provincial perspective	36
Coast	12
Southern Interior	8
Northern Interior	13
Other or unknown	8
Total	**77**

6.3 User Needs Summary

6.3.1 User needs

The following details the most common types of uses that were described to the Panel during the review (from most common to least common):

- By far the greatest use of the inventory is at the strategic scale for timber supply decisions. The inventory is the underpinnings by which existing managed and unmanaged stands inform determination of a sustainable rate of cut.
- A suite of forest operational planning uses was detailed by users, including the inventory to target harvest profiles, for general operational planning, or to estimate current stand level conditions including forest health.
- Key land use planning decisions, most commonly wildlife habitat supply, hydrologic recovery and biodiversity modelling.
- Fire hazard mitigation planning and implementation.
- Forest carbon modelling.

6.3.2 Defined themes reported from users

Themes and sub-themes were identified during the review of submission and interview inputs. Themes were documented where there were distinct patterns, and then inputs were thematically binned accordingly.

6.3.3 Notes on content analysis from user feedback

Issues and solutions can be synonymized easily, with frequent overlaps between the themes. However, if the content was sufficiently nuanced it warranted keeping these broad themes separate. Where there are conceptual overlaps between sub-themes, the premise of a submitted statement was only used once per participant (not included in both a solution and an issue). A participant may have multiple records of sub-themes, so long as the premise of each record was different. Only comments that were relevant within the scope of the Panel’s mandate were included in this compilation.

The content analysis looked at the frequency a certain theme would re-emerge. While frequency is a good indication of the degree of user concerns, the merit of the premise is what informed the summarized priorities listed in sub-section 6.5 below. The frequency of reoccurrence of themes are divided into minor, moderate or major agreement between users[22]. Note that the following findings do not necessarily reflect the opinions of the Panel, but rather summarizes user feedback.

6.4 What is Working Well and What Needs Improving

6.4.1 Praise for BC's Forest Inventory Program (FAIB)

Throughout the user feedback process, commendation was expressed for the work undertaken by the Forest Inventory Program. Much of this praise came for the ongoing efforts of staff to deliver complex products, maintain programs on time and budget, and provide technical support despite limited resources. Many comments extolled the programs ability to support strategic level decision-making by providing objective and methodical means to maintain a complex inventory with notable improvements in currency and completeness. In addition, there was common praise for the program's ability to provide free and open access to data. Many users were supportive of the program's development of new growth and yield models (TASS III), and exploration towards integrating new technologies to enhance the inventory.

6.4.2 Increase program linkages to improve program inter-compatibility

Participating users were in **major agreement** there are multiple ground-inventory programs with data collection overlaps, but lack linkage for leveraging efficiencies. The most common comments related to a Program that needs to become more focused on projects being part of a system rather than being independent. They included:

- Concerns regarding weak links between cruise, silviculture, forest health and the inventory:
    - Regeneration information via silviculture survey standards focus on licensee liabilities towards free-growing rather than collecting inventory information (e.g., excludes or under-represents species compositions of non-commercial or non-well-spaced stems). The free growing silviculture information is fed into the BC Forest Inventory Program (which it was not designed for) and consequently does not best reflect what is on the ground.
    - Silviculture survey procedures and compilations can be (re) aligned to produce data more compatible with inventory and GY model inputs.
    - Incorporation of RESULTS data into the inventory should be designed to maintain data integrity (e.g. maintain "standards unit" level scales).
    - Massive resources go into measuring stand attributes via cruise to fulfill appraisal requirements and are never linked to the inventory. Improve the ability to reconcile cruise with inventory data for system feedback, calibration and improvement.
    - Forest health data (either via silviculture surveys, forest health overview flights) are not adequately incorporated into the inventory at the stand-level.
    - Fire hazard criterion could be incorporated into inventory attributes.

[22] Agreement is qualified as a percentile function measured in 1/3rds. Example: minor, moderate, major agreement between users. Example: In the submitted data, out of 400 premises for the *issues* theme, 33% had 20 or fewer agreements between users, qualifying it as a minor agreement.

- Need optimized efforts for field sampling:
  - Permanent Sample Plot re-measurement and establishment needs opportunity cost evaluation to prioritize which site types are over or under represented for the development and evaluation of GY models and site index estimates.
  - Long term experimental plot establishment and maintenance/compilation and storage requires committed funding.
  - Stand development monitoring must continue to cross-validate growth and yield predictions (e.g., Young Stand Monitoring program).
  - It is important to systematically evaluate mid-succession stands (after free-growing and before harvest) to validate inventory estimates.
  - Field plots are imperative to calibrate enhanced forest inventory tools (e.g., LiDAR derived forest attributes). Where practicable, these plot-types could be paired with other mensuration programs (e.g., CMI sampling, PSPs) where samples suit specific modelling needs.
  - Align methodologies between ground sampling programs where objectives are complementary.

6.4.3 Growth and Yield model issues

Participating users were in **major agreement** that either the model parameters or the scope associated with TASS, TIPSY or VDYP needs review or improvement. The most common concerns included:

- Models provide inadequate projections for complex stands (multi-species, deciduous/coniferous, or uneven aged) and miss or substitute many species: specially for spruce-aspen mixes, and birch stands (northeast)[23] and stand dynamics in the Interior Douglas Fir BEC Zone (IDF).[22]
- TASS was originally designed for monocultures, which does not represent the majority of the forests of BC.
- The newer TASSIII platform has responded to this by incorporating complex stand dynamics but is too long in development and under resourced.
- Prognosis^{BC} is a useful software platform and more areas in BC should be calibrated to it.
- There are too many unsubstantiated assumptions and extrapolated data use such as.
  - Model outputs often over estimate stand volumes, relying on reduction factors that are unqualified at a local/regional level.
  - Tree species may have site curves that have a biogeoclimatic dissimilarity.[23]
  - More field research is needed to weed our indefensible outliers.
- Models do not sufficiently account for forest dynamics (biotic/abiotic stand disturbance factors).
  - This includes projections of overstory/understory volumes of bark beetle affected stands, root disease, defoliator effects or from wildfire regeneration or other post-disturbance recovery trajectories.
  - VDYP7 projection system could be improved and calibrated with data collected from ground sampling programs.

Some focused contributions included:

- VRIMS is older technical software that needs updating (e.g. has file size limitations).

[23] [22] [23] See appendix 8 for Panel considerations related to this feedback

- Growth and Yield models rely on basal area to project growth - but this is a difficult attribute to photo interpret. Moving to computational inputs (vs. interpretive) for quantifying basal area (as a function of other inventory attributes and/or remote sensing data) may increase GY model accuracies.

6.4.4 Attribution issues

Participating users were in **major agreement** that inventory attributes need to be improved, including issues related to the integrity of data inputs into the inventory. The most common concerns included:

- Attribution does not account for the heterogeneity of stands:
  - Data on intermediate or suppressed canopy layers (typical of uneven aged stands or shelterwoods) can be inconsistently attributed when represented as part of a rank 1 layer, or are maintained in another spatial layer that is not well documented and therefore misunderstood by users.
  - Updates from RESULTS do not reflect multiple distinctive planting or Standard Units. Instead they are based on selecting a dominant stratum and applying the associated attributes to the entire opening, that may, in turn, lead to over-representation of certain species and under-representation of others. Differences in species can also lead to over- or under- estimating potential growth and yield impacts associated with forest health related concerns.
  - Stand structural attributes are missing, or inconsistent (e.g., canopy closure) due to differences in interpretations amongst photo interpreters.
- More information on non-timber resources would be helpful, for example:
  - Key attributes to aid the management of focal wildlife species (e.g., caribou).
  - Attributes relative to fire management.
- Concern regarding age class breaks[24] and definitions
  - Age is a significant attribute used in a wide variety of analyses (wildlife, biodiversity, hydrology, wildfire risks etc.), the data may be poorly populated (i.e. there are missing data) in some units.
- Concern over quality assurance
  - Particularly for site index, species composition, and age.
  - What is in the inventory may not be what is found in the field on polygon or landscape/watershed scales.
  - Inventory attributes often lack defensible magnitude of certainty with respect to differences in scale.
- Many attributes are not populated, too difficult to reliably populate, not needed for users, are based on other mapping programs and consequently not updated (e.g., BEC mapping[25]), or there are surrogate and independent products (e.g., SNR/SMR from ecosystem mapping).

[24] [25] [26] [27] See appendix 8 for Panel considerations related to this feedback

Some focused contributions included:

- Inconsistencies between photo interpreters needs to be systematically addressed; this sometimes becomes particularly apparent where two different interpreters have worked on opposite sides of a map sheet boundary for example.
- Published inventory omits relevant silvicultural information (managed vs. natural, harvest history etc.).
- Biomass estimations from VDYP7 are not based on measured stand conditions and are therefore less useful for fuel management planning.[26]
- Correlating First Nation values with inventory attributes would be useful.

6.4.5 Continue to develop and refine enhanced forest inventory methods

Participating users were in **major agreement** that the province should broaden its use of proven technology and methods to enhance the forest inventory. The most common solutions included:

- Integrate remote sensing into inventory: LiDAR acquisition is scalable therefore versatile (from tree to stand) and key for savings at the operational scale (e.g., engineering, terrain stability, safety) tactical scale (e.g., watershed management).
- The Forest Inventory Program should develop baseline acquisition standards for LiDAR.[27]
- Structural attributes derived using LiDAR are generally less subjective (when compared with photo interpretation), can be generated using automated processes, and can include quantification of uncertainties.

6.4.6 Communications/Data access

Participating users were in **moderate agreement** there are issues related to the dissemination of information from the Forest Inventory Program. The most common comments included:

- There is limited documentation and/or extension for the access, intended use and limitations of the forest inventory[25] or analytical products from the program.
- Increase training is needed relative to product use, particularly for GY platforms.
- It would be beneficial if more peer-reviewed, easily accessible published documentation were available to support transparent accountability. This includes information on the models are built and validated, preferably supported with peer review publications. Any deficits in this documentation leads to anxiety and mistrust amongst the public and forest professionals.
- Provide inventory based spatialized Timber Supply products (e.g. harvest constraints layer) will increase public confidence.
- Provide forest summaries (age classes, disturbance histories), including information on VRI updates at a regional level.
- Provide public access to ground plot information.

[25] See appendix 8 for Panel considerations related to this feedback

6.4.7 Resourcing

Participating users were in **moderate agreement** that there are specific constraints (human/financial/capital etc.) that impedes the inventory program objectives. The most common concerns included:

- There is not enough capacity for core business areas due to limited base funding which:
  - Hinders GY model development, new inventories & updates, ground sampling and data acquisition.
  - Causes resources to be diverted to meet operational problem solving needs (internal/external to government) that in turn undermines FAIB's ability to meet business area goals.
- There is not enough targeted (additional) funding for focal program areas, such as:
  - Transitions to new technologies that requires additional planning, tools and pilot funding.
  - Investments in new technologies (e.g., LiDAR, ground plots, software, and additional processing capacity).
  - Multi-year commitment to funding research and development in an effort to reach a stage ready for operational applications (e.g., Enhanced Forest Inventory methods, etc.).
- Increase data demands have stressed corporate data infrastructures (data management and information technology) to their limit resulting in
  - The need for operational re-evaluation and alignment of resources and associated upgrades.
  - The need for dedicated branch-specific IT support.

6.4.8 Update issues

Participating users were in **moderate agreement** that there were problems with the annual inventory updates. The most common concerns included:

- Generalization of silviculture records (RESULTS) when brought into the inventory:
  - Blending polygons to the block level (versus "standard unit" level) [26] introduces avoidable errors such as generalizing species composition, over/under estimating species components, losing complex stand structural data such as mature retention areas being recorded as depleted, or depleted units being recorded as mature.
  - Distinct units within RESULTS will grow at different rates based on site type and species composition. Generalizing them into one broad unit will misrepresent growth forecasts. These errors facilitate a divide between forest inventory and actual forest conditions.
- Currency:
  - Harvest data is not always updated in a timely manner, creating a considerable disagreement between actual gross openings/harvest areas and what is represented in the inventory[28]
  - Effects from natural disturbance, namely Mountain Pine Beetle and fire, are too slow for effectual planning (volume recovery) responses.[30]

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[26], [28, 30] See appendix 8 for Panel considerations related to this feedback

Some focused contributions included:

- The removal of trees makes room for roads or oil and gas development are not always accounted for in inventory updates.
- Published inventories do not incorporate findings from Phase II audits.

6.4.9 Incomplete inventory

Participating users were in **moderate agreement** that the forest inventory is not always up to VRI standards (e.g., FC, LVI), or there are other kinds of inventories related to other programs/objectives that were described as inadequate and yet are within the scope of the BC Forest Inventory Program. Some common concerns included:

- Currency of the inventory
    - Even some areas with significant forestry activities are made up of older inventories.
    - Timing of when a new inventory is completed, relative to its use in Allowable Annual Cut determinations is not always synchronized (e.g., there have been significant intervals in time between inventory update and deployment for AAC determination).
    - Many attributes that rely on growth and yield projections during an inventory cycle may be incorrect (i.e. the longer you wait between inventories, the greater the risk of error).
    - Concern that systematic re-inventory timing/scheduling is no longer being applied as a function of provincial prioritization of areas of highest change (e.g., natural disturbance/harvesting).
- Many users are frustrated by the inconsistency of how the data standards are applied (i.e. no VRI-level mapping throughout BC), including not having VRI standard mapping in areas with significant forestry activity.

Some focused contributions included:

- Many users pointed to the need for ecosystem mapping to be funded, benefitting from new Digital Elevation Models derived from LiDAR- primarily to complement wildlife habitat supply management and site productivity estimates.

6.4.10 Develop partnerships

Participating users were in **minor agreement** that stronger partnerships can be built between the BC Forest Inventory Program and its users. Some common solutions included:

- Initiate a collaborative platform between users (licensees, academia, and government agencies) to centralize the acquisition and access to LiDAR or other remote sensing products.
- Support greater academic involvement in growth and yield development.
- Support the development of a growth and yield cooperative among forest managers and professionals.

6.4.11 Disparity between data

Participating users were in **minor agreement** that there are increasing differences between inventory standards, data collection, data management and data availability across the public land base. Note that this theme is an effect of other concerns raised by users. Therefore, while it may not have been raised directly by many users, it is a symptom or result of other issues. The most common concerns included:

- The public or Forest Inventory Program generally does not have access to proprietary inventories (primarily Tree Farm Licences).
    - Some TFL's have higher resolution inventories that include the integration of Enhanced Forest Inventory products using remotely sensed products like LiDAR.
    - Inconsistency between standards (VRI vs. TFL Licence proprietary data) creates uncertainty for public, First Nations, planners and decision-makers related to such issues as land-use, wildlife management.
    - Efforts to acquire and integrate third-party inventory data is piecemeal.
    - First Nations, public or government do not have access to proprietary inventories.
- Insofar as inventories of independent forest managers (TFLs, Woodlots, Community Forests, BCTS etc.) are being advanced through a multiplicity of innovative products, the relevance of the province's current inventory data may be increasingly called into question (unless the two are well-integrated).

6.4.12 Uncertainty in innovation

Participating users were in **minor agreement** that a lack of certainty in technological advancements impedes the BC Forest Inventory Program. Some common concerns included:

- LiDAR provides a basis for more reliable estimation of heights, basal area, volume, and biomass but the general consensus is that it does not, by itself, provide reliable information on ages or species composition.[27]
- New remotely sensed technologies (such as digital air photogrammetry) should contribute to computer-aided interpretation standards or automatable attribution, but there is seemingly reluctance among interpreters and policy makers to make the changes.[28]

There is such a wide range of new remotely sensed data, kinds of sensors, data processing and analysis techniques, and data applications, such that no one system configuration can be identified as being preferred in all situations.[33]

6.4.13 Training

Participating users were in **minor agreement** that there are issues with training, attrition/succession in the workforce. Some common concerns included:

- Contractor capacity for specialized experts for growth and yield measurements (permanent sample plot work) is aging and these skills are not being adequately provided by secondary education.
- There are limited training opportunities to understand the products and tools provided by the Forest Inventory Program.
- Error-prone inputs into the inventory, such as through RESULTS, can be mitigated through improved training opportunities. See *update issues* above for other RESULTS-related user input.

A discussion regarding providing more training is included in Appendix 6.

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[27] See appendix 8 for Panel considerations related to this feedback

[28] [33] See appendix 8 for Panel considerations related to this feedback

6.5 Top priority areas for meeting user needs

The frequency of recurring themes from the solicitation of user feedback is one way of prioritizing user needs. Major agreements of themes among these user groups indicate strong trends for advising the direction of the program (See Figure. 6.1). However, many of the themes are interdependent. For example, increased program linkages or level of efforts for ground sampling may improve growth and yield models and improve attribution quality (or contribute to enhanced forest inventory or both), thereby addressing user expectations regarding scale, limit the need for ancillary third-party datasets and help with estimates of error.

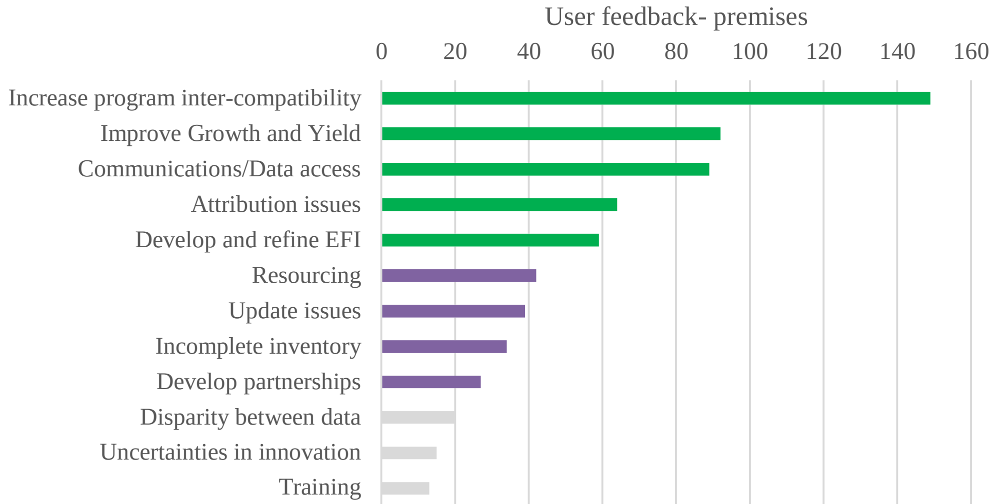

Figure 6.1. Content analysis of user feedback premises. Green indicates major agreement, purple moderate and grey minor agreement.

Regardless of the frequency of emergent themes, important undercurrents emerged time and again throughout the engagement with user groups.

There is a general conflict in expectations between the provincial inventory being suitable for strategic purposes but with users wanting it to fulfil a tactical or and operational scale applications of inventory. This affects a spectrum of important uses, most notably operational planning for timber, wildlife and fire management.

As forest licensees complement the provincial inventory with refined operational data, there is a growing divide between access to the best available information for the management of public lands. Reconciling this difference between user expectations and government objectives should be a top priority.

Another important undercurrent of user feedback was the need to better quantify/qualify uncertainties, the lack thereof undermining confidence in the veracity of resultant decisions. Three immediate effects of this include: a) where Timber supply units are high risk (vulnerable to short or mid-term fall downs), the AAC may be very sensitive to minor changes in inventory attributes at a polygon scale, but the accuracy of those attributes have not been estimated quantitatively; b) policy decisions are being made and implemented to protect or maintain wildlife habitat or biodiversity attributes (e.g., old forest) but policy makers cannot attest to the veracity of the baseline inventory (e.g. age class distribution by forest type) that informs those policies, and c) low confidence in the inventory can undermine trust and preclude meaningful reconciliation with First Nations. Therefore, incorporating explicit estimates of uncertainty throughout the program will help resolve many critical themes raised by users.

7.0 Panel Assessment of the BC Forest Inventory Program

7.1 Importance of the BC Forest Inventory and Our Review Process

Forest inventories provide the essential information needed to develop forest management policies and management plans. A key use is assessing the long-term sustainability of forest benefits including economical, such as timber values, environmental, including carbon sequestration, animal and bird habitats, and social benefits including high water quality, recreation opportunities, and human health. This is particularly relevant for BC where forests are largely publically owned and managed and cover approximately 60% of the BC land base.

As the province developed its timber industry and the demand for forest resource uses other than timber expanded, governments have made substantial efforts to review, reorganize, and sometimes increase investment for a short term in the development and implementation of the forest inventory system to meet the changing needs of British Columbians. This vast forest land area has continued to provide extensive benefits for communities, including remote First Nations communities, and to the Province as a whole. Because of the critical importance of inventory data as the base data needed to assess Provincial goals of sustainability of this array of benefits, periodic assessments of the BC forest inventory have been conducted over the long history of more than 100 years, including the review provided in this report.

7.2 Current state of the Forest Inventory

In this review, the Panel sought to understand the current state of the Forest Inventory Program, with a view of history, and of the future. Using best practices around the world, a list of criteria was developed to assess the inventory. Information was also sought from other jurisdictions across Canada and elsewhere to compare processes and resourcing of their Forest Inventory Programs to those of BC. The Panel reached out and received commentary from a wide variety of users and producers of forest inventory data as to what is working well and what needs improvement.

Given the large amount of information received by the Panel, focus and refinement was needed. To that end, the Panel used the criteria for supporting well-managed BC forests from Section 5.1 as the framework for the assessment, and the information in Sections 4, 5.2, and 6 as evidence. This review was conducted within the framework of:

1) The mandate of the Panel was a review of adequacy of the Forest Inventory Program, rather than decisions based on the inventory. For example, the Panel did not explicit review the analysis process supporting AAC determinations. However, the Panel did ask if the available inventory system was adequate for supporting AAC determinations and other similar applications.

2) The standard for the Panel assessment was based on the concept of "well-managed forests", and the criteria for assessing well-developed forest inventory processes and outcomes. While there is no single, well-accepted definition for this standard, the Panel recognized that BC

seeks to be a world leader in sustainable forest management. Each Panel member brought their sense of how the forest inventory would meet this standard, based on extensive professional experiences in BC and elsewhere.

7.2.1 Clear Lines of Responsibility

Overall Statement: FAIB is generally well-organized as task groups. However, there is a perception that activities could be better coordinated within FAIB and across government units (See Section 8, Recommendations #6 to 9).

Generally, there are clear lines of responsibility for the BC Forest Inventory Program, based on:

- The Forest Inventory Program is the responsibility of the FAIB.
- The organization chart for FAIB clearly indicates the organization of personnel by inventory task.
- Users of the forest inventory data expressed commendation for FAIB staff for the efforts made to deliver the complexity of inventory products on time, and on budget, as well as providing technical support to users despite limited resources.

However, there are overlaps with other government agencies that have contributed to difficulties in delivering inventory products:

- The highest level of concern expressed was concerning the multiple entries to the same land area to collect data. Practicing forest professionals perceive this as evidence collaboration and coordination among administrative units within government could be improved leading to possible data and budget efficiencies such as:
  - While FAIB has made efforts toward reducing overlaps by utilizing YSM and NFI ground plots, supplemented by CMI plots for audits of VRI Phase I data, there is still confusion since, in some locations, VRI Phase II ground plots are still used for this purpose (audits) instead. With regards to young stands, the overlaps of the YSM and stand development monitoring (SDM) programs have also resulted in concerns expressed by forest professionals.
  - There is a general concern that the cruise plots collected for timber appraisal are not being used in some way for forest inventory products, given the considerable costs of collecting these data. Even if technical issues in using these could be addressed (See Section 4.4), only summaries of timber cruises are received by Revenue Branch for stumpage appraisal. The cruise plot data are not commonly made available to the BC government by licensees other than BCTS.
  - There is also a general perception that silvicultural survey plot data could be used for forest inventory products, particularly to indicate the initial state for forecasting growth and yields in these openings. However, reports commissioned by the Ministry have shown difficulties in using these data outside of meeting regulatory requirements post-harvest (See Section 4.4).
- PEM/TEM mapping responsibilities reside within the Ministry of Environment, but these have been funded, at times, by the FAIB. The other site productivity products (SI, SIBEC, OGSI, etc.) are managed as a task group within FAIB. This division of responsibilities across ministries reduces the understanding of site productivity measures within and outside of government.
- Although there is good collaboration among government staff involved with developing GY products, the GY program is not cohesively organized:

- Although VDYP and TASS/TIPSY products are produced by FAIB, these are separated into two task groups. This has led to different user interfaces for the GY model products of BC, unlike other jurisdictions (e.g., USDA Forest Service, FVS platform). Also, gaps in the deliverables may be partially due to this split of the GY program.
- While the PSP program is within FAIB, the EP plots program is within the Resources Practices Branch. The EP data are critical for developing GY models that can be used to forecast future forests under a wide variety of silvicultural regimes (e.g., thinning, improved genetic stocks, assisted migration of species, etc.).

- The Forest Inventory Program requires extensive IT resources to store current and historic data, as well as substantial computing power to analyze these data for inventory products and reports. Further, with increasing uses of new technologies, this use will only exponentially increase. It is the Panel's understanding that most of these IT resources are provided centrally within the BC government. While this is understandable, given the increasing needs for data security, this has contributed to under-resourcing of IT needs for the Forest Inventory Program.
- Feedback received by the Panel indicated that users have a desire to have more say regarding the Forest Inventory Program, particularly, outputs needed to meet the needs of resource professionals. Generally, feedback from users is only sought during periodic reviews. Officially integrating support groups in key areas into the policy, planning and program implementation of the Forest Inventory Program would help to improve communication and collaboration (See Appendix 7 for a discussion).

7.2.2 Stable and Adequate Funding

Overall Statement: FAIB has been historically under-resourced based on programs in other provinces in Canada, and other jurisdictions. This under-resourcing has become more notable in recent years with a substantially lower budget at the same time as increasing forest disturbances and information needs (See Section 8, Recommendations #1 to 5, and Appendix 2).

FAIB has been following their 2012-2022 Strategic Plan (FLNR, 2013) to deliver forest inventory products within the budget of an average of $9 million in the last 10 years. The stated strategic plan goals are being met, based on their 2018 status report. Comments received highlighted the efforts of FAIB in producing inventory products under the budget, but there was moderate agreement that the program is underfunded.

The budget for BC forest inventories has always been sparse relative to the information needs and the challenges in obtaining these data (See Figure 3.1 and text concerning this figure), including:

- The vast forest land area of 60 million ha.
- Mountainous terrain over most of BC.
- Limited accessibility for perhaps one-half of the Province.
- The extensive ecological diversity of forests from the Pacific Coastal forests to the boreal forests of northeastern BC.
- The limited tax base to fund inventories of the vast public resource, since the human population is low relative to forests in other countries including the USA (See Section 5.2).

Recently, this challenge in providing inventory products within budget has been further exacerbated by the following:

- Recent large-scale changes to forests, including large natural disturbance events have greatly reduced forest stocks. In particular the Mountain Pine Beetle (MPB) epidemic affected very large areas of Central and Interior BC, and, in recent years, large and numerous forest fires have affected many of BC's forest lands. Climate changes have contributed to these disturbance events, but past management activities are also considered a factor.
- There is an increasing diversity of information needs by a wide range of information users. For example, detailed high-resolution spatial information is needed to assess critical habitats for endangered species (a major concern highlighted by the Special Committee on Timber Supply, 2012) and to assess fire risks near communities.
- The accessibility of information via the Internet has increased visibility of forests and forest management activities also, leading to greater scrutiny by various publics. A number of recent news articles (e.g., Britneff, 2018) show increasing concern on the reliability of forest inventory information for making resource decisions.
- New technologies are emerging at a fast pace. There are pressures to make use of these technologies; however, these are largely untested with regard to meeting the Province's forest information needs, particularly given the unique challenges in BC.
- Changes to forest survival and growth, along with species shifts, are expected in response to changing climates. Models that forecast future forests under changing climates, along with an associated increasing diversity of stand-level management regimes, are needed.

At present, the FAIB is charged with assessing and meeting information needs, and has had an average annual budget for the last 10 years of $9,420,000/year and only 31 FTEs (FAIB Staff, 2018). Relative to other provincial agencies across Canada, the expenditure is the lowest at only \$0.16 per m^3 harvested and only 1% of Crown Revenue from timber harvests (See Table 5.3). As well, BC forests provide an array of benefits, not just timber products.

What are the budget shortfalls? If we consider the 60 million ha of forest land in BC with a 10-year cycle (i.e., complete 1/10 of the area each year in a continuous forest inventory system), 6 million ha would need to be re-inventoried each year. Given the cost of VRI Phase I is about $1.50/ha, about $9 million would be needed to cover this aspect of the Forest Inventory Program alone, leaving about $0.4 million for inventory updates, ground plots, GY models, and other aspect (See Figure 4.1). While efficiencies have been sought, including using (what is believed to be) the less accurate LVI instead of VRI Phase I in some locations, the current budget clearly does not adequately cover the delivery of the Forest Inventory Program.

Given this limited budget, FAIB has focused on delivering the necessary base products while having to divert funds for urgent information needs (e.g., 2018 BC wildfire impacts). To resolve the resourcing versus workload issues, FAIB has made a number of decisions including:

- With only 31 FTEs on staff, much of the work conducted by outside-government contractors (average of 68% of the FAIB budget; FAIB Staff, 2018). While this has resulted in high-quality work by consultants, this tends to decrease the cohesiveness of the Forest Inventory Program since each consultant works on only a small part of the inventory program. As a result, this reduces the critically important need to consider the Forest Inventory as a system in all activities and in communications to forest practitioners.
- FAIB has had to limit hiring of high-quality staff that can meet the challenges of the existing inventory system (e.g., qualified photo-interpreters), as well as current and future

innovations (e.g., model-based approaches using multiple source data for a suite of forest attributes).

- FAIB has postponed, cancelled, or greatly reduced components within inventory tasks. Here are a few notable examples:
    - The PSP maintenance and re-measurement program has been greatly reduced, even though these legacy data representing long trends in growth and yield are essential for GY modeling.
    - LVI has been used instead of VRI Phase I for forest inventory type mapping, and other areas remain as FC inventory coverage only.
    - VRI Phase II ground sampling using variable radius (i.e., prism) plots and unequal probability selection has been severely curtailed. Instead, a combination of NFI, YSM, and CMI plots based on systematic sampling to locate fixed area plots is being used. Where available, existing NFI and YSM plots are used which reduces costs. Further, the analyses are sampling using systematic sampling and fixed area plots.
    - Communications and training programs have been greatly reduced.

Because of the importance of forests in BC, a detailed commentary on improving funding was included as Appendix 2.

7.2.3 Effective Quality Assurance System

Overall Statement: While FAIB supports several useful processes to assure the quality of the inventory information, the use of oversight committees and additional accuracy assessments could improve this system (See Recommendations #6 to 9, and 14).

FAIB has a number of processes in place for quality assurance:

- FAIB maintains and regularly updates standards for VRI Phase I forest inventory photo-interpretation, as well as all ground-plot programs including PSPs, VRI Phase II plots, CMI, and YSM plots. Forest Practices Branch maintains EP plots measurements standards. These are generally available to forest professionals and the public in general.
- Data dictionaries are generally available for data within the BCGW. Standards for database integrity within FAIB and other affiliated programs not housed in BCGW are not available publically.
- Certification programs for ground plot personnel are in place via ABCFP (i.e., Accredited Timber Cruisers (ACT) for cruise and forest inventory plots) and certification is required for inventory programs as noted in the Ministry website: https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-inventory/training-and-qualified-contractors [Accessed November 23, 2018).
- FAIB conducts inventory audits of the VRI Phase I forest inventory information using existing and/or new ground plots, using well-qualified consultants.

There are concerns, however:

- Although standards are in place for VRI Phase I during the process of creating the spatial and attribute data, including the use of available ground plots, installing new plots, and doing fly-overs, time and budgetary constraints limit these activities. Further, although cruise plots are in this process when available, data are often not available, since this information is provided generally as compiled summaries only to Revenue Branch. User comments indicated that while they were generally satisfied with VRI Phase I forest inventory spatial and attribute data, they were concerned about the data accuracy and data availability.
- Because of the complexity of forest inventory data systems:
    - There is concern about data integrity, particularly given the cross-agencies data sharing (e.g., RESULTS information used to update forest inventories), and the centralized IT resources. As an example, a Forest Practices Board special investigation was initiated in 2011 (FPB, 2011) that concluded that late and erroneous silviculture tracking via RESULTS subverted provincial forest inventory updates.
    - The quality of the data is not generally reported, since most inventory data are the result of a complex system of data, interpretation, and analyses. However, this greatly reduces the confidence of resource professionals regarding using the data, as well as assessments made with these data (e.g., AAC determinations).
- The low budget and staffing levels contribute to the perception (and possible reality) of data integrity issues.
- The GY models are the result of research using PSP and EP data. Documentation regarding the processes used in TASS is mostly nonexistent. Further, most of this research is not peer-reviewed. Recent efforts have been made by the Stand Development Modeling group to present some of their research at international conferences, thereby allowing interchange of ideas with other researchers. However, that does not generally provide much critical positive or negative feedback.

7.2.4 Accessibility of Data and Products

Overall Statement: Limited access to forest inventory data is provided within the DataBC website, and greater access is provided via direct requests to FAIB staff. Data users indicated that they appreciate the open FAIB response to requests. Improvements can be made including: reduced response times; improved documentation (i.e., meta-data); increased direct access via DataBC where possible; and communications describing the inventory system to improve user knowledge of connectivity among alternative datasets (See Recommendations #4, 10, and 11).

Access to forest inventory data and products is available via:

- The BC government has a number of public access data products and have provided a central data link: https://www2.gov.bc.ca/gov/content/data (accessed September 15, 2018). These include the DataBC, iMapBC, and Geographic Data (including BCGW) programs. Some forest inventory data products and associated land maps and data are housed in BCGW. This includes the often-downloaded basic forest information provided as the VRI Phase I, layer 1.
- For data not generally available, users commented that the FAIB staff are approachable and very helpful in completing other data requests, within the constraints of available budgets.

- Inventory software products can be downloaded from websites, including VRIMS, SiteTools, TIPSY, and VDYP. TASS III is under limited public release for review, including pine/spruce mixed-species stands of the BC Interior.

Although forest inventory data and products have been made available for public use, there are a number of concerns:

- The data quality is often not included with the data.
- Related to the data quality issue, detailed meta-data are often not provided with the data. For public data, data dictionaries are generally included, but the nuances of the data often collected or produced by a number of government units and other agencies is not available. The sources of the data and how they were created are often not documented. This is generally the case with government and other data not collected/created by the user, but this greatly increases the uncertainty in any analyses conducted on these data by users within and outside of the BC government.
- Although the forest inventory maps are available for the canopy layer, more detailed VRI data, plot data, and nuances of the data must be obtained from FAIB staff. Given the limited budgeting and staffing of FAIB, this takes away from base programs to create the data and respond to data needs within government. The Panel received comments regarding the desire to have plot and other data more generally available.
- In terms of GY models:
  - The models are only available on separate platforms, since they have been developed independently over time. This makes updating platforms for new technology and training more difficult based on comments received. As noted, USDA Forest Service developed a common platform allowing users to conduct a variety of activities using a single application some years ago (FVS, described on https://www.fs.fed.us/fvs/whatis/index.shtml , Accessed November, 2018) which has received wide acceptance with generally positive feedback from users.
  - Some valuable products are no longer supported by FAIB. For example, Prognosis^{BC} which was developed using public funding, but this is only available from ESSA, a consulting firm, and this may be discontinued since ESSA obtains no support for housing and distributing this GY model.
- While historic aerial photos have been made available for users, other spatial datasets could be made available, including LiDAR data.

7.2.5 Reporting

Overall Statement: Documentation for most inventory aspects is very limited, and often only internally accessible. Further, there is no program for regular reporting on the status of BC forests provincially or by community. Providing regular BC forest status reports would help build a larger constituency for FAIB, both internally to the government and with external users (See Recommendation #10).

Standards for ground plots and VRI Phase I data are well-documented and publically available. FAIB staff are also very approachable with regard to questions on the inventory.

However, based on the Panel's review:

- A number of reports made available to the Panel were internal to government only as consultancy reports.

- During this review, the Panel relied on a 2010 State of BC Forests publically available report for overall information on BC's forests. The Panel searched the current BC government website and other websites to find current information on forests, but were not able to find an update either as a complete report or as separate communication pieces.
- Comments received from users were in moderate agreement that there is interest in overview reports (i.e., maps and statistics) on the status of BC forests as a whole, but also for specific areas within the Province. However, these are not available.
- Prior websites, no longer supported, provided more details on aspects of the forest inventory. Current websites generally provide high-level overviews only (e.g., a one-page overview of the GY part of the BC Forest Inventory Program).

Overall, while some of the difficulties in finding information on BC's forests may be partly due to web re-design causing a change in type of information presented, finding information including specific facts on BC forests is difficult. Thus, it is difficult for forest professionals to respond to comments made by publics in their communities.

Because of the importance of reporting and communications to practicing professionals, forest-depending communities and the public in general, a more complete commentary on this issue and possible solutions are presented in Appendix 6.

7.2.6 Innovation and Research

Overall Statement: BC faces one of the most daunting forest inventory challenges in the world. While methods developed elsewhere can be applied, the unique scale and complexity of the circumstances suggest that innovations within BC could pay off in lower costs, better data, and, perhaps, economic opportunities to apply (i.e. export) innovations elsewhere. However, FAIB has neither an explicit mandate for innovation nor a budget to fund this important function (See Recommendations #3 and 15).

FAIB has supported research and innovation including:

- Initiatives to describe aspects related to the state of the forest:
    - Some collaborative research has been conducted with universities (e.g., UBC and University of Victoria; some examples provided in Section 4.4)
    - FAIB has contributed to collaborative operational trials with industry for enhanced forest inventory (e.g., FAIB, 2016, LEFI trials).
    - FAIB is collaborating with the Natural Resource Ministries Coordinated Free and Open LiDAR Program Initiative which is a provincial multi-agency initiative under GeoBC to acquire publically accessibly LiDAR for the province.
- Initiatives related to forecasting the future forest (See also Section 7.3.3):
    - Investigations of tree growth under different management regimes initiated by Dr. Ken Mitchell continues within the Stand Development Modeling Group of FAIB. This research is very high quality, but publications and other reviews have been limited.
    - Site productivity research managed by Dr. Gordon Nigh has been published in high quality peer-reviewed journals.

Through these initiatives, new technologies have been implemented, notably the use of Landsat and a model-based approach for forest inventory mapping known as LVI. FAIB is also working toward greater use of LiDAR, where possible, including the plan implemented for Vancouver Island (FAIB, 2015).

However, this research has been limited given the needs expressed through interviews and submissions, including:

- There are pressures to assess, and possibly implement new technologies.
- Practitioners have many questions regarding the impacts of insects and disease on GY, reliability of forecasts of mixed-species complex stands, and the need for tools to examine the GY impacts of a variety of harvest/silvicultural practices prior to implementation (e.g., single-tree removal, patch cuts, removal of CWD).
- Habitat assessments require other attributes, but how can we obtain this information given budget constraints? Are there creative ways to use available multi-source data to obtain tree-lists including species and dead materials?
- High quality forest inventories have been independently developed and are often proprietary data on public forests. This is in part through enabling legislation (*Forest Act* Section 35.1) requiring TFL holders to maintain a sufficient forest inventory), but also out of the need for tenure holders (TFLs, woodlots, CFAs and even BCTS) to self-invest to gain access to operational-level inventories, often created using innovative technologies. This disparity of data quality brings into question a duplication of investments and efforts.

The main barrier to research is likely the limited resources of money and staff supported by the FAIB budget. A large number of research projects were supported by government in the past (e.g., Forest Science Program) on elements within forest inventory, including inventory innovations, GY research, and decision support systems that link GY to the inventory. Even under the current budget, further collaborations with universities, research agencies including CFS, and industry are very possible, as discussed in Appendix 6.

The Panel has identified a number of recommendations related to improving the Forest Inventory Program. However, the Panel recognizes implementation of these will be constrained by resource and operational challenges. Also, the Panel recognizes that the current Forest Inventory Program provides support for key decisions. Overall, an incremental approach to implementing improvements will most likely be required. The following are comments relative to the identified criteria for providing forest inventory support for achieving well-managed forests.

7.3 Improvements to the Forest Inventory

7.3.1 Currency

Overall Statement: The standard of inventory frequency for well-managed forests appears to be a cycle of 10 years in most jurisdictions. Some of the BC Forest Inventory data is 30 years out of date, which is not adequate for most purposes. Additional resources, personnel, and better IT systems are needed, along with increased use of emerging technologies, to improve currency of the forest inventory (See Recommendations #1 to 4, and 11 to 13).

As noted, the entire FAIB budget is not sufficient to implement all components of the Inventory (Figures 4.1 and 4.4) on the 60 million ha of forest land assuming a 10-year inventory cycle. At the same time, there are evermore increasing demands for current forest inventory data, for example:

- There are urgent needs to update forest inventory data at whatever vintage for large disturbances (e.g., MPB and fire), as this affects community timber supplies in particular.
- The considerable fire impacts in 2017 and again in 2018 have increased the need for better information to mitigate fire risks.

In spite of this considerable budget shortfall for base inventory information and increasing pressures, FAIB has:

- Provided forest inventory maps for almost all of BC based on a composite of: i) FC inventory (i.e., prior to VRI) for areas of very low human and natural disturbance (e.g., northwest BC); ii) LVI (less accurate than VRI) for areas with less human and natural disturbance; and iii) VRI Phase I for much of the province of BC (i.e., 54% covered by VRI Phase I) (Figure 4.2).
- Developed and implemented a strategic plan to improve currency (FLNR, 2013).
- Made progress to reduce the areas under FC inventory since 2006 and 2011 reviews for ABCFP (Moss et al., 2006; Moss, 2011).
- Implemented LVI to improve currency over FC inventory, while reducing costs relative to VRI Phase I.
- Implemented the use of Landsat and other low-resolution, low-cost imagery to update large-scale disturbances, to improve the timeliness of inventory updates.

FAIB has utilized this limited budget very effectively, but the budget is not sufficient to meet information needs, as evidenced by:

- The Panel received moderate agreement from users that there were problems achieving the annual inventory updates planned by FAIB.
- Urgent demands for disturbance updates without any new funding has resulted in changes due to harvests not being updated in a timely manner.
- Updates for natural disturbances are too slow for effectual planning and possible log salvage.
- Updates reflecting oil and gas developments resulting in forest depletions are slow, and effect planning (e.g., cumulative impact assessments).

In general, the vintages of forest inventory data vary across BC since there has never been enough funding to implement VRI Phase I even under a 10-year cycle. All other jurisdictions reviewed have indicated their intent is to fund a 10-year re-inventory cycle. Further, although updates are being made for harvest removal and large-scale natural disturbances, users are concerned these updates are not being made in a timely manner.

7.3.2 Coverage and Sufficiency

Overall Statement: FAIB's main focus is necessarily on strategic-level base products. They have made advancements in using new technologies to reduce costs for strategic-level information (i.e., LVI), and have funded a limited number of operational trials using LEFI for greater accuracy in stand-level estimates of selected attributes.. However, some areas of the Province remain not covered in the forest inventory. Further, communities and forest practitioners need accurate data at a lower resolution for many resource issues, including timber operations (See Recommendations #1, and 11 to 13).

As well as being current, the forest inventory information should be available for all forest lands of BC. To that end:

- Most of BC's forests are publicly owned and managed by the Province and included in the Forest Inventory Program.
- However, there is a limited area of federal lands, including national parks, and also private forest lands, that historically have not been included. Further, provincial parks and other reserves were not always included.
- Urban areas have not been included, even though the urban-forest interface is critical to determining risks and losses due to forest fires. Forest inventory in urban areas is very complex, however, given the large variety of native and non-native species, as well as the spatial patterns (e.g., tree lines along roads, etc.), and the frequent disturbances resulting in both tree removals as areas are developed and tree additions as landscapes are revegetated.

As a result, there are "holes" in the coverage of BC's forests which impacts many aspects of land use and resource planning decisions on public lands. While the desire to improve coverage is there, again the budget limits what is possible as well as difficulties with obtaining access on private lands in particular (e.g., see FAIB, 2015a; plan for south Vancouver Island). Overall, the forest inventory maps include most of BC, but, as noted, the vintages and sources of these data vary across BC (Figures 4.2 and 4.3).

In terms of sufficiency, FAIB defines the Forest Inventory Program as a strategic inventory, indicating that this is intended for larger-scale strategic applications (e.g., TSA), but may not be adequate for smaller-scale operational applications. However, many forest management issues that receive community and public attention have no other source of forest inventory data. As a result, these data are being used for much smaller spatial scale analyses assuming that the information in each stand is sufficiently accurate. For this purpose, the Panel received feedback that indicates:

- Professionals generally "field-check" the forest inventory information with regard to species in particular, but also volume, basal area and other attributes, based on these field checks and their knowledge of the stands in that area.
- Generally, users stated the VRI Phase I information was good enough for strategic analyses, but requires additional field checks for other uses. Additional caveats were:
    - VRI Phase I data are not always available.
    - Even when available, the VRI Phase I data may not have been updated to the date of the analysis.
- There were concerns expressed about having to use a mixture of types of forest inventory data (e.g., a mixture of VRI Phase I, LVI and FC inventory data) when VRI was not available for the entire area covered in the specific analysis.
- For particular applications, including fire-risk assessments and habitat assessments, some of the forest attributes needed are not available even in VRI Phase I. This was ranked fourth in the areas of concerns expressed to the Panel. This has been partially ameliorated by including interpretation of standing dead tree components in the newest VRI Phase I protocols.

The Panel found that FAIB has made every effort to address these demands for improved information at a lower scale, when possible, including additional attributes, as with dead materials. Examples of this include the FAIB (2016) LEFI project in Kamloops and the south Vancouver

Island project (FAIB, 2015a) using LiDAR data to obtain greater within stand structural information for wildlife habitat analyses in particular, however:

- Every special project for more attributes for smaller-scale analyses diverts limited budget and staff away from deliverables in their Strategic Plan, including timely harvest and natural disturbance updates.
- As well, further efficiencies in using multi-source data (e.g., forest inventory maps + LiDAR + high-resolution DAPs+ground data+Landsat) requires high-level expertise to build complex model-based approaches, which is not fully available in-house at FAIB.

7.3.3 Forecasting and Linking Historical and Spatial Data

Overall Statement: Forest inventory necessarily requires forecasting both to update past sample data to the current period and to provide estimates of such key concerns as sustainable harvest levels, future habitat conditions and carbon stocks. Due to the ecological complexity of BC's forests, accurate forecasting represents a considerable challenge. GY models need to be improved to provide better coverage of all stand types and the increasing breadth of management regimes, as well as to include likely growth impacts under expected climate changes (See Recommendations #15 and 16).

As well as current, accurate forest inventory information, accurate models are needed to forecast future forests. BC forests are very diverse, as indicated by the BEC classification, even at the highest scale of BEC zones, and up to 20 trees species in a variety of sizes and ages within a stand. A wide variety of harvest/silvicultural regimen are being applied. Further, practitioners expect to have even more options to respond to changing climates, and new bio-products as well as other ecosystems services and products.

FAIB manages the GY and site productivity components of the Forest Inventory Program (Fig. 4.4). There have been noted successes in this program:

- VDYP and TASS/TIPSY have been developed and are being used to provide forecasts for Timber Supply Analyses.
- GY and SiteTools software are available for public use.
- Further development of TASS has been occurring for a broader range of forest and management conditions, resulting in a prototype release of TASS III for user testing.
- Efforts have been made to model insect and disease impacts, and to improve estimates involving the use of improved genetic stocks.
- Staff are highly regarded within the GY and site productivity programs of FAIB.
- Well-qualified consultants are used to increase capacity beyond that of FAIB staff.
- EP plots data is managed by Resource Practices Branch, but there is an excellent, collaborative relationship with FAIB staff in the GY and site productivity programs.
- High-quality, basic research in growth and yield under a variety of management regimes is being conducted by staff in FAIB and Resource Practices Branch. Some of this research is in collaboration with university and CFS researchers.

However, there are concerns:

- There was major agreement (second most common) by users that GY models need to be improved particularly for multi-species and complex stands. The issues are:
  - From a user point of view, it appears there has been limited progress toward Mitchell's stated goal of covering all commercial species of BC in the approximately

  40 years of TASS research. This is particularly the case for forests outside the BC Coast. It should be noted that high-quality growth research requires years of inquiry.
  - TASS was not originally designed to cover mixed-species or the complex stands occurring across BC BEC zones. Efforts have been made to use the existing structure of TASS for these types of forests initially by assuming complete separation of different species over the land area but, more recently, through spatial integration of a very limited number of mixed-species stand types (See Section 4.2.6).
  - VDYP handles mixed species stands by assuming the species composition does not change over time (See Section 4.2.6). This is mostly unrealistic, as shade-tolerant species become more prominent over long periods of time. Further, complex structures with many ages or differences in tree sizes are not well-represented with this modelling philosophy. VDYP was designed to forecast existing (so-called, natural) stands, whereas TASS was designed to forecast post-harvest (so-called, managed) stands. However, stands may be only partially harvested (or burned). Both models are extremely challenged to handle partial harvests and partial removals due to natural disturbances. Efforts have been made in TASS for variable-retention and patch harvests in recent years by segmenting the land area (See Section 4.2.6). Other efforts have been made to use VDYP for post-fire stands, although the model structure was not designed for partial removals.
- There was major agreement from the users that practitioners are uncertain about the reliability of GY forecasts.
  - The base research is very high quality based on the limited number of peer-reviewed papers (notably, more in the site productivity program).
  - However, most of the growth research within TASS has not been published; recent efforts have been made to present at international conferences.
  - Practitioners expressed concerns about the reliability with regard to extrapolations and assumptions made in using the models.
- GY models require PSP data, particularly, high-quality heritage data covering long time periods and many repeated measures over time; the PSP re-measurement program was greatly curtailed because of budget constraints.
- Neither VDYP nor TIPSY was designed:
  - To forecast critical habitat features such as CWD. This could be estimated from other stand characteristics that are forecasted, as noted in research papers.
  - To forecast stands under future climates. There are a number of methods that could be used to simulate future climate impacts on yields, including altering the SI as shown in a large body of research papers (e.g. See Messaoud and Chen, 2011).

7.3.4 Resolution, Scalability, Reliability, and Level of Detail

Overall Statement: Since BC forest lands are primarily publically owned, and therefore, managed by government, public funds must be used to provide answers to forest resource questions and to fulfill ongoing management of BC’s forests. To meet increasing information needs, collaborative projects and funding will be needed and is discussed in Appendix 7 (See Recommendations #3, 10, and 14).

In the prior sections, the issues brought forward with regard to resolution, scalability and level of detail in particular were:

- The Forest Inventory Program provides support for strategic-level analyses. At the same time, a number of projects have been completed by FAIB to support lower spatial scale needs including improved within-stand details. These efforts have been extremely limited due to the FAIB budget, and expenditures on these "one-of" projects take away from base program needs. FLNR has taken a balanced approach in making decisions as to where funds are best allocated based on an assessment of risks versus rewards in inventory investments.
- Two GY models are supported with FAIB. These were not designed to cover all needs for forecasting future stand conditions.
- There are increased demands for not only lower spatial scales (higher resolution), but also more forest attributes.
- Changes in harvest/silvicultural/natural disturbance regimes have already occurred, but more will likely be tested to respond to expected future climates.

The questions regarding availability and reliability are:

- How can all demands for current forest information, as well as future forest forecasts, be met?
- Given the limited budget, compromises will need to be made. How reliable will the information be at the strategic and finer scales of spatial resolution? Is this sufficiently reliable to ensure confidence in decisions made?
- Can emerging technologies provide all the solutions? What expertise will be needed to use these new technologies if they do prove useful?
- How can new processes be introduced, while continuing to use existing processes to meet current information needs?
- What basic research is needed to support the future changes in forest disturbances and in growth, in the areas covered within the Forest Inventory Program? Who will conduct this research?

8.0 Recommendations

The forest inventory needs to focus on meeting the needs of the Chief Forester, government in general and users from the perspective of supporting well-managed forest decisions. The Panel believes the forest inventory has to be constructed and implemented as a system using a number of criteria to measure adequacy. In this regard, it is the Panel's view FAIB has done an admirable job in implementing an inventory program to work toward meeting this requirement within the resources government has allocated. However, there are areas needing improvement that the following recommendations, many of which require additional resources, are directed.

The following 16 recommendations are listed under the following headings:

- Resourcing (Recommendations #1-5)
- Administration (Recommendations #6-9)
- Communications (Recommendation #10)
- Inventory (Recommendations #11-14)
- Innovation (Recommendation #15)
- Growth and Yield (Recommendations #16).

RESOURCING

Recommendation #1: Provide adequate and sustainable funding to move toward a robust forest inventory system with the data and analysis to support decision-making for well-managed forests.

Process:
• Government establish a legislated mechanism that provides long-term, stable funding for a robust forest inventory system that meets the needs of well-managed forests.
• FAIB to determine a transition schedule and resources necessary to meet the criteria for an inventory required to support well-managed forests. In the analysis, FAIB to:
  o Adopt an approach to building the updated inventory while maintaining the short term needs of users and building internal and external expertise regarding acquiring and delivering the inventory;
  o Consider implementing a schedule of implementing the necessary steps during a 10 year transition period;
  o Review internal processes and new technologies regarding collecting, analyzing and interpreting data and modelling from the perspective of improved cost-efficiencies; and
  o Investigate partnership opportunities with users to share the costs of components of the system where benefits accrue to both parties.
• FAIB to recommend to government, through the Chief Forester, the resources and schedule of resource allotment required to move toward a robust forest inventory system that meets the needs of well-managed forests decision-making.

Essential Resources: • Stable and long-term funding to support a robust forest inventory system
Innovations: • The forest inventory being thought of as a system, • Identifying partnerships in support of the resourcing needed to achieve the desired inventory products and make them readily available for application.

Rationale:
• The Chief Forester identified the need for an inventory that provides:
  o Data and information to address the current and expected timber and non-timber related issues associated with its use; and
  o Reliability, accuracy, with an appropriate level of detail at the desired levels of resolution necessary for confidence in its use on major issues raised by users and critics.
• The ABCFP (2012) reported the government had not achieved the “stable and adequate funding” of $15 million annually to “…maintain a reasonably current inventory required to underwrite the mandate of the Chief Forester…”
• The forest sector is responsible for 32% of BC exports amounting to $17 billion and government revenue of $1 billion.

- The Forest Inventory Program is fundamental to decisions that generate the provincial revenue that support societal values such as education, health, etc. Increasing funding for the program is an investment in maintaining these financial benefits now and into the future. Many ministries, Crown corporations and forest sector companies depend on the forest inventory in their decision-making.
- The 2017-2018 FAIB budget is $11.3 M. If this was doubled to $22 M the cost per cubic metre of harvest volume would increase from $\$0.21/m^3$ of the provincial TSA cut level to $\$0.42/m^3$. Relative to the importance of the information to decision-making and government revenue this is a small investment in the asset.
- The recent Professional Reliance Commission (*The Challenges of Using a Professional Reliance Model in Environmental Protection – British Columbia's Riparian Areas Regulation*) report recommendation (R28) highlighted the importance of resource information being available to the public.
- The Professional Reliance Commission report also identified the need to identify opportunities to improve the quality of natural resource information to help improve professional reliance outcomes (R33). The review noted that a number of disputes concerning the quality of resource information presented in professional work products.
- Achieving the needs of the Chief Forester, forest professionals and public requires a sustained well-resourced forest inventory system that has a sustained level of adequate funding for staff and operations.

Recommendation #2: Maintain and increase qualified workforce in terms of both number of people and their skill levels.

Process:

- Develop a strategy that aims to address labour force shortages within the Forest Inventory Program. The strategy articulates:
    - A clear vision of roles of branch staff, how each section (inventory and analysis) and teams work together towards common goals of the inventory system;
    - Identify training gaps;
    - Measures to build team cohesion as a part of addressing a geographically distributed workforce; and
    - Anticipated skill sets necessary to meet the programs strategic goals.
- Communicate skill needs (identified above) to Canadian post-secondary institutions. Identify the congruencies between government and industry skill requirements to emphasize labour market trends to schools.
- Support research collaborations and publications that support graduate level specialization.
- Provide workshop training and professional accreditation for staff, contractors and users on standards (e.g., VRI), software products (e.g., Growth and Yield models) and professional user-driven applications (e.g., RESULTS) maintained by the program and Ministry.

- Identify and prioritize shortcomings (e.g., risks through rates of attrition) in specific skills (e.g., forest mensurationists, photo interpreters, forest biometricians, computer analysts, etc.) in both government and in the contractor community.

Essential Resources:

- Focus training for an internal (FAIB) and contractor community workforce to address attrition and succession in the workforce,
- Utilize training collaboration mechanisms through academia, the ABCFP and the Canadian Forest Service;
- Consider re-instating forest inventory specialists in Natural Resource Districts

Innovations:

Designing training that emphasizes forest inventory systems, with focused links between forest ecosystems (e.g., ecosystem id), forest activities (e.g., silviculture surveys, mensuration) and their application (inventory and growth models) that builds links from data collection and inventory products to their support in decision making, and in turn, investment and stewardship of BC's forests.

Rationale:

While BC has some of the most highly trained forest inventory staff in Canada, current staffing levels are not sufficient to meet certain core business needs. Sustainable forest management, and public trust, requires that products (e.g., re-inventories, forest change mapping, AAC analyses) are continually and promptly delivered. The Inventory Program is often strained by high analytical demands in answering pressing socio-economic questions, as well as demands to refine the spatial resolutions and shorten the delivery time for decision-support products. This often leads to triaging staffing resources, at best diverting or postponing certain key business deliverables, and at worst diluting key program areas. There are 46% less staff in the inventory program between the 2000-2009 period and 2010-2017 period; however, the rate of harvest only dropped 8% over the same periods in BC. In an era of skilled labour decline and high rates of attrition, it is important to identify current skills, facilitate staff knowledge transfers, anticipate future skills required, and pro-actively engage post-secondary institutions and the contractor community to find mutually beneficial solutions.

Recommendation #3: Establish an innovation fund within the FAIB annual budget.

Process:

- Mandate the *Forest Inventory Technical Advisory Group* (See Recommendation #9) to advise on innovation direction to explore new (or established) technologies, such as:
    - Remote sensing data (e.g., aerial/terrestrial laser scanning; digital aerial photogrammetry, hyperspectral imagery);
    - Analytical methods using multi-data sources (e.g., machine learning, advanced modelling methods;
    - Open sourced web-based applications (e.g., common platform for Growth and Yield models; increased capacity within DataBC); and
    - Collaborate with other provincial agencies (e.g., Ministry of Education), Provincial governments and industry to advocate for resources from Federal

science and technology funding agents to support forest biometrics research (e.g., NSERC). Forest biometricians specialize in big-data analytics, a versatile and highly sought skill set across professional disciplines.

- Complete literature review of promising innovations.
- Complete an opportunity cost analysis that articulates cost, limitations and benefits of employing new technologies relative to the program's responsibilities.

Essential Resources:

- Treasury board request for additional annual budget for an innovation fund.
- A collaborative technical committee (provincial and federal government, academia and industry) of experts to facilitate knowledge-transfer and increase access to operational networks.
- An innovation fund can help initiate the architecture and administration of a growth and yield data sharing and collection multi-user platform (See Recommendation #4).

Innovations:

- Leverage funding with collaborative Partners and funding sources to research and test new technologies (e.g., NRM Coordinated Free & Open Lidar Program Initiative)
- Accessing advanced technology through pooled resources helps realize economies of scale (multiple regions, stakeholders, uses)
- Existing bodies of research and operational application through peer-reviewed publications helps direct resources in a rapidly changing sector.

Rationale:

Some of the methods for developing forest inventories in BC and the tools to maintain those inventories are becoming antiquated. While the Forest Inventory Program successfully pursues projects in collaboration with research leaders, many projects are piece-meal rather than part of a focused plan for integrating technological advancements.

The business demands of the Forest Inventory Program have limited the province's capacity to conduct research, and develop and implement methodological changes to its inventory system. Since 2011, most of the programs operational budget has gone towards meeting core business activities and deliverables, with only 4% of the budget going to research in other spatial inventories. While the contribution from forestry to the provincial economy is one of the highest in Canada, BC spends the lowest amount on forest inventory relative to crown revenues directly sourced from the sector.

Innovation is fueling change in forest inventories across Canada and around the world. An innovation fund could harness that knowledge base and find efficiencies through initiatives that can be practically applied. For example, research and limited trials using new technologies have shown that reasonably accurate operational-level forest inventories at finer spatial scales can be achieved at lower costs using model-based approaches and a mixture of remotely sensed data. Higher levels of accuracy, efficiencies through automatable products (e.g., error of estimations built into the inventory production process), and short-term returns on investments are a few benefits that align directly with the programs strategic plan. A formalized fund with a spending strategy guided by a committee of experts will tangibly link technological advancements with the Forest Inventory Program's core business needs.

Recommendation #4: Establish a Growth and Yield Partnership to build financial and collaborative support for a long-term and sustainable Growth and Yield program.

Process:

Chief Forester to investigate the interest by forest companies and forest professionals in a *Growth and Yield Partnership* (See expanded description in Appendix 7) under the direction of the Chief Forester with a mandate to:

- Focus on modifying the existing Growth and Yield Program to:
  - Be sustainable over the long-term,
  - Demonstrate the value of participation by companies or organizations,
  - Be organized with the principles of cooperation,
  - Focus on current and long-term specific user and provincial issues and associated priority needs, and
  - Provide user advocacy support the FAIB Growth and Yield Program,
- Provide a focused effort on:
  - Investigating and establishing, if supported by key parties, a *Growth and Yield Partnership*;
  - Identifying to the Chief Forester the priority projects and activities for funding allocation,
  - Encouraging the understanding of growth and yield as a foundation for forest management,
  - Advocating and facilitating provision of the necessary multi-year funding for sustainability of Growth and Yield research and model development,
  - Advising on opportunities to integrate silviculture surveys and standards with the requirements of data collection to efficiently and effectively support the forest inventory and Growth and Yield programs,
  - Identifying new technologies that would assist in improving efficiencies and effectiveness in data collection, distribution and analysis,
  - Conducting communications to interested parties (professionals and laypersons) regarding the forest inventory, and
  - Acquiring expert advice on topics identified in delivery of the mandate items above.

Essential Resources:

Sustainable and adequate funding for the Growth and Yield Program, such as:

- Government, in collaboration with participating forest companies, establish a funding mechanism based on Growth and Yield stumpage allocation, in-kind industry and levered research funds contributions, considering:
  - Government legislating an annual stumpage allocation (consistent with the Canada-US Softwood Lumber Agreement) directed to the Growth and Yield research, data collection and model development to ensure Program sustainability.

- Government increasing stumpage as a means of acquiring the necessary funding for the Growth and Yield program and providing leverage funding from research funding organizations applications.
- Government include recognition of the eligibility of in-kind industry costs associated with Growth and Yield Partnership data collection, research and model development consistent for stumpage credits against the company stumpage contribution up to a maximum based on AAC allocations.

Innovations:

- Changing the funding mechanism for the Growth and Yield Program from one totally dependent upon government funding allocation to one in partnership with the forest industry recognizing the benefits of the Program accrue to both Parties.
- Providing a sustainable and long-term funding mechanism consistent with the requirements of the Growth and Yield Program.

Rationale:

- The inventory system is dependent upon a Growth and Yield Program that projects forest growth through computer models supported by on-the-ground plot data and verification procedures. A BC Growth and Yield Program is a critical component in realizing the full benefits of the forest asset to the government, communities and industry over the long-term.
- The Chief Forester has the responsibility to advise government and inform the public on Sustainable Forest Management. Growth and Yield data and projections are integral to providing advice on this matter.
- Growth and Yield Programs are long-term and need sustainability to reflect the growth of the forest under historical conditions and environmental changes such as insect attack and climate change. This can be best achieved if the key Parties (i.e., government and forest companies) are committed and actively involved in the Program and resourcing mechanisms which can withstand economic environmental changes. It takes leadership by both key Parties who benefit greatest from sound data and projections generated through a Growth and Yield Program. They must to work as a team and be committed to the Program, if the full benefits are to be realized.

Recommendation #5 Provide independent IT resourcing to increase efficiency and expansion of data storage and analytical capacity.
Process: • Recognize that inventory processing and supporting software requirements are becoming more demanding in terms of supporting software and hardware, particularly as it relates to the use of advanced techniques for processing of LiDAR, satellite imagery, and very high resolution digital multispectral and hyperspectral data. • Identify areas with the greatest potential for advancing forest inventory processing and production techniques in pursuit of better outcomes. • Recognize the opportunities to produce base products from remote sensing data that can be used to advance forest inventory products to enable these to be made available to users and supplements base inventory products (e.g., canopy height models, point-cloud based estimates of forest crown cover with respect to height, etc.). • Recognize the need to produce custom built software with supporting documentation that can be maintained in a central repository (e.g. GitHub) and is open to upgrading over time by way of versioning. This will ensure the conversion of tacit knowledge related to long-term inventory data analysis, production, storage, and management capabilities into codified or explicit data products that can be accessed by government and outside users. • Consider using innovations to speed up processing and access, including parallel processing, and access to cloud or other storage processing services to reduce inventory production times and improve access to inventory products across multiple devices. • Conduct a review of near to mid-term software and hardware computing capacity and provide recommendations to ensure that these are not constraining inventory productivity and innovation. Include considerations regarding how these are structured and organized in terms of their contributions to long-term institutional knowledge and infrastructure. • Identify critical points for quality control in processing of inventory products. • Produce a multi-year infrastructure development and implementation plan that will enable FAIB to advance inventory production, maintenance, and delivery services over time, and evolve the forest inventory system towards more automated production processing.
Essential Resources: • Funds to complete evaluation. • Staff time to devote to the evaluation. • Access to expertise to undertake the evaluation.
Innovations: • Making an effort to better ensure that forest inventory is adequately supported in terms of software and hardware requirements, such that they are not constraining productivity.

- Making sure that new sources of data can be easily stored and retrieved as a means of building up long-term sources of information on forest, stand, and tree characteristics over time. - Providing greater assurances that custom computing software is being built in such a way that it can be utilized within a larger institutional framework, particularly where it is to be deployed for routine processing, and that it is sufficiently well documented for application by a third party knowledgeable user.
<u>Rationale</u>: The FLNR is confronted with changes in technology that are placing increasing demands on processing and data storage capabilities, particularly as it relates to the processing and storage of LiDAR, and LiDAR related datasets. There is also a tendency to move data processing into cloud-based services as means of accessing increasing computing capacity, and as a means of controlling software development without dependencies on multiple platforms.

ADMINISTRATION

Recommendation #6: Restore the Chief Forester's legislated responsibility for the forest inventory.
<u>Process:</u> • Consideration should be given to using FRPA (instead of *Forest Act*) to restore the Chief Forester's legislated responsibility for the forest inventory • Having the authority rests in FRPA enables the Forest Practices Board (See Recommendation #8) to provide independent advice regarding the delivery of the inventory program.
<u>Rationale</u>: • The forest inventory provides fundamental information necessary to make decisions for forest planning and practices. • Prior to 2002, Section 2 of the *Forest Act* stated that: *The chief forester must develop and maintain an inventory of the land and forests in British Columbia.* • When the responsibility for the forest inventory was moved from the Ministry of Forests (now FLNR) to the Ministry of Sustainable Resource Management, section 2 of the *Forest Act* was repealed. • When the provincial government returned responsibility for the forest inventory to the Ministry (now FLNR), government did not put back the repealed Section 2 of the *Forest Act.* • As a consequence, the province has no legislative mandate to develop and maintain a forest inventory. • Without a legislative mandate, the forest inventory annual budget plummeted from $15.0 million with 75 staff in 2002/2003 to $5.9 million with 40 staff in 2005/2006. • A major reason why the forest inventory responsibility was returned to FLNR was to improve the forest inventory in support of timber supply review and the chief forester's AAC determinations.

- It therefore makes sense that the chief forester's legislative responsibility to develop and maintain a forest inventory be restored.
- A reliable forest inventory is also necessary to support sound land use decision-making, and for numerous other reasons as outlined in the Panel report.
- Without a legislative mandate, future government will likely make budget decisions in absence of consideration of legislative responsibilities.

Recommendation #7: Establish a Ministry policy to view all inventory project and program decisions from the perspective of contributing to the BC forest inventory system as a whole, not as separate projects or programs.

Process:

- Describe the current process(es) and method(s) used to construct, maintain, and update forest inventories in the context of the flow of information, rather than separate tasks within the forest inventory system or programs within the Ministry.
- Establish a goal of increasing program inter-compatibility, with specific indicators or performance measures.
- Insofar as cruise data can inform forest inventory products (e.g., phase I interpretation), work with the Timber Pricing Branch and BCTS to identify current means or prioritized policy changes that facilitate the delivery of readily useable cruise data (e.g., plot level) to FAIB.
- Ensure updates to the silviculture survey program, including the Silviculture Survey Manual, compliment the forest inventory system. The Resource Practices Branch Silviculture Program to work closely with FAIB to identify congruencies between the programs.
- Clarify the division of responsibilities between the Ministry of Environment, the Resource Practices Branch and FAIB, and where appropriate narrow the responsibility to one agency relative to improving site productivity measures, products and estimates.
- Work with the Resource Practices Branch to ensure data fidelity from the RESULTS program is maintained when integrated into forest inventory updates.
- Describe how these forest inventories are/can be used across agencies both internal and external to FLNR given the inventory method(s) of production, and evaluate the strengths and weaknesses of the inventory process in relation to the intended application in terms of decision support.
- Evaluate the costs and benefits of using different kinds of forest inventory processes and applications with a better accounting for sources and degrees of uncertainty in the information provided and how these impact on decision making.
- Maintain an awareness of what is being done in other jurisdictions, and how advances in technology are impacting inventory system design and applications.
- Provide assistance with review of project proposals, both internal and external to FAIB, to ensure that they are contributing to maintenance and development of the system as a whole, and to consider potential impacts if changes would be required.

- Provide an annual report on the work that has been completed under this position, and provide a summary of the findings and any recommendations that have accrued as a result.

Essential Resources:

- A forest inventory systems specialist within FAIB. Given the complexity of model-based/model-assisted methods needed for forest inventories that are accurate, lower-cost, and, at the same time, higher resolution, this specialist must have: i) experience in the production and application of forest inventory (both technical and managerial skills); ii) a strong forest biometrics background; iii) experience using a variety of remote sensing data in forest inventory; and iv) experience in inventory systems, rather than separate inventory tasks. As well, this specialist must have excellent communications and inter-personal skills to facilitate interactions with a wide variety of stakeholders in both the producer and user communities.

Innovations:

Recognizing inventory as a system:

- Will facilitate the maintenance of a solid foundation concerning an awareness of the strengths and weaknesses of the current inventory process.
- This is a starting point for bridging gaps between user needs and the current information products available to address these needs.
- Places more emphasis on advancing the inventory production process and techniques, with assurances that the advances will contribute to the inventory system as a whole.
- Advance awareness of the uses of forest inventory across a broad spectrum of applications.

Rationale:

The shared understanding of inventory as a system, both in terms of production and the variety of applications, is a necessary prerequisite ensuring effective allocation of resources for maintaining, updating, and advancing the system as a whole. Large-scale forest inventory systems are both complex and demanding in terms of the breadth of knowledge required given the multi-source data, advanced methods (i.e., a mixture of design-based, model-assisted, and model-based methods), decisions made using these data, and requirements for accurate information within budget constraints. One of the greatest limitations is the tendency to focus on fulfilling our immediate responsibilities and needs without sufficient consideration or understanding of impacts elsewhere in the process; this is particularly the case where resources are limited and timelines for completion of work activities are demanding. Viewing the forest inventory as a system, increasing inter-program compatibility, as well as adding an inventory specialist, will reduce these barriers among separate inventory tasks, and advance the system as a whole. Overall, considering the forest inventory as a system, rather than separate tasks, will reduce redundancies between Ministry agencies, facilitate communication to users inside and outside of government, facilitate identifying opportunities to utilize new technologies, and refine the production process. This will, in turn, increase the quality of the information and reduce delivery times, which will improve the timeliness and quality of decisions made.

Note: One specific issue that arose during the course of Panel review was the need to ensure that methods for integrating site productivity estimates into the forest inventory were more clearly identified. Concerns were also raised as to whether the SIBEC estimates were being maintained up-to-date given changes in the BEC site series system of classification. Other concerns related to integration of datasets external to FAIB, but important to the overall inventory process, including for example RESULTS. On a larger scale these issues also raise the need for better integration of growth and yield models into inventory update and longer term forecasting. The inventory system and the proposed inventory specialist would give more complete consideration of these concerns within the concept of a inventory system as a whole, ensuring that site productivity estimates and growth and yield forecasts are part of the system, leading to improved products and methods.

Recommendation #8: Expand the mandate of the Forest Practices Board to include providing independent advice regarding delivery of the Forest Inventory Program.

Process:

- Revise the *Forest and Range Practices Act* to expand the mandate of the Forest Practices Board (FPB) to conduct assessments of the Forest Inventory Program.
- Establish the mandate of the FPB to:
  - Conduct fixed periodic audits (e.g., every 5 or 10 years) of the Forest Inventory Program, recommendations from the *Forest Inventory Technical Advisory Group* and the *Growth and Yield Partnership*, and
  - Periodically review inventory protocols and requirements.

Essential Resources:

Government would benefit from the administrative infrastructure costs already within the FPB.

Innovations:

The public continues to voice the need for independent evaluations regarding public resources. Utilizing the existing FPB, with their positive reputation, would satisfy the public need while limiting additional costs.

Rationale:

The Chief Forester has the responsibility to advise government and inform the public on Sustainable Forest Management. The Panel heard user and public questions regarding the status of the data within the forest inventory system. Even though the FAIB staff provides updates on the available inventory, a review by an independent body would provide the Chief Forester and the public with a higher degree of confidence in delivery of the components of the system. The intent of involving the FPB is to provide the Chief Forester with external advice regarding:

i) FAIB progress to delivering a Strategic Plan that addresses user issues and progress in meeting user needs, and

ii) Resourcing (staffing and funding) required to deliver the Forest Inventory Strategic Plan.

This model would capitalize on the FPB's positive public reputation of an independent voice and their audit expertise.

Recommendation #9: Establish a Forest Inventory Technical Advisory Group.

Process:

- Establish a *Forest Inventory Technical Advisory Group* reporting to the Chief Forester under a Memorandum of Understanding (MoU) between the primary users of the forest inventory, including FLNR membership, and academia. The MoU would be based on a jointly held view and commitment of delivering a forest inventory that meets the current and projected future needs of users while taking advantage of new and emerging technologies.
- Include in the MoU a mandate that provides advice to FAIB in:
- Developing and implementing an innovative Forest Inventory Program that delivers, at a high and innovative level, the required information and data to meet well-managed forest and user needs;
- Establishing forest inventory data collection standards to meet government and user forest inventory needs;
- Identifying areas of the Province where the quality of the forest inventory requires upgrading to better underwrite both strategic and operational planning;
- Establishing inventory data collection and management programs to provide information to respond to natural disturbances and climate change; and
- Create potential membership representation commitments from:
  - Government, including FAIB, BCTS and Ministry of Environment users,
  - The forest industry, including a member from each of the coastal and interior TFL licensees and each TSA Association,
  - The perspective of First Nations forest companies,
  - The forest mensuration and biometrics research community (academia and government),
  - The perspective of the forest inventory consulting community

Essential Resources:

- The funding and secretarial support for the Forest Inventory Advisory Group and the required actions to deliver the mandate would be borne by government throughout the life of the *Technical Advisory Group*.

Innovations:

- The *Forest Inventory Technical Advisory Group* establishment will facilitate on-going communications and dialogue between forest inventory users and forest inventory providers. It will also provide an on-going, external advocacy support voice for the FAIB Program.

Rationale:

The Chief Forester has the responsibility to advise government and inform the public on Sustainable Forest Management. Users identified a desire to have more say in the inputs and outputs of the forest inventory system necessary to meet their needs. Although it is proposed government have the responsibility for establishing the standards for each type of forest inventory data collection, advice from a *Forest Inventory Technical Advisory Group* would assist in providing support to FAIB in developing their Strategic Plan, informing them of user needs on an on-going basis, and encouraging government to provide the necessary resources required to achieve well-managed forests.

A Technical Advisory Group can:

- Help build inventory program support
- Facilitate improved communication
- Foster innovation
- Encourage collaboration
- Help the program be responsive to user needs

Detailed recommended actions are included in Appendix 7

COMMUNICATIONS

Recommendation #10: Develop a robust inventory system communications program to support an informed base of professional users and public audience.

Process:

- Develop a communications strategy in support of the next 10-year Forest Inventory Strategic Plan.
- Improve transparency to the inventory data and information through making previously constrained data and information accessible on-line for use by the public and professional users, such as:
    - Publish state of forests maps (such as 10km x 10km tiles) updated with harvest/disturbance annually.
    - Publish annual summary statistics on BC forests (including annual changes, rate of harvest, carbon sequestration etc.).
    - Improve extension regarding the role and use of audits in the inventory; and
    - Increased linkage to DataBC (BC Data Catalogue) services; Publish methodological standards that are currently in use but not available for users (e.g., LVI).
- Build and implement, in partnership with the ABCFP, industry and other professional inventory users, a comprehensive forest professionals training package that includes understanding what is in the forest inventory, the components that are interrelated, its uses and limitations. As an offshoot of this product, develop forest inventory educational materials such as short videos and brochures for public audiences.

Essential Resources:

- Dedicate extension personnel to implement the communications strategy.

- Standardize user request forms for internal and external analytical or product requests to support direct connections to experts.

Innovations:

- Collaborate with ABCFP, academia and the Canadian Forest Service for support in journal publication or other extension material relevant to growth and yield or Forest Inventory Program research.
- Benefit from social media platforms to announce availability of new or updated products, publications, contributions to key decisions or the programs participation in public or professional events.

Rationale:

Improvement in communications and data access was the third most agreed upon premise by users surveyed by the Panel. Transparency in how the products are made and applied is tantamount to building trust within the public and professionals. This is even more important when much of the responsibility of sustainably managed forests relies on forest professionals. Understanding the needs and application of the inventory and Forest Inventory Program products by the user base will be essential to a successful communications strategy. Increased extension will also build government decision-makers awareness of the importance of the inventory as part of many decisions across government, industry and Crown Corporations and the associated economic, environmental and social benefits.

INVENTORY

Recommendation #11: Obtain full LIDAR coverage for BC

- Adopt a mandate within the FAIB strategic plan to acquire LiDAR to support forest inventory for the entire province over a multi-year timeframe, with explicit purposes to: a) develop a Digital Elevation or Digital Terrain Model for the operable forested land base; b) further enhanced forest inventory for VRI; c) implement enhanced forest inventory methodologies outlined in Recommendation #13.
- Prioritize the acquisition plan to the operational forest land base first (e.g., 25 million hectares).
- With other agencies and industry, make the cost recovery business case to Treasury Board for LiDAR acquisition given the multiple benefits (e.g., Digital Elevation Model (DEM), reduced engineering costs, floodplain mapping, and enhanced forest inventory).
- Develop inventory sharing agreements with TFL licensees that will:
  - Have industry provide funding for LiDAR inventories on the TFL using LiDAR acquisition specifications developed by the province; and
  - Agreements between the government and Licensee for government to acquire the inventory data at a cost that reflects the benefits to both parties.

Essential Resources:

- Through collaborative initiatives such as the *Natural Resource Ministries Coordinated Free and Open LiDAR Program Initiative* with other Ministry Branches (e.g., BCTS), other agencies (e.g., MOE, MOT or EMPR), crown corporations (e.g., BC Hydro), and third parties (forest industry) ensure access to the acquisition of existing LiDAR datasets.

- Government and industry need to enter into an agreement to get full coverage of the forest area of the Province with the costs being shared relative to the benefits to each party.
- LIDAR acquisition standards need to be developed and shared to fulfill needs of the forest inventory system.
- Funding should come from shared provincial agency budgets, not entirely within the FAIB budget.

Innovations:

- Consider cost-recovery data sharing models that leverage hectare-for-hectare access between third-party and government LiDAR coverages by creating pooled LiDAR datasets (e.g., *Okanagan Watershed Lidar Consortium, Kootenay/Boundary Lidar Consortium, Haida Gwaii LiDAR data-sharing initiative*).
- A significant number of publications and operational applications in BC and across Canada detail the direct application of LiDAR to enhancing forest inventories (See section 4.3).

Rationale:

LIDAR is viewed as a critical technology to increase efficiency and the quality of the inventory system. LiDAR is proven valuable as an inventory tool, with most large tenure holders having already invested with costs recovered through forest-engineering savings alone. BC Timber Sales has acquired as much as 5.2 million hectares of forest with LiDAR with costs of approximately $1.20 per hectare. LiDAR is not only a valuable contribution to operational forestry (e.g., engineering, stream mapping), it is foundational for developing point-cloud enhanced inventories (canopy height models), but the LiDAR derived- DEM or DTM also crucial for exploring other (possibly less expensive) remotely sensed methods for deriving model-based attribution (e.g. digital aerial photogrammetry). Aside from investments by BC forest licensees, this technology has been widely invested by government Forest Inventory Programs in Canada e.g., Quebec and New Brunswick, and the world e.g., Sweden, Norway, Washington state (See section 5 and Appendix 4).

The multiplicity of LiDAR use is testified through a variety of provincial agencies who list its acquisition within annual budgets or as focal users, ranging from the Ministry of Transportation, Energy Mines and Petroleum Resources, Emergency Management BC, the Oil and Gas Commission, the Ministry of Environment, and BC Hydro leading to collective distribution rights for up to 9.5 million hectares of LiDAR through the *Coordinated Free and Open LiDAR Program Initiative.* Collaboration between users is therefore key. BC's Forest Inventory Program will be a key beneficiary to a clear multi-year funding strategy creating a foundation for several decades of high-resolution forest inventory for BC's public forests.

Recommendation #12: Produce and maintain an up-to-date VRI rank-1 layer dataset throughout the entire Province of BC.
<u>Process</u>: • Coverage for the entire forest land of BC • Update annually • Redo inventory every 10 to 20 years, as priorities dictate in response to extent and severity of changes due to natural and human induced disturbances since the last complete re-inventory, and in response to needs for better information, and/or additional kinds of information, required to resolve strategic and operational forest management issues.
<u>Essential Resources</u>: • Funds to acquire remote sensing data, including aerial photography • Photo-interpreters (forest inventory) and geomatics experts (large disturbance mapping) • Funds for adequate field checks/feedback on accuracy of forest inventory mapping during the project • Funds to assess user-perceived accuracy of forest inventory products • IT resources including computers house database and IT staff to secure data and provide data to publics in a timely manner • Funds to train new photo-interpreters in-house.
<u>Innovations:</u> • Develop methods for photo-interpretation assists that can improve productivity of each interpreter, and also to train new photo interpreters • Develop automated methods to classify aerial images (and using ground data and LiDAR data) as a "first-cut" to support photo-interpreters and speed up progress.
<u>Rationale</u>: Forest inventory maps are the basis for all land-based assessments including timber supply analyses, habitat analyses, impacts of fires, pests, prioritizing silvicultural investments, assessing fire risks, etc. Professionals and public lose confidence in all analyses when data are not accurate in time and space. This was very frequently a concern expressed in interviews and other feedback, since this affects all forest management in BC.

Recommendation #13: Utilize advanced forest inventory information, tools and processes to achieve additional information important for forest management planning and practices in prioritized areas of the province, particularly to support AAC determinations in areas where timber supply is constrained and/or contentious.
<u>Process</u>: Use model-based approaches and a variety of data sources (e.g., aerial photographs, Landsat, LiDAR data, photo plots, ground plots) to provide: i) additional within-stand detail (e.g. diameter distributions by species, coarse woody debris, dead standing trees); ii) additional remote sensing processes and/or indices for use in forest inventory production; iii) more accurate estimates of key VRI Phase I attributes (e.g., volume and basal area per ha, Lorey's mean tree height, dominant tree height, quadratic mean tree diameter); and/or iv) higher resolution by providing data at a scale that further subdivides VRI polygons into smaller subunits (e.g., line segments, or grid cells at 20m x 20m, or both). Use the resultant information to update VRI Phase I attributes as required to ensure compatibility of attribute estimates (i.e. as an inventory update or as a re-inventory) within the Provincial forest inventory standard. Provide documentation of the process and reliability of the results generated from application of the process.
<u>Essential Resources</u>: • Funds to acquire remote sensing data, including aerial photography, ground plot data, and/or photo plot data. • Have/provide access to expertise in: i) the application of model-based approaches using forestry data (i.e., forest biometricians); and ii) the organization and processing of remote sensing data. • Funds to assess accuracy/precision of forest inventory products at different scales. • IT resources including computers and in-house database and IT staff to secure data and provide data to publics in a timely manner. • Adapt, adopt, or develop additional inventory, growth and yield, and associated forest estate modelling frameworks as required to utilize these kinds of data effectively and efficiently with respect to fulfilling their intended purpose. • Personnel: Where appropriate, provide opportunities and associated funding to support of training new forest biometricians in collaboration with universities; this facilitates replacement of others as they leave the workforce, and leads to advances in the capacity to undertake these kinds of projects within FLNR and the broader BC forest management community.
<u>Innovations:</u> • Advance the applications of advanced model-based methods within the Province of BC and gain a more complete understanding of their reliability in relation to the variety of BC forest conditions. • Develop automated tools, methods, and routines that can be combined in different ways to obtain end-to-end processing of forest inventory datasets as a means of testing and comparing different protocols and increasing productivity.

Rationale:

There are certain landscape areas and/or forest management units within the province that may require additional information as a means of better ensuring sustainable forest management plans and practices. It recognizes that there are situations where additional resources are needed to characterize the current state of the forest and its expected changes with time relative to the information that is available in the Province-wide VRI Phase I inventory. It also recognizes that if there is additional or improved information, then the VRI Phase I inventory information should be consistent with the improvements (and vice versa).

The decision as to where additional information may be required and how best to develop that information is at the discretion of FLNR; however, some examples are provided. One situation where the information may be needed is where forests are complex and where further differentiation and/or stratification of these complexities would lead to improvements in articulating the current state of the forest and in establishing improved short-, intermediate-, and long-term growth and yield forecasts to better support forest management decision making. Another example is where there are high demands for various goods and services (e.g., old growth, habitat, water supply, fire risk reduction, wood supplies, pest management, etc.) and there is considerable uncertainty as to whether forests are, in reality, in a state to fulfill any or all demands, where and to what extent, either now and/or in the future. Professionals and the public lose confidence in analyses when inventory, growth and yield data are lacking in necessary and sufficient detail, or sufficient accuracy across time and space. This was a very frequently expressed concern in the Panel review, with potential application to all forest management plans and practices in BC. If long-term strategic forest management plans are not based on activities that can be operationally implement on the ground, it is unlikely that the desired strategic outcomes will be obtained.

Recommendation #14: Investigate and implement methodologies to estimate inventory uncertainty to better underwrite evaluation of the potential for risk versus reward in forest estate management planning and decision making at the forest, landscape, and polygon scales.

Process:

- FAIB to establish a short-term expert advisory Task Force to:
    - Review, internally and in other jurisdictions, current methods, costs and benefits in reporting uncertainty statistics in inventory data and projection estimates.
    - Recommend uncertainty assessment methods to meet the priority needs of FAIB and forest inventory users including a justification for increased funding, if needed, and
    - Recommend existing datasets that provide spatially explicit information that has the potential to provide incremental value in combination with the inventory in operationally assessing uncertainty in inventory data and projections.

- FAIB to make datasets that provide incremental value in combination with the forest inventory publicly available.
- FAIB encourage research on the value of inventory information to decisions taken on the basis of the inventory; use the results to identify areas where inventory bias and precision should be improved and possible areas where less can be expended on inventory.

Essential Resources:

Additional resources are expected in developing an analytical approach to identifying uncertainty within the forest inventory data and projections. However, once developed, the methodology should provide a small component of including results as part of inventory reports. Additional resources may be needed to analyze and maintain the data.

The costs associated with conducting the research noted above may require additional resources to lever funds from other sources.

Innovations:

- Comprehensive assessments of inventory uncertainty comprise an emerging area of sustainable forest management.

Rationale:

Uncertainty in inventory estimates and projections based on them is likely to deter investment and create social and economic costs to the people of BC.

BC's forest inventory system should be capable of *quantifying* at the current point in time and *forecasting* into the future the volume of harvestable (merchantable) timber within an estimation or prediction interval suitable for the decisions to be made on the basis of such information. At present, there are few formal measures (VRI Q/A and audits) within the FAIB Program to identify inventory uncertainty.

The Task Force could consider such factors as:

- Source of errors include such factors as: sampling error, measurement errors, and modeling accuracy, for such key parameters as diameter, basal area, height and tree volume; uncertainty in growth and yield models.
- Recent research has demonstrated the methods for and the value of such formal assessments of inventory accuracies.
- Routine comparisons of actual harvest volumes with volumes carried in the inventory system for the same stands are a component of well-managed forests in other jurisdictions. Such comparisons not only provide the basis for improving forecasting but are also critical to monitoring the sustainability of actual forest management activities. The Panel acknowledges the difficulty of making such comparisons with the extant inventory system where inventory polygons may not conform to harvest-unit boundaries. This disparity highlights the need for an inventory system on the THLB that reflects operational realities.
- Inventory information is costly to collect and maintain. There is a clear economic basis for justifying expenditures on this activity. It is likely the Province is spending too little in some areas where complex, complicated forest management decisions are being made against the backdrop of rapid forest and market dynamics. It is also possible the Province is spending too much in other places.

INNOVATION

Recommendation #15: Establish three (or more) inventory system research, development, and implementation test sites within the province to ensure that any all new innovations will provide the information needed at an acceptable cost.

Process:
• Identify and establish three or more inventory test sites (e.g., central/southern interior, coastal, ICH-Kootenay regions) with the objective of advancing the development and implementation of advanced forest inventory systems.
• The primary goals of these installations are to:
  o Establish a network of permanent ground plots representative of the forest inventory that can be used for (re)inventory using advanced remote sensing techniques;
  o Produce software and supporting databases to compile data, render it in a form that can be accessed in a geospatial context, and that can be manipulated and downloaded or otherwise be made accessible for use in the field;
  o Establish linkages to key datasets (e.g., site series mapping, soil and terrain mapping, streams and wet areas, habitat mapping, etc.);
  o Evaluate opportunities for developing different inventory products (e.g., forest fire hazard and risk rating, wildlife species habitat mapping, hydrologic impact assessment, monitoring of growth and yield response to climate change, carbon stock mapping);
  o Evaluate alternative techniques for producing stand and stock tables (or tree lists) on a high-resolution polygon/grid-cell scale;
  o Evaluate alternative methods for inventory projection and update using a combination of: growth and yield forecasts, measurements from permanent plots, additional ground samplings;
  o Evaluate alternative methods for inventory update following disturbances.
  o Establishment and demonstrate improved methods for linking the inventory into both strategic and operational planning decision-making and monitoring programs, preferably with explicit accounting for uncertainties;
  o Ensure that the inventory protocols are sufficient to meet the VRI standard;
  o Provide evaluations of the costs versus benefits of each inventory approach as part of the program; and
  o Provide opportunities for advanced training in inventory development, management, and applications, preferably in association with one or more universities and other education institutions.

Essential Resources: • Selection of areas that are broadly representative of the range of conditions in British Columbia and that are with a manageable size (e.g., 3000 to 20,000 ha) to contain costs. • Sufficient funding to develop inventory systems that are operational, and that include the establishment of an intense set of permanent sample plots that are representative of the inventory as a whole.

- A focus on development of inventory systems that move beyond the current BC forest inventory system.
- Coordination and cooperation amongst the participating agencies with a program coordinator who reports to FLNR.
- Implementation of administrative protocols to ensure developments are open and transparent.

Innovations:

- The primary innovation is to establish test sites wherein inventory research and development can take place, and where appropriate, be integrated into an inventory system for the purpose of testing different applications.

Rationale:

One of the main barriers to adopting new inventory techniques is difficulty in introducing the resultant information into practice within a broader inventory framework. The inventory system test-sites would be designed in a way that made it easier to do so, with one of the main barriers, lack of ground plot data, built into the process. The systems can be periodically reviewed and used as a basis for advancing inventory systems used both by private and public agencies.

GROWTH AND YIELD

Recommendation #16: Develop Growth and Yield models that cover the main stand types and management regimes in BC.

Process:

For any forest land analysis, forecasts of the current state to the future is needed (e.g., Fig. 4.4). GY models that link to forest inventory data for each spatial unit (e.g., polygon representing a forest stand) provide these future forests. These models must cover all stand types of BC, including complex stands which can have upwards of 10 or more species in a mixed-species, uneven aged stand, as well as current and future silvicultural/harvest methods (i.e., stand management regimes), including retention harvests, single tree harvests, planting improved stocks, planting mixed species, etc. Further, these models must incorporate forecasts under possible future climates that may affect mortality and growth. Unfortunately, the current supported GY models (TASS, VDYP) do not cover all of these forecast needs. There is also uncertainty as to whether these two supported models could be modified to provide all of these needed stand-level forecasts with sufficient accuracy.

Essential Resources:

- Long-term PSPs re-measured on a regular schedule to support GY models. These include the legacy PSPs in selected locations (i.e., purposive sampling) in particular, as well as EP data from experimental trials, but may also include other repeatedly measured plots (e.g., Recommendation #16).
- Full documentation of existing supported models (i.e., TASS and VDYP), including flowcharts of the GY processes.
- Reports and published papers summarizing all EP trials.
- Reports and published papers on TASS research and innovations.

- Gap analyses of:
    - Long-term re-measured heritage PSPs;
    - The types of stands covered by TASS and VDYP as the supported models;
    - The management regimes covered; and
    - Reports and published papers for EPs, TASS, VDYP, and other GY research within FAIB and Resource Practices Branch.
- A review on how all stand types and management regimes could (or could not) be incorporated into the supported GY models, TASS and VDYP, including recommendations for alternatives where TASS and VDYP may not provide the needed GY forecasts.
- A review of how climate changes, including possible changes in disease/insect incidences, can be incorporated into GY forecasts using the supported GY models, as well as considering supporting other BC GY models.
- New interface software for GY models that integrate all GY models in one platform (e.g., FVS in USA).
- Administration changes:
    - Reorganizing GY tasks as an integrated task group within FAIB, rather than separate management of managed stands, unmanaged stands, and site productivity (e.g., see Fig. 4.4);
    - Improved EP data storage and documentation for use by this GY task group (i.e., EP data managed by Resource Practices Branch); and
    - Improve the number of high-qualified personnel (i.e., Master's degree or higher) within the GY group.

Innovations:

- Methods that incorporate future climates into GY models.
- Improvements in tree-level (or cohort-level with groups of trees) GY models that could support a wider variety of management regimes, including single-tree selection, complex stands with 10 or more species, etc. It should be noted that Prognosis^{BC} could support these particular management regimes, as a previously supported GY model. However, consideration might also be given to cohort-level models that may provide greater computational efficiencies, while providing sufficiently accurate forecasts.
- While methods that incorporate improved genetic stocks that may increase yields have been implemented in TASS/TIPSY, methods that model yields of stocks that may reduce vulnerability to changing climates and insects/disease incidence are needed.

Rationale:

GY forecasts are critical to any forest analysis, including determining AACs under current and possible future climates. While the current state of the inventory provides the base for the future forecasts, the GY models forecast these stands forward 100 years or more. The currently supported GY models are being used to forecast future forests, but these models do not cover all stand types nor management regimes, resulting in uncertainties that could be reduced given improved GY models. Further, the documentation of the supported GY models is insufficient to promote confidence by forest professionals. Of note, many changes have been made to TASS in the 40 years of development, but there is a great paucity of documentation on the changes, as well as the current TASS versions (i.e., TASS II and III). Changes in yields and mortality rates under future climates also need to modelled to reduce forecast uncertainties. Contributing to these gaps is the very low level of support attributed to this task within the forest inventory system.

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Glossary

AAC	Allowable annual cut: The maximum amount of timber that the chief forester determines, under section 8 of the *Forest Act*, is reasonable to harvest from the TSA or TFL, usually expressed in cubic metres.
BEC	Biogeoclimatic Ecosystem Classification is a multi-scaled, ecosystem-based classification system that groups ecologically similar sites based on climate, soils, and vegetation; widely used as a framework for resource management and scientific research in BC
CMI	Change Monitoring Inventory is a large landscape-level initiative with the intent to estimate forest and land cover attributes over large areas. CMI is based on a systematic sample design, with a 20 km grid across the entire province. Some of the CMI ground sample plot locations coincide with NFI plots that FAIB is now re-measuring.
DEM	A digital elevation model is a bare-earth grid referenced to a vertical datum. When you void vegetation and man-made features from elevation data, you generate a DEM.
LiDAR	Light Detection and Ranging is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth
LVI	Landscape Vegetation Inventory is a low cost inventory solution to VRI. The goal of the relatively new LVI tool is to provide broad landscape level forest inventories over large areas of the province deemed low priority, in simple forest types, or areas where recent disturbance has rendered the current VRI unusable. The LVI design includes three basic components: (i) high resolution Digital Camera System (DCS) sampling that when interpreted, provides tree attribute estimates; (ii) Landsat multispectral imagery for segmentation providing spatial products; and (iii) the nearest neighbor matching to extrapolate tree attribute estimates to the spatial product. The main features of the LVI design are: low cost, flexible to be implemented at various scales/resolutions, statistically valid, and robust.
NFI	National Forest Inventory is a collaborative effort involving federal, provincial and territorial government agencies that monitors a network of 20,000 sampling points across Canada on an ongoing bases to provide information on the state of Canada's forests and a continuous record of forest change.
NVAF	Net Volume Adjustment Factor is used during sample compilation to produce unbiased estimates of net merchantable tree volume. It works to adjust the combined estimates of gross volume produced by the taper equation and decay and waste losses estimated by the cruiser through the net factoring process. NVAF sampling involves detailed stem analysis of sample trees, calculation of

actual net volume, and calculation of the ratio between actual net volume and estimated net volume (where estimated net volume is obtained from net factoring and taper equations).

OAFs	GY predictions from both TASS and TIPSY approximate the productive potential for a given combination of species, density and site. Consequently, their yield predictions need to be adjusted, using OAFs, for various operational realities such as forest health losses and stocking gaps.
OGSI	Old Growth Site Index adjustments estimate site index for a regenerated stand from an adjusted site index of an old-growth stand.
PSP	Permanent Sample Plots provide a unique long-term re-measurement dataset that is used to develop growth and yield models that support timber supply analysis and sustainable forest management decisions.
RESULTS	Reporting Silviculture Updates and Land Status Tracking System application tracks silviculture information by managing the submission of openings, disturbances, silviculture activities and obligations as required under the *Forest and Range Practices Act.*
SI	Site Index is an expression of the forest site quality of a stand, at a specified age, based either on the site height, or on the top height, which is a more objective measure. SI is the most common measure of forest site productivity and forest growth used in BC. In BC, for a particular target species, site index is the height of the largest diameter (at breast height) site tree on a 0.01 ha plot at breast height age 50, provided the tree is suitable.
SIBEC	This comprehensive model correlates site index with BEC site series.
TASS	Tree and Stand Simulator: A biologically based, spatially explicit, individual tree model that has been predicting the growth and value of BC's future forests for over 45 years. Also see TIPSY.
TFL	Tree Farm License: An area-based tenure agreement, entered into under the *Forest Act,* that issues the rights to harvest an AAC in a specified area, and outlines responsibilities for forest management.
TIPSY	Table Interpolation Program for Stand Yields: A FLNR computer program used to generate yield projections for managed stands based on interpolating from yield tables of a model (TASS) that simulates the growth of individual trees based on internal growth processes, crown competition, environmental factors, and silvicultural practices. TIPSY is used to project growth of managed stands.

TRIM	Terrain Resource Information System provides the based data for the Province of BC. TRIM is a set of three-dimensional digital files that support development and management of land-related information.
TSA	Timber Supply Area: A geographically based administrative area designated under the Forest Act. TSAs have an AAC that are used to provide a sustainable flow of timber to both replaceable and non-replaceable forms of volume-based tenures.
VDYP7	Variable Density Yield Projection version 7: An empirical yield prediction system, supported by FLNR, designed to predict average yields for unmanaged natural stands.
VRI	Vegetation Resource Inventory: A data standard developed in 1998 that supports the inventory of both timber and non-timber vegetation and associated ecological attributes at a strategic, management unit level in BC. The VRI attempts to answer three questions: (1) How much do we have? (2) Where is it located? (3) How does it change over time?
VRI Phase 1	Refers to process involving aerial photo estimation of detailed land cover attributes.
VRI Phase 2	TSPs selected by PPSWR intended to improve volume estimates at the stand-level (VRI's statistical adjustment process) or for other purposes.
VRIMS	Vegetation Resource Inventory Management System is used to update the provincial forest inventory – to grow and project the trees annually using VDYP7.
YSM	Young Stand Monitoring, like CMI, is also a landscape-level initiative whose original objective was for comparing ground sample data with model estimates of forest attributes within 15-50 year old stands. Because YSM is based on a systematic sample from an intensification of the CMI 20 km grid, it can be employed for point-in-time estimates of forest attributes and to monitor change in forest attributes over time.

Appendix 1: List of Information Providers

FLNR = BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Stuart Aird, Nesoo Watchie Resource Management
Analysis Section, FLNR Forest Analysis & Inventory Branch
Jonathan Armstrong and Mike Landers, Western Forest Products
Michael Armstrong, BC Council of Forest Industries
Association of BC Forest Professionals (Mike Larock, Christine Gelowitz, Casey Macaulay, Paul Nuttall)
Kevin Astridge
Keith Atkinson, First Nations Forestry Council
Rick Baker
Sally Bardossy, BC Timber Sales Cariboo-Chilcotin Business Area
Alexandre Beaulieu, Geobase, Canada Centre for Mapping and Earth Observation, Natural Resources Canada
Judi Beck, Pacific Forestry Centre, Canadian Forest Service (with input from Joanne White, Glenda Russo, Byron Smiley, Paul Boudewyn, Frank Eichel, Graham Stinson and Jeff Dechka)
Doug Beckett
Tzeporah Berman, Stand.earth
Pierre Bernier, retired from Canadian Forest Service
Celine Boisvenue, Canadian Forestry Service
Tom Bradley, Federation of BC Woodlot Associations
Anthony Britneff
Viktor Brumovsky and Scott McNay, Wildlife Infometrics, Inc.
Cam Brown
Noel Carawan-Hubin, NRM Coordinated Free & Open Lidar Program
Nicholas Coops, University of British Columbia Faculty of Forestry
Dave Daust and Karen Price
Don Davis, LiDAR specialist, BC Timber Sales
Decision Support Team, FLNR Forest Analysis & Inventory Branch
Pamela Dykstra, FLNR Resource Practices Branch
Adam Dick, Canadian Wood Fibre Centre, Canadian Forest Service
Blair Ellis, FLNR Skeena Region
Bianca Eskelson, University of British Columbia Faculty of Forestry
Marvin Eng
Stephanie Ewen. University of British Columbia Alex Fraser Research Forest
Mike Falkiner, BC Timber Sales
Hannah Fehr, Ecora Engineering & Resource Group Ltd.
Christine Fletcher, FLNR Forest Analysis & Inventory Branch
Lane Gelhorn, Saskatchewan Ministry of Environment – Forest Inventory
Peter Gould and Jeffrey Ricklefs, Washington State Department of Natural Resources – Forest Inventory
Liam Grant

Kerry Grozier, BC Timber Sales Chinook Business Area
Sybille Haeussler, Skeena Forestry Consultants
Winnifred Hays-Byl, Natural Resources Canada
Ray Hanson
Temesgen Hailemariam, Oregon State University
Graham Hawkins, FLNR Forest Analysis & Inventory Branch
Kim Haworth, Terrace Community Forest; and Rick Brouwer, Coast Mountains Natural Resource District Steering Committee
Adrian Hickin, A/Chief Geologist and Executive Director, BC Geological Survey
Gary Johansen, FNLR Forest Analysis & Inventory Branch
R. A. (Bob) Krahn, FLNR Forest Analysis & Inventory Branch
Joe LeBlanc, Interfor Corporation
Marie-Lou Lefrancois, BC Timber Sales Skeena Business Area
Yvan Levasseur, Carl Bergeron, Frederic Dufour, Andre Larouche, Antoine Leboeuf, Quebec Ministry of Forests, Wildlife and Parks – Forest Inventory
Cameron Leitch and Georgina Magnus, Forest Practices Board
Nancy Liesch, GeoBC, FLNR
Satnam Manhas, Ecotrust
Peter Marshall, University of British Columbia Faculty of Forestry
Patrick Martin
Eleanor McWilliams
Tim Moser, Brinkman Forest Ltd.
Tyler Muhly, FLNR Forest Analysis & Inventory Branch
George Muldoe, Gitxsan
Jeff Mycock, West Fraser Mills Ltd.
Shudao Ni, College of New Caledonia
Dan Myrah
Diane Nicholls, FLNR Office of the Chief Forester Division
Gord Nigh (responses from two others), FLNR Forest Analysis & Inventory Branch
Omineca Natural Resource Region, FLNR (submitted by Greg Rawling and Tammy Baerg)
A. Y. Omule
Bert Parke
Mihai Pavel, FPInnovations
Dave Peet, Survey and Geomatics, B.C. Ministry of Transportation and Infrastructure
Quesnel Natural Resource District, FLNR
Don Reimer, D.R. Systems Group
Geordie Robere-McGugan and Ian Sinclair, Ontario Ministry of Natural Resources and Forestry – Forest Inventory
Donald Robinson, ESSA Technologies Ltd.
Marc Rousseau and Update Team, FLNR Forest Analysis & Inventory Branch
William Schlosser, D&D Larix, LLC
Christopher Smith, BC Hydro
Barry Snowdon, FLNR Resource Planning and Assessment Branch
Jeff Stone

Strategic Natural Resource Consultants Inc. (Jonathan Lok, Jason Smith, Kim Lefebvre, Jason Hutchinson, Devesh Bahaguna)
Catherine Bealle and Stand Development Modelling Team, FLNR Forest Analysis and Inventory Branch
Ira Sutherland
Mark Tamas, Tolko Industries Ltd.
Nyssa Temmel, Knowledge Management Branch, BC Ministry of Environment & Climate Change Strategy
David Tesch, Knowledge Management Branch, Ministry of Environment and Climate Change
Dan Turner, FLNR Resource Practices Branch
Ray Travers
Union of BC Municipalities' Community Economic Development Committee
Dan Upward, BC Timber Sales Kootenay Business Area
Martin Watts and Anthony Britneff
Jens Wieting, Sierra Club BC
Beverley Wilson and Darren Aitkin, Alberta Ministry of Agriculture and Forestry – Forest Inventory
Dale Wilson, New Brunswick Forest Planning and Stewardship Branch - Inventory
Murray Woods, Canadian Forest Service
Alex Woods, FLNR Skeena Region
Mike Wulder, Canadian Forestry Service

Appendix 2: Justification for Long-Term Sustainable Inventory Program Resourcing

It is impossible to adequately manage a forest unless you have a reliable inventory of the resources. This applies to all the resources dependent upon the forest inventory.

The Chief Forester has identified a Ministry of Forests, Lands, Natural Resources Operations and Rural Development (FLNR) vision for sustainable forest management[29] that includes:

- Managing forests to meet present needs without compromising the ability of future generations to meet their needs;
- Providing stewardship of forests based on an ethic of respect for the land;
- Maintaining and restoring proper ecosystem function and promoting ecological resilience for influences such as climate change;
- Balancing economic, social, spiritual, ecological and recreational values of forests to meet the needs of people and communities, including First Nations; and
- Conserving biological diversity, soil, water, fish, wildlife, scenic diversity, and other forest resources.

The Forest Analysis and Inventory Branch has developed the following forest inventory vision to be consistent with that of the Ministry:

- Natural resource management in British Columbia is informed by reliable forest inventory and stand growth models.
- The data and models of the provincial forest inventory are current, complete, reliable, accessible, and relevant. Together they provide information on the status, trends and condition of B.C.'s forests and the capability to forecast future condition under alternative scenarios.
- The BC Forest Inventory Program engages and communicates with stakeholders, and collaborates with partners in project delivery. The program is innovative and adopts new technology and methods. The program is responsive to priorities and mobilizes to deliver information on demand.

Obvious by these statements is the recognition a reliable forest inventory is needed for the protection and management of a number of resources who are dependent upon the forest. Some of the priority areas within the mandates of lead Ministries that require a reliable inventory include:

1) Economic sectors

   a) Forest industry – FLNR, Ministry of Jobs, Trade & Technology (JTT), Ministry of Finance

      i) The primary basis for determining Allowable Annual Cut and sustainable forest management
      ii) An information basis to support opportunities for operational cost reductions
      iii) A basis for sustainable local employment

[29] 'Sustainable forest management' has been defined to mean management that maintains and enhances the long-term health of forest ecosystems for the benefit of all living things, while providing environmental, economic, social and cultural opportunities for present and future generations.

iv) A basis for identifying Corporate investment opportunities

b) Secondary wood manufacturing **– FLNR, JTT**
   i) A basis for investments in existing and new facilities
   ii) A basis for encouraging investments in new bio-economy businesses

c) Wilderness tourism **– Ministry of Tourism, Arts and Culture (TAC)**
   i) A basis for forest management that includes protection of priority wilderness tourism opportunities

d) Range management **– FLNR, Ministry of Agriculture**
   i) A factor in restoring degraded grasslands and minimizing encroachment by forests
   ii) A major factor in management of range under forest canopies

e) Crown Corporations – **Oil and Gas Commission, BC Hydro**
   i) OGC uses the inventory for on-going assessment of cumulative impact analysis of disturbances in areas where oil and gas extraction occurs or contemplated
   ii) BC Hydro uses the inventory when clearing new transmission lines on rights of way to get volume estimates, and use table rates to pay stumpage and waste.

2) First Nations reconciliation **– Ministry of Indigenous Relations and Reconciliation, FLNR**
   a) A major contribution to First Nations land use planning to address land management Rights and Title issues, including the basis for calculating Forest Consultation and Revenue Sharing agreements
   b) A major factor in building First Nations forest based sustainable economy within communities
      i) Basis for Woodlands Licenses justification
      ii) Basis for Community Forest Agreements justification

3) Non-forest sector government programs

a) Climate change – Ministry of Environment and Climate Change Strategy (ENV),

Canadian Forest Service-Natural Resources Canada
   i) The basis for carbon accounting analyses
   ii) The basis for climate change adaptation management
   iii) Input into flood adaptation management

b) Species at Risk (SAR) **– ENV**
   i) The primary input into caribou habitat management
   ii) The primary input into forest dependent SAR habitat management

c) Land use planning **– FLNR**
   i) The basic input into land use designations to maintain a sustainable forest economy
   ii) The basic input into balancing protection of economic and social and environmental values

d) Wildfire management **– FLNR**
   i) The basis for developing forest resources protection
   ii) The basis for management of urban interface protection

iii) The basis for protection of forest sector timber supply
iv) The basis for protection of infrastructures

e) Emergency management **– Ministry of Public Safety and Solicitor General**
i) Ability to adapt to current and potential natural and anthropogenic disturbances

f) Parks and Protected Areas management **– ENV, TAC**
i) The basis for identifying locations of key values within the Parks and Protected system

g) Recreational fish and wildlife management **– ENV**
i) The basis for protection of fish and wildlife habitat

These various users utilize the forest inventory for:

- Land use planning
- Sustainability/certification reporting
- Environmental protection
- AAC determination
- Partitioning of wood supplies for allocation to different end uses and/or users.
- Allocation of quota
- Land/license appraisal, acquisition and disposition
- Short, medium and long term cash flow projection
- Sourcing and bidding on log supplies
- Mill design and harvest equipment planning and allocation
- Forest management/stewardship plans
- Total Chance planning
- Operating area development planning
- Non timber forest products
- Habitat assessment
- Watershed management
- Recreation and landscape viewing management
- Fire hazard/risk/management/impact assessment
- Bark beetle hazard/risk/management/impact assessment
- Road and cutblock location, design and layout.
- Harvest scheduling
- Silviculture prescription guideline development, planning and application
- Compliance monitoring
- Effectiveness monitoring
- And more

Overall Objective

The overall objective of the Forest Inventory Program is to deliver on the FAIB vision by moving toward an inventory that is continuous across the BC forest land base by:

- Meeting a set of criteria for achieving well managed forests,
- Addressing user issues and needs,

- Being consistent with the levels of detail[30], resolution[31], precision, and accuracy needed for each geographical area, and sufficient to fulfill a minimum set of Province wide inventory requirements,
- Being consistent with a government-identified set of standards for each level of data collection,
- Providing the necessary data for input into stand projection models that facilitates reasonably reliable forecasts with an accounting for responses to forest management activities and adaptation of environmental conditions such as climate change and natural disturbances,
- Utilizing remote sensing technologies for cost-effective data collection and analyses, and
- Providing data and information in a form readily available to users and the public that can be easily applied for a set of well-defined use cases.

Achieving this objective will require inventories that are accurate and precise for the purpose of intended decision-making. The inventory will have a minimum of bias and be of sufficient resolution to meet user needs and perhaps involve the use of tree lists/stand and stock tables. The inventory system must enable efficient and effective updates using localized growth and yield and mortality curves. Such curves must reasonably reflect differences in stand structure and in turn reflect ground-based measurements of permanent monitoring plots. The expectation is this will need much more emphasis on ground sampling and re-measurement than presently occurring and will involve the use of remote sensing data mixed with imputation to grapple with all of the expected disturbances to be confronted on a continuous basis and/or at scales and levels of severity that can have dramatic impacts within well managed forests.

Funding mechanisms

Achieving the overall Forest Inventory Program objective is expected to require resources beyond the current levels. The main areas for increased resourcing are in delivering the needs of the Chief Forester and users through data collection, data management and stand projection modeling. The increased resourcing will be in the form of staffing and dollars. A phase in period for increasing funding to the required sustainable level may be required as the ability to utilize it efficiently and effectively develops. The forest inventory benefits the BC public and in many cases others (e.g., forest companies, non-timber resource organizations, etc.). Consequently, there should be a reflective sharing of the costs. Not all aspects of the forest inventory are justified for this type of arrangement reflected in the funding mechanisms.

Whatever funding or advisory mechanism are decided upon, the models must be guided by the following principles:

- Be based on a long-term commitment by involved parties,
- Be sustainable across a range of economic times,
- Be sustainable through changes in governments,

[30] Level of detail refers to the kinds of tree, stand, and landscape level attributes referred to in the inventory and the manner in which they are described (e.g., quadratic mean tree diameter to the nearest centimeter for trees > 7.5, 12.5, and 17.5 cm dbh).

[31] Level of resolution is determined relative to the scale(s) of attribution, be these grid cells, rasters, segments, or polygons.

- Address companies or organizations who do not wish to participate directly in providing in-kind or direct funding,
- Be organized with the principles of cooperation[32] being applied to involving users and FLNR,
- Be advisory to FLNR but with the understanding they are expected to give due consideration to user requirements,
- Include government being responsible for the cost of staffing to fulfill the responsibilities,
- Be integrated into the FLNR hierarchy and operations of FAIB in a meaningful way, and
- Include an independent oversight organization to assess and provide recommendations regarding whether the inventory meets user needs.

The following are some examples of potential funding sharing. The mechanism for cost sharing should be negotiated between government and the forest industry but with the understanding the principle of sharing will be followed. A notional cost sharing responsibility is presented in the following table.

INVENTORY TASK	**RESPONSIBILITY**	**COST RESPONSIBLITY**
Data Collection and Management		
Inventory standards development	Government	Government
Mature stand field plots	Government	Government
Cruise plots (regulation requirement)	Industry	Industry
Scale data (regulation requirement)	Industry	Industry
Stand establishment plots (regulation requirement)	Industry	Industry
Free to grow plots (regulation requirement)	Industry	Industry
Young stand monitoring plots	Government	Government/Industry
Data management	Government	Government
Data distribution	Government	Government
Remote sensing data collection	Government/Industry	Government/Industry
Stand Projection Modeling		
Projection model development & analyses	Government	Government
Permanent sample plots	Government	Government
Growth & Yield research	Government/Industry	Government/Industry

In instances where government has the primary responsibility of funding the inventory task, the resources should be provided through the FLNR budget. In areas where the industry has a responsibility to collect data to satisfy Regulations, obviously the companies are responsible for the costs. However, in both of these instances cost savings for the companies and the Forest Inventory Program can benefit from team approaches, such as building a collaborative environment outlined in Appendix 7 *Forest Inventory Technical Advisory Group* discussion.

32 http://effectivecooperation.org/about/principles/

There are inventory data collection and management tasks that can benefit both government and industry. In these instances a collaborative approach to cost sharing would be beneficial to both parties. The cost sharing should be negotiated between the Parties to reflect the benefits to each. In all cases this needs to be done with the joint understanding they are working as a team to meet the data and information needs to support decisions regarding achievement of well managed forests.

Growth and Yield research is an area of forest inventory that lends itself to a cooperative arrangement from the perspective of both the focus of the activities and the funding. A suggestion regarding this is presented in the *Growth and Yield Partnership* component of Appendix 7.

In all the areas where the forest inventory is used in decision-making, the data and information contributes to sustainable government revenue and employment.

The forest inventory is an asset to the Province and users. Like all assets, continuous management and resourcing are critical. If these two factors are not provided, the asset declines. In the case of the forest inventory, the value to the Province and users drops and the benefits associated with the asset are lost. Consequently, a sustained long-term commitment to funding and staffing for the Forest Inventory Program is essential!

Resourcing the Forest Inventory Program involves obtaining and managing the necessary data to deliver on user needs. This must be in the form of both staffing and program funding. As noted in the Panel recommendations, not all areas of BC need the same level of data acquisition or analysis. However, there does need to be a core set of data across all forested lands. Also, a stable and long-term resourcing is essential to:

- Provide a core data, management and model projections appropriate across all BC forested lands,
- Provide a forest inventory extension program that includes communications to all interested parties, training for users of the inventory data and projections and publicly reporting on the forest inventory,
- Become prepared for future forest inventory product needs,
- Respond, through data collection and analysis, to unplanned major events, and
- Build the research knowledge base to respond to critical forest inventory issues and new technologies.

Appendix 3: Assessing the Optimal Level of Expenditure on Forest Inventory

The Panel recognizes the inventory needs differ across the province. At the same time, the view is there is a minimal level of coverage required everywhere. Furthermore, the province might be able to determine the optimal level of expenditure on inventory and its allocation among different areas through a formal cost-benefit analysis. To augment the informal assessment of the costs and benefits of collecting additional data and information.

Economic analysis of investments in information does not differ from the procedures for other capital investments: are the benefits of the investment greater than the costs? Is the current level of investment optimal? As with any investment, the socially optimal amount of it is determined by the point where the total benefits exceed the total costs by the largest possible amount.

Start with costs, the easier side of the equation. When thinking about costs of an inventory system, we have to be mindful that we are talking about *efficient* production of inventory information. That is, one can produce a certain amount of information in many ways, some costly and some less so. For example, simple grid-based system with ground sampling might be a costly way to achieve a specific standard, e.g., total merchantable volume/ha +/-10% with 95% confidence. An alternative system based on remote sensing and model-assisted design might achieve that same precision at a far lower cost. So, when we speak of choosing the level of investment that maximizes the difference between benefits and costs, this has to be the costs of an *efficient* inventory system.

Assuming that the production of information is done efficiently, the second task is to ask if the amount and kind of information produced at the socially optimal point—what is the relative cost and benefit of additional information at the current point of production?

Economists have addressed this question. The costs are pretty clear—more data means more cost; more information means more cost; better models mean more high-talent labour, and, frankly, probably more data as well.

The benefits of additional information are much harder to estimate. The benefits of better information are found in the avoidance of the losses associated with errors in decisions. As Gordon Baskerville pointed out, all decisions are made under uncertainty about the future—if that were not the case the decisions would be trivial. A corollary of this perspective is that a decision thought to be "optimal" *before* the uncertain future state of the world is known may turn out to be the "wrong" decision once the future state is known. The value of better information is in reducing the cost of errors inevitably made due to uncertainty about the future.

For our purposes we can think about "uncertainty" as the variation in decisions caused by the variation in forecasts about the future. In the case of forest inventory, the uncertainty arises due to errors in the statement of the initial forest condition and errors in the projection of those initial conditions into the future. We might usefully distinguish between errors that can be reduced by better data and models, and errors that arise from such random events as insect and disease outbreaks and changes in climates. The former can be reduced though better inventory; the latter are—at this time—inherently unknowable. We might note in passing that uncertainty is also introduced when management actions deviate from those assumed in the forest management plant. Managing and reducing such errors are beyond our remit.

The cost of uncertainty is the loss (actual loss or opportunity loss) associated with a “bad” decision that could have been improved by greater expenditure on information. A key point here is that the *benefit* of additional information depends on the *decisions* that are taken based on that information and the *losses* associated with “bad” decisions that could be improved via better information.

Here is a stylized way to think about this question:

Consider the “decision” of setting the AAC level. We recognize that the AAC is “determined” and not “calculated”, but the determinations are informed by the inventory system and additional analysis.

First recognize the uncertainties in the inventory system—starting data (measurement and sampling error), models (model and parameter error, management error (actual management actions differ from modelled actions) and errors in forecasts of exogenous variables (weather, wildfire, insect attacks). Then draw a random sample from the distributions of each of those uncertain variables (including their correlations, if relevant). For each of those random draws, calculate the initial harvest levels in a sustained yield harvest flow. Redo this analysis for, say, 1000 times, and look at the resulting distribution of harvest flows, especially those in the first 10 years. A focus on the first 10 years makes sense for several reasons: standard practice is to redo forest management plans on a regular basis; the early years carry the greatest economic importance; and the consequences (due to discounting) of errors are the greatest.

To determine if the current inventory system is adequate, ask “is the uncertainty in this key output variable—harvest levels—tolerable for making decisions?” More specifically, “is the loss from an incorrect decision resulting from the uncertainty in the projection system less than the cost of improving the accuracy of the projection system?” If it is, then the current system is OK; if not it is logical to spend more money on improving the projection system.

Such an analysis is beyond the scope of our inquiry, for a host of reasons—that kind of analysis would require considerable data and analysis; the AAC is determined not calculated; the AAC is not the only decision supported by FAIB; calculating the cost of errors is nettlesome and likely asymmetric—just to name just a few. We recommend that the Ministry embarks on a modest research program to address this question following the path laid out in the academic literature on the subject.

Appendix 4: Description of Provincial Forest Inventories

The following summarizes some characteristics of the jurisdictions compared, with a focus on innovation. See tables 1 and 2 for a comparison of inventory update methods and staff training and levels.

Alberta

Alberta has an inventory system called the Alberta Vegetation Inventory (AVI) which is a standard based on photo-interpretation much like BC's VRI. It was designed as a strategic inventory (1:20 000) but the use of technology and deviations from the standards now classes the product as **tactical** in scale. The program aims to update its inventory (complete re-inventory) on a 10-year cycle. While it maintains a Growth and Yield modelling program (GYPSY), the inventory attributes are not projected (e.g., heights or volumes) on an annual basis. Silvicultural records are not incorporated into the forest inventory, but rather maintained separately in an a-spatial data format. The program has 9 staff including 4 with post-graduate education, and an annual budget of approximately $8.6 million.

Spatial forest inventory data for lands outside of Forest Management Agreements (FMA) is freely available upon request, however data within FMA's, which makes up approximately 68% of crown AAC's (Luckert, Haley, & Hoberg, 2011), is generally not available to the public.

Innovation

Alberta has completed 100% LiDAR coverage for the Province- a move funded by the Province (over 30 million hectares), primarily to provide a complete wall-to-wall Digital Elevation Model (DEM). LiDAR has been used in some areas for Enhanced Forest Inventories (EFI) with a focus on merchantable volume quantification in pure stands (>80% single species). EFI attribution models have been developed for pure white spruce, pure pine and deciduous stands. Individual tree recognition using high-resolution LiDAR is being explored. Other LiDAR applications have included Wet Area Mapping, ecosite phase classifications, forest structure for habitat mapping, and use for research in forest productivity. Very high spatial resolution imagery (30-50cm) has been used for reforestation assessments, as well as quantifying Mountain Pine Beetle impacts in western Alberta and Digital Aerial Photogrammetry (DAP) is being used to assess forest attributes at the stand level.

Alberta collaborates with the University of Alberta with the development of an individual tree growth and yield model (Mixedwood Growth Model- MGM) that can handle complex stand structures. Alberta is part of the Forest Growth Organization of Western Canada, an independent organization with membership across industry, academia and government to lead growth and yield research and a central repository for growth and yield information in western Canada.

Alberta's forest industry has extensive area-based raster inventories used for operations. Alberta aims to update the AVI standards within 2 years to reflect the technological contributions (such as the use of LiDAR or DAP) to Enhance Forest Inventories.

Saskatchewan

Saskatchewan's Forest Vegetation Inventory (SFVI) is standard based on photo-interpretation like BC's VRI. Much of the inventory for the operable land base is considered **tactical** in scale, although it was designed as a strategic inventory. The program aims to update its inventory (complete re-inventory) on a 10-year cycle. Saskatchewan uses the same Growth and Yield modelling program as Alberta (GYPSY and MGM) with some modifications customized to Saskatchewan's forests, is also part of the Forest Growth Organization of Western Canada. While the inventory is not projected on an annual basis using growth and yield models, staff are working towards building such a function into the inventory. The program has 9 staff (6 full time staff and 3 part-time), including 2 with post-graduate education, and have an annual budget of approximately $1 million. Spatial forest inventory data is available upon request and at a fee to the user.

Innovation

Saskatchewan's Forestry Development Branch has recently implemented a pilot Enhanced Forest Inventory Program, testing methodologies in a 70,000 ha area with 150 ground plots. A total of four approaches were tested, ranging from area-based LiDAR inventory to pixel-based satellite imagery, deriving attributes at either stand level or individual tree mapping scales. The approaches tested Machine Learning (ML) techniques (regression parametric approaches such as Random Forest algorithms) to estimate stand attributes[33] and benchmark outputs, costs and limitations.

As a result Saskatchewan is currently updating their forest inventory standards with a focus on required attributes and accuracy criteria without prescribing methods to derive those attributes. This results-based framework can account for the variability of scales needed for different management objectives, while acknowledging evolving technologies used to attain key attributes. The Forest Development Branch is aiming to deliver (re-inventory) base mapping (5m Digital Elevation Model and 30m raster-based inventory attributes) while leaving species and site index attribution to Forest Management Agreement and Timber Supply Licence holders for 6 million hectares. The province also has a goal of acquiring LiDAR for 30% of their forested operable lands within 2 years.

Saskatchewan systematically checks and reports inventory volume estimates relative to scaled timber, rolled up to 50,000 ha sized management units, however acknowledges that it is difficult use this as an indicator for reliability. Efforts are considered better spent on the validation of new inventories.

A key element of ongoing public outreach is that the Forest Development Branch publishes 10km x 10km vegetation inventory and depletion maps available to the public on an annual basis for download.

Ontario

Ontario's Forest Resource Inventory (FRI) standard is also based on digital aerial photogrammetry (Airborne Digital Scanners- ADS) and interpretation. The inventory is considered **strategic** in

[33] Ex. Basal area, volume, height, density, size class distributions, quadratic mean diameter at breast height, biomass, etc.

scale and targets re-inventories on a 10 year cycle. A Growth and Yield program (separate from the inventory program) maintains approximately 1200 permanent sample plots to calibrate their growth and yield model which is used for sustained yield calculations. The inventory does not project volumes on an annual basis, in fact volumes are not attributed in the inventory directly. Silviculture records are maintained in a separate spatial file, however the inventory is not updated with those records on an annual basis. The inventory budget is allocated on 10 year increments and is overseen by a collaborative 'Forest Futures Trust', which is a crown agency that is independent of the FRI branch and is made up of representatives from government, academia and industry. The current annual budget is $9,293,000 which supports a staff of 27, including 2 with post-graduate education. Access to the inventory is made internally to the Ontario government, however public access is via user request and a nominal fee.

Innovation

Currently Ontario's MNR has a budget to cover 3 million hectares for new LiDAR acquisition and has a goal for acquiring another 47.8 million hectares within 8 years, completing coverage for their forested operable lands. One planning unit (Romeo Malette Forest/Hearst Forest SFL) has complete LiDAR coverage (1.9 million hectares), with Enhanced Forest Inventory done in collaboration with industry (Tembec/Rayonier), NGO (FPInnovations), academia and Federal and Provincial Governments. The EFI methods were published (Woods, et al., 2011) and validated against scaled volumes with short term return on investments.

Ontario is also acquiring some Single Photon LiDAR SPL (Petawawa research forest) which may prove useful for individual tree mapping. There is an active research project looking at remotely sensed species identification (using Sentinel high resolution satellite) and ongoing research in high resolution (30cm) semi-global matching (SGM) using 3D photogrammetry and pixel correlation to get at Enhanced Forest Inventory attributes. The Forest Management Unit attempts to maintain a plot to sq.km ratio of 1:5 km^2, with placement bias to represent forest stand species composition that are lacking re-measurements.

There has been some experimentation with Unmanned Aerial Vehicles (UAVs), but line of sight restrictions limits applications.

Quebec

Quebec's Forest Inventory Program has begun its third re-inventory cycle for its 76 million hectare forest land base, the largest in Canada. The Forest Inventory Directorate maintains the provincial standards, known as SIFORT (Système d'information forestière par tesselle), which is considered **tactical** in scale. It's Growth and Yield program maintains two distinct models (stem level and stand level for modelling uneven aged stands). The GY program maintains approximately 12,000 permanent sample plots to calibrate/validate the GY models (there are an additional 360,000 temporary sample plots across the province), however GY models are not used to project the inventory (increase heights/volumes) annually. Silvicultural records are maintained separately from the provincial inventory (also administered by a separate division) in an a-spatial database. Quebec has a long history of formal review/advisory committees between Federal, Provincial governments and academia for reviewing inventory methods, products and their use in forest management (e.g., AAC calculations). Quebec has the largest Forest Inventory Program budget in

Canada, with approximately 77 [34] staff, including 20 with post-graduate education, and is supported by an annual budget of $20 million. Spatial forest inventory data is freely available and downloadable to the public.

Innovation

The Forest Inventory Directorate (FID) uses ISO 90001 quality management system to measure quality assurance targets for its inventory program. In 2017, Quebec introduced remotely sensed Enhanced Forest Inventory standards for attribution and verification using non-parametric imputations (K-nearest neighbour functions- KNN). Areas completed using this technique have been fully implemented into the provincial inventory. Enhanced Forest Inventory techniques are producing operational level inventories (20m pixels) allowing re-aggregation to stand-level estimates where needed, particularly at FMU level pilot projects. The FID is evaluating remotely sensed derived attributes with 1km by 1km plots using systematic probabilistic sampling by strata and machine learning algorithms. They have explored validation using harvest volumes, but for a variety of reasons it is not the preferred validation indicator. There is exploration of new multi-variate random forest approaches for Enhanced Forest Inventory in collaboration with NRCAN. Since 2012 Quebec has acquired 5 million hectares of LiDAR and is working towards 100% provincial LiDAR coverage within 4-5 years, with some ongoing species recognition research using LiDAR derived models. It is anticipated that with a complete LiDAR derived Digital Terrain Model (DTM), inventory attributes will be updated with Digital Aerial Photogrammetry (20cm resolution) or high resolution satellite imagery. Some additional research includes the use of near-infrared spectroscopy to examine physical and mechanical properties of wood.

New Brunswick

New Brunswick's Renewable Resource Inventory Section maintains their inventory standards which is considered operational in scale. The program aims to conduct complete re-inventories on 10 year cycles. Its growth and yield program (supporting a staff of 5) help administer and maintain 1500 plots annually (out of their total 18,000 permanent sample plots provincially) which are used to calibrate/validate their growth and yield model. The outputs from that model do not update/project the forest inventory annually. Silviculture records are submitted annually for crown land (50% of the forest land base) however records are not intersected annually with the forest inventory. New Brunswick has the highest ratio of inventory budget to forested area under management in Canada, with an annual budget of $2.35 million which supports a staff of 13, including 5 with post-graduate education. Access to digital forest inventory spatial (including LiDAR) data is freely available online.

Innovation

New Brunswick has 100% provincial LiDAR coverage (as of September 2018) at 6 points/m^2, as well as continual annual acquisitions of 700,000ha for high resolution imagery (and LiDAR). The Inventory and Forest Planning sections produce a variety of 1m raster products (etc. DEM, Hillshades) which are freely available to the public (through Service New Brunswick's GeoNB web portal). While the original Land Classification System produced a strategic level inventory, their adoption of Enhanced Forest Inventory techniques (as described in (Woods, et al., 2011)) has

[34] An additional 12 staff work on value-added research projects that are indirectly related to the inventory.

created 20m rasters for forest attributes such as basal area, volume, height, and quadratic mean diameter, while still relying on species identification from historic photo interpreted mapping. New standards are being worked on to document the use of EFI for their inventory. The inventory section is involved in a research project through AWARE[35] related to identifying species from LiDAR, as well as working with JD Irving and the University of Quebec in Montreal to help improved model-based forest attributes. New Brunswick conducts systematic comparisons of their forest inventory data to scaled volume of wood from recently harvested stands but also maintains a 'Continuous Landscape Inventory System' of random plots measured annually to calibrate/validate LiDAR derived inventory and calibrate forest and individual tree G&Y models. It is anticipated that image-based point clouds (of LiDAR) will be systematically used to update forest inventory in the near future.

New Brunswick is also exploring the use of Unmanned Aerial Vehicles (UAVs) for building orthophotos, acquiring high resolution imagery, point clouds and real-time kinematic positioning, but these techniques have not been systematized for enhancing the inventory.

Table A4.1. Summary of staff resourcing and training by jurisdiction (not double counting staff with both graduate and undergraduate qualifications)

Unit	PhD	Masters	Undergraduate	Technical certifications	Total
British Columbia	6	9	10	5	33
Alberta	2	2	2	2	9
Saskatchewan		2	2	2	6
Ontario		2	12	13	27
Quebec	3	17	6	58	89[36]
New Brunswick	2	3		1	13
Nova Scotia					
Washington DNR	2	1	2	5	10

Inventory updates

Forest Inventory Programs have devised strategies to account for the dynamic changes of forests over time due to anthropogenic (e.g., harvesting, land use change) and natural disturbances (e.g., fire, wind, insect/disease). Most jurisdictions track these spatial changes annually but may not chose to incorporate the results into the broader forest inventory until a new re-inventory is completed. Table A4.2 summarizes some methods used by different jurisdictions to track dynamic forest changes.

[35] Assessment of wood Attributes from Remote Sensing (AWARE) is a collaborative research and development project including industry, government and universities that aims to improve modelling of forested ecosystems.
[36] 77 staff work directly on forest inventory, 12 staff work indirectly on forest inventory

Table A1.2. Summary of update methods to track dynamic changes in forests.

Unit	Frequency	Methods
Alberta	Annual	Disturbance mapping (including fire boundaries and harvest depletions) are kept separate from the inventory and captured by industry/tenure holders for FMAs. Data is acquired using the AVI standards and maintained in a separate file geodatabase. Changes in forest (species/growth) is accounted for during cyclical re-inventories.
Saskatchewan	Annual	Sub-metre resolution satellite imagery is used to map and then manually interpret harvest areas (and leave patches)- with 80% of this responsibility carried by forest licencees and 20% by government. Disturbance mapping (fire) is done by a separate Ministry agency using Landsat to map boundaries and severity (normalized burn ration calculations). This data is not incorporated into the forest inventory until the next re-inventory cycle (10 years).
Ontario	Annual	Industry maintains/updates an Operational Planning Inventory which includes harvesting/silviculture and natural disturbance records as a separate data set from the Forest Resource Inventory. Annual reports are submitted for review by the Province and this data is used for forest management planning and eventually to inform the next re-inventory cycle (10 years).
Quebec	Annual	Forest harvesting updates by industry using GPS/aerial photography and submitted to Province. Natural disturbance (fire/wind) updates using 5m satellite imagery (includes fire severity mapping using Landsat and Sentinel satellites) but do not adjust species composition for partial cutting or natural disturbance. Only stand replacing insect/disease events are mapped on a 5 year basis. All disturbance (harvesting and natural) are maintained as a separate spatial layer (not intersected with the inventory).
New Brunswick	Annual	Inventory layer updated annually with harvests, silviculture, fires and other disturbances annually by 2019 but the forest attributes will not be updated annually. 10-30cm (Ground Sample Distance) is captured annually for 1/10th of the province for this work. SPOT 1.5m FCIR Satellite imagery will be used by 2019 to complete province wide annual updates on all ownerships (harvesting).
Washington state	Bi-Annual	New inventory every 2 years meets needs to track harvesting/disturbance updates.

Table A4.3. Data used in Table 5.2, Section 5.2.1

	BC	Alta	Sask	Ont	Que	NB
Forest land (ha)	60,000,000 (MFLNRORD, 2017)	35,200,000 (Wilson, 2018)	34,300,000 (GoS, 2018)	71,000,000 (MNRF, 2018)	76,000,000 (MFFP, 2017)	6,000,000 (MacDonald, 2004)
THLB/ commercial	25,000,000 (MFLNRORD, 2017)	23,300,000 (Wilson, 2018)	11,700,000 (GoS, 2018)	27,096,400 (MNRF, 2018)	28,200,000 (Bergeron & Lavasseur, 2018)	3,306,500 (MacDonald, 2004)
Harvest ha/yr [37] (NRCAN, 2018)	192,615	79,720	17,416	131,688	202,060	83,345
Harvest m3/yr (NRCAN, 2018)	67,970,000	23,031,000	3,712,000	15,829,000	28,559,000	9,363,000
Crown stumpage ($)	805,000,000 (Barnes, 2016)	170,000,000 (GoA, 2013)	9,600,000 (Gelhorn, 2018)	98,000,000 (MNRF, 2016)	300,000,000 (Bergeron & Lavasseur, 2018)	86,365,500 (GoNB, 2015-2016)
Inventory budget ($/year)	11,000,000 (FAIB, 2018)	8,600,000 (Wilson, 2018)	1,000,000 (Gelhorn, 2018)	9,293,000 (Robere-McGugan, 2018)	20,000,000 (Bergeron & Lavasseur, 2018)	2,350,000 (D.Wilson, 2018)
# inventory staff	33 (FAIB, 2018)	9 (Wilson, 2018)	7.5 (Gelhorn, 2018)	27 (Robere-McGugan, 2018)	77 (Bergeron & Lavasseur, 2018)	13 (D.Wilson, 2018)
Domestic Economic Impact (revenue from goods manufactured)- Millions ($) (NRCAN, 2018)	19,263	5,440	888	10,546	17,838	4,410
GDP Millions ($)	251,744	312,482	78,377	680,086	384,511	33,028

[37] BC, Sask, Ont, Que, NB references 2015 (corresponding harvest stats and revenue stats); AB references 2012 (corresponding harvest stats and revenue stats).

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Appendix 5: Overview of BC Inventory History

This brief history is an extension of the work done by the Association of BC Forest Professionals in the 2006 BC Forest Inventory review (Moss et al. 2006). The history has been extended and updated herein to provide a more complete context for inventory review. The BC forest inventory has been continuously evolving since its inception starting in 1910 with recommendations under the Fulton Commission (See Parminter, 2000) and so too has the technology to support it, in response to changing demographics, demands, and direction established by forest management policy and legislation. Particular attention is given to events that occurred starting with the ForestryResources Commission (Peel, 1991) report, a report that ultimately initiated the current Vegetation Resources Inventory (VRI).

This review highlights the enduring role that forest inventories have in the development forest management policy in BC as applied under variety of paradigms (e.g., Economic Development, Environmental Protection, Multiple Use Resource Management, Integrated Resource Management, Sustainability, and Ecosystem-Based Management). Effective and efficient application of these paradigms requires reliable forest and stand-level information as to what kinds of forest types exist, with what kinds of attributes, where, and to what extent. They also require understanding as to how these attributes are expected to, and do indeed, change with time for inventory update and to forecast reasonably possible future forest conditions. This forest inventory information resides within a broader framework defined by topography, land cover, and BEC characteristics, land survey and ownership, demographics, and societal demands for various land uses, products, and services. The inventory and its applications provide a critical link between strategic, tactical, and operational decision making, and thus, it is a foundation for establishing good forest management policies, guidelines and practices.

The first BC Forest Resource Commission (Fulton et al., 1910) noted that inflated estimates of timber supply can lead to careless waste and "…distorted theories of annual destruction, by fire and lumbering, enable alarmists to harm the common-sense campaign for conservation by their exaggerations." This produces uncertainty in the business world and makes the government's task of "creating sound forest policies" more difficult. The commissioners recommended that all provincial government agencies dealing with forestry be consolidated into a Department of Forests, headed by a Chief Forester. In recognition of the need for accurate forest inventory information, it was made quite clear that the Chief Forester would be expected to begin a program to inspect, survey, cruise and valuate the provinces forested lands and timber resources.

In 1912 the BC Forest Branch, the predecessor to the BC Forest Service, was created in accordance with the new Forest Act (Forest Act, 1912). H.R. MacMillan was recruited to the post of Chief Forester in May of that year. Under his direction, forest reconnaissance surveys were undertaken and reported, including information on topography, soil, climate, agricultural and grazing potential, known mineral resources, settlement history, and transportation infrastructure for each area surveyed. Observations of tree species presence, distribution, size, and quality characteristics precede descriptions of forest types and associated estimates of the area and volume of merchantable and other timber resources. During these early years in BC forest policy development, land was classified as being statutory timberland (legally defined as of 1896 based on the timber volume present – at least 8,000 board feet per acre on the West Coast; 5,000 board feet per acre in the Interior), other forest land (mature stands with less volume or immature stands), agriculture, burned over, barren (usually alpine), or other cover (wetlands or lakes).

Under the Commission of Conservation of Canada, a first Provincial overview was started in 1913, directed by Dr. Harry N. Whitford of Yale University, who was joined by forester Roland D. Craig in 1914. After completing surveys in 66 geographic units in both coastal and interior regions, their final report was published in 1916. Their report dealt with geography, physiography, climate, soil, forest types, land tenure, forest administration on provincial and federal lands, forest policy, timber harvesting, and utilization. Along with a breakdown of land classification were estimates of timber volume by species, information on land alienation, the history of land use, and known natural disturbances.

The next major advance occurred when the Forest Surveys Division was created at the BC Forest Branch's headquarters level in 1927, with Fred Mulholland in charge. A new provincial forest inventory was soon begun in the districts. This inventory consisted of both a forest land classification system and a compilation of timber volumes. A forest atlas (at 1 inch to the mile) was developed, consisting of 174 maps, each averaging just under 12 square feet in size, and the accompanying statistics revised in response to harvesting, wildfire, other depletions, reforestation, and stand growth. Mulholland considered forest surveys to be required for many aspects of forestry (Mulholland, 1931, p. 185, cited in Parminter, 2000):

> *"A timber cruise, however detailed and thorough is simply a crop survey; how much wood? How and at what cost can it be moved to the manufacturing plant? A forest survey is an economic survey, concerned with all branches of forestry; policy, management, silviculture, regulation of the cut, utilization, protection. Its ultimate object is to provide information to enable a forest to be administered for permanent wood production."*

The science of forest inventory was rapidly advanced when aerial photos were first adopted for use in 1933. In 1949, the Canada Forestry Act was established that resulted in federal funding to assist with BC inventory work over a seven-year period, starting in 1951. As of 1950, forestry work was carried out exclusively at the headquarters level.

As to the state of forest inventories during this pre-war era, Mulholland raised serious concerns about the condition of B.C.'s forests in a report on "the Forest Resources of British Columbia" (cited in Wilson, 1987). It was estimated that in relation to their sustained annual yield capacity, the accessible coastal forests were being overcut by 100 percent and the total forest accessible and inaccessible, by 20%.

> *"On the Coast not only is reforestation unsatisfactory, but rapid expansion of industries is making it apparent that it will be impossible to avoid a conflict between the desire of private interests to utilize all mature stands as quickly as markets can be found for the timber, and the public interest which requires the great basic industries dependent upon natural resources should be regulated on a permanent basis. Increased effort should be made to conserve the remaining*

virgin timber by reduction of waste, because the Coast forests are now being overcut in relation to the rate of replacement by growth. In the Interior local regulation of cut is needed, but the more urgent requirement is better protection from fire and insect damage."

After the war there were a number of institutional changes affecting forest inventory:

- The Foresters Act brought the Association of Foresters into being by way of Royal assent in the BC Legislature on April 3, 1947 (ABCFP).
- Aerial forest survey became institutionalized under the guidance of Gerry Andrews in a newly created survey branch involving the use of both oblique and vertical photographic techniques (Sherwood, 2012).
- The Forest Surveys and Inventory Division of the Forest Service was established in 1951 with the first complete inventory of the province being developed by 1957 (Thrower, 1992; Gilbert, 2013). Forest types were identified using aerial photographs and ground sampling was used to complete attribution.
- Sustained yield became a guiding principle of forest management, and along with this new management units in the form of Public Sustained Yield Units (PSYU's) and Tree Farm Licenses (Pearse, 1976a). The policy had first been proposed by C.D. Orchard in 1942 (Wilson, 1987).

In the late 50's and early 60's problems of land-use conflict, and competition for land and land misuse were becoming more common from a Canadian perspective (Pierce and Ward, 2013). As a result the Canada Land Inventory was established under the Agriculture Rehabilitation and Development Act (ARDA). The focus of this inventory was on soil capability mapping, in particular with the view of rehabilitating sub-marginal agricultural lands to more productive uses (McCormack, 1966). Land use capability classes were developed for agriculture, recreation, wildlife, and forestry.

Alongside of this capability mapping, soil series mapping continued from its inception in British Columbia in 1935-36. The primary focus to begin with, was on Agricultural lands (McKeage and Stobbe, 1978). During these early years (1935-36) a preliminary soil mapping project was carried out, "… at Campbell River to assist the Forest Service in its tree planting project by designating the location of arable lands." The first Canadian taxonomic system for soil classification was developed in 1955 (Canada Soil Classification Working Group, 1998). By 1975, 51.8 million hectares had been surveyed at the reconnaissance level of resolution (1:50,000 to 1:200,000) in British Columbia (McKeage and Stobbe, 1978). Here we see the beginning of an interest in evaluating potential site productivity as a means for determining the "highest and best use" of forested and non-forested lands.

Within forestry the land capability and soil mapping activities were eventually replaced with a newer initiative to undertake a province-wide development and application of the Biogeoclimatic-Ecosystem classification starting in 1976 (MacKenzie and Meidinger, 2018). This system was first developed by Krajina (Krajina and Brook, 1970) and then modified with continued development on a provincial scale (See Pojar et al., 1987, and Haeussler, 2011). Out of these developments were two primary inventory products, Terrestrial Ecosystem Mapping (TEM; Terrestrial Ecosystem Task Force, 2000) and

Predictive Ecosystem Mapping (PEM; Terrestrial Ecosystem Mapping Alternatives Task Force, 1999). The Biogeoclimatic-Ecosystem-Site-Series Classification has had many applications, including ecosystem conservation and protected area planning (BC Conservation Centre, 2018; MacKenzie and Meidinger, 2018). It has been the basis for developing species selection guidelines underlying forest regeneration stocking standards (BCFLNRORD, 2018b), and so too for estimating site productivity by way of site index (Mah and Nigh, 2015). Associated with this initiative is the alternative of estimating site index using a biophysical approach (Nigh, 2012; BCFLNRORD, 2016) with input variables available from climateWNA (Wang et al., 2012, and 2016)

In 1972 a new NDP Government established an Environment and Land Use Committee Secretariat (ELUCS). The primary focus of this secretariat was beyond the bounds of forestry. However, concerns were raised in at least two studies about the sustainability of the prevailing harvest levels (Chambers, 1974; Farquharson, 1974; and ELUC, 1976). As stated by Wilson (1987):

> *"In their view, overly optimistic technological assumptions had resulted in exaggerated inventories. As a result, harvest levels premised on these inventories will be difficult to sustain. The reports also contain some of the earliest references to the inevitability of timber supply falldown."*

In 1973 the Forest Productivity Committee was created to address issues regarding the growth of the second-growth forest. This led to the establishment of a set of installations in coastal second-growth Douglas-fir and western hemlock designed to generate a managed-stand database (FPC, 2001). Productivity committee responsibilities were identified as follows:

- To provide the Chief Forester with recommendations for developing a co-operative growth and yield program for forest stands, monitoring its progress and recommending necessary changes in policy.
- To develop council goals and five-year operating objectives.
- To annually assess forest productivity work and communicate this assessment in a report to the Chief Forester and all forest managers.
- To periodically review available forest productivity information in relation to the short- and long-term needs of forest managers and making appropriate recommendations to the Chief Forester.
- To recommend funding, and possible additional needs, for reviews undertaken for the Chief Forester.

This was the beginning of a long cooperative venture in growth and yield plot establishment, re-measurement and model development.

In 1975 the Government established the Pearce Royal Commission on Timber Rights and Forest Policy. In 1976 Peter Pearse reported his findings with some perspective on forest inventory (Pearse, 1976b, p. 133): "… forest inventories are required for purposes of long-term harvest planning. When rights to specific tracts of timber are granted, much more detailed information is required for purposes of operational planning and appraisal of stumpage values. Current tenure arrangements divide responsibilities for both inventories and operational cruises between licensees and Forest Service."

To be specific, inventories were the responsibility of the Province or industry within Tree Farm Licenses. Pearce (1976b, p. 20) was not optimistic with respect to the concept of a reliable forest inventory:

> *"The continuous physical, economic, and technological changes frustrate precise measures of the merchantable timber inventory, and any such measure would be meaningful only at a particular moment in any event. Instead, recourse must be taken in physical measures of acres and cubic feet of standing timber, based on explicit assumptions about what is valuable or potentially so."*

These statements stem from the rapid development of pulp mills during the 60's and attendant changes in both the coast and the interior from intermediate to close utilization standards, wherein the minimum tree diameter defined as merchantable timber were reduced, thereby opening up access to increased volumes of timber. Inventories in this context, were not connected with growth and yield forecasting. The comment seems to suggest the strategy of administering sustained yield by dividing the total area available for harvest by the average number of years required to produce merchantable timber and accordingly determine an allowable annual cut according to how much area rather than volume can be cut in any one year.[38]

This pessimism surrounding a reliable inventory arises again when Pearce (1976b, p. 236-237) seeks a method for what eventually leads to land use and/or capability classification:

> *"For reasons already explained, the inventory data used in allowable cut calculations is most deficient for the Public Sustained Yield Units. Even in these cases the main deficiency is not the physical inventory itself, for although some data are badly out of date, the present inventory system appears to be of an adequate standard for long-term planning. Rather the problem lies in the interpretation of the inventory for purposes of yield regulation."*

Pearce was satisfied that the inventory was, "… suitable for long term planning." Forest management had progressed up to this point with a strong economic development agenda and focus on forests and forest lands for timber, mining, and power production (see Griffin and Rajala, 2016).

Pearce proposed the following categories of forested lands as means of resolving the situation (paraphrased his remarks in parentheses):

- Un-harvestable lands (not suitable for timber production).
- Multiple use timber lands (lands managed for timber but with modification to accommodate other uses).
- Primary timber lands (timber production is clearly the dominant use; lands that if dominating a forested area should be placed in a reserve).

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[38] This concept is currently provided for under the Forest Act, BC Reg. 482/2004, the Tree Farm License Area-Based Allowable Annual Cut Trial Program Regulation. http://www.bclaws.ca/civix/document/id/complete/statreg/482_2004/search/CIVIX_DOCUMENT_ROOT_STEM:(TREE%20FARM%20LICENCE%20MANAGEMENT%20PLAN%20REGULATION)%20AND%20CIVIX_DOCUMENT_ANCESTORS:statreg?13 [accessed August 21, 2018]

- Unclassified lands (productive lands where other land uses require further consideration).

The forest inventory is needed to inform forest land management decision-making, but other information is needed to provide a complete context in how it is to be used.

Looking back on this period of time, Wilson (1987) noted that during the 1970's there was growing unease concerning the timber supply, and that this was further exacerbated by the NDP defeat in 1975. This was also a period of growing environmentalism. The defeat was followed by, "… waves of policy debate throughout the remainder of the decade," and into the next. According to Wilson (1987), rather than shying away from this conversation the Ministry of Forests joined into the debate, ultimately arguing for the need, "… for increased spending on forest management and for strong moves by the Ministry to protect the forest land base." The Ministry continued to raise concerns about timber supply and associated fall-downs, potentially in the near future. Given a decline Forest Service authority during the early 70's, this approach helped the Ministry to regain a central role in forest and timber supply management by the early 1980s.

In 1978, revisions to the Forest Act required the Chief Forester to inventory the Province's lands and assess their potential for growing trees, providing for recreation, producing forage for livestock and wildlife, and accommodating other forest uses. The Forest Service's inventory program became even more sophisticated to meet these requirements, using tools such as low-level 70 mm aerial photography, computer-assisted mapping, geographic information systems, and satellite imagery in the late 1970's and early 1980's.

After another 10 years of inventory development, the Forest Resources Commission was convened in 1990 (Forest Resources Commission, 1991). It was recommended that "a Land Use Commission be created by appropriate legislation and charged with implementing the land use planning process" that ultimately led to the creation of the Commission on Resources and the Environment (CORE) in 1992. CORE was charged with devising plans for land use and related resource and environment management throughout the Province.[39] The Forest Resources Commission report noted the importance of inventories in forest management decision-making (p. 75):

> *"Accurate and up-to-date inventories of all forest values are critical to the success of any resource management policy. They form the basis for land use classification decisions and provide the raw materials used to determine the appropriate level of enhanced stewardship called for in the Vision Statement. Without this information, Land Use Planners and forest managers are severely hampered in making intelligent choices and recommendations. Sadly, the state of renewable forest resource inventories in this province is inconsistent at best, and woefully inadequate at worst."*

This statement seems to be the reverse of what Pearce had said. The forest inventory is needed to inform land use planning rather than the other way round. Clearly this is a two-

[39] CORE was ultimately disbanded in 1995. The Land Use Coordination Office (LUCO) was instituted instead as a means of coordinating the development of Land and Resource Management Plans (LRMPs; see Rayner and Howlett, 2009).

edged sword that cuts both ways. The Commission went on to highlight the importance of growth and yield and its relationship to increasing demands for goods and services other than timber:

> *"In that context, the importance of accurate and complete inventories of the trees growing on provincial lands, the different productive capacities of those lands, and the reliability of future growth forecasts cannot be overstated. As the industry moves from harvesting mature, natural forests to growing "second growth" managed forests, the reliability of inventory information becomes even more important. Adding to the importance of this information is the fact that changing social values are demanding more from forests than commercial timber. There is tremendous pressure to withdraw forest lands from commercial timber production for parks, wilderness preserves, recreation areas, etc. To make intelligent choices society must know what resources are there and what the physical and biological capacities of the land are."*

The Commissioners recognized that at that time the provincial timber inventory was over 20 years old, it did not provide dependable estimates of site quality, nor was there a regular schedule for inventory updates – continuous forest inventory updating should be the norm. The Commission identified ten provincial ministries that maintained a wide variety of resource data (See Appendix 1). They stated that government needed to "… examine and implement ways by which the full range of forest related inventories can be made standard and able to be used on compatible systems, while at the same time, retaining the values for which they were originally intended." They recommended that a Ministry of Crown Lands be responsible for coordinating all forest resource inventories on Crown lands in the province. They further stated that:

> *"Improved inventories of wildlife and fisheries habitat, range, water, soils, timber, recreation and tourism potential are needed to assist in the preparation of sound, reasoned Land Use Plans and renewable forest management plans. They will also be useful in helping to quantify what benefits accrue to society from land use decisions that involve value trade-offs."*

> *"An overall master plan is essential for the development of the inventories of renewable forest resource values. These inventories should be developed within a framework that enables all data essential to forest resource planning is collected. The inventories must also satisfy the needs of resource user groups, and the public must have ready access to the information contained in them."*

The Commission recommended, among other things, that:

- BC undertake a commitment to complete inventories for all renewable forest resources using standardized compatible systems;
- a provincial Forest Resource Inventory Committee be established to plan and guide the development of a master plan;
- a Timber Inventory Task Force, comprised of technical experts from the private and public resource users, be established to design and plan the development of an accurate timber inventory;

- an updated provincial timber inventory, complying with new standards, be completed over the next 10-year period;
- the new inventory program must be designed and funded to provide reliable statistically sound data that can be used by local resource planning groups (and other resource interests);
- a system for continuous updating of the provincial timber inventory must be established; and
- a growth and yield program to quantify the growth rates of second-growth forests, for all commercial species in the province, must be established on a systematic, priority basis.

The Commission recommended development of a system of accounts "… to monitor additions and deletions throughout a year of both physical attributes, such as wildlife forage production, recreational use, and other market-valued activities, such as timber harvesting and silviculture activities." They believed that this approach would "… generate a high level of confidence in the adequacy of management effort and expenditures for non-market values, as well as the long-term sustainability of all values."

They clearly stated their belief that it was "… important that the inventory process apply to all lands, including parks, wilderness areas, ecological reserves, etc. Only with a complete picture of resource values in all lands can the best land use decisions be made."

Many of the recommendations regarding forest inventories were published in an interim report in 1991 (Forest Resources Commission, 1991. Appendix 4). Phil Halkett, Deputy Minister, Ministry of Forests and Range, responded (March 22, 1991) by outlining the activities that were either under way or to be initiated such that the concerns of the Commission would be met (Forest Resources Commission, 1991. Appendix 5). In April of 1992, the Resource Inventory Committee, Timber Inventory Task Force published their first report on a review of the current inventory with recommendations for the future. There were over 32 summary recommendations addressing administrative issues (10 recommendations), forest inventory and base mapping (3), forest classification and reporting (12) and volume and size prediction. Progress on at least some of the Peel Commission recommendations was underway.

In March of 1995 the Vegetation Inventory Working Group (VIWG) submitted their final report to the Resources Inventory Committee (Vegetation Inventory Working Group, 1995). The committee was co-chaired by Imre Spandli, RPF of the Ministry of Forests, Resources Inventory Branch, and Don Munro, PhD, RPF of the University of British Columbia, Faculty of Forestry. Kin Iles, PhD was identified as an Inventory Design Specialist. There was 1 industry representative (John Barker, PhD, RPF, Western Forest Products), 1 Federal Government representative (Mike Bonner, PhD, Canadian Forestry Service), 1 College representative, (Norm Shaw, A.Sc.T., BC Institute of Technology), 1 consultant (Dave Jamieson, RPF, Timberline) and 10 Government employees, including 1 from the Ministry of Environment (Dave Clark, P.Ag specializing in Habitat Inventory). Funding for their work starting in 1991 was provided by the Canada – British Columbia Partnership Agreement on Forest Resources Development (FRDA II).

The VIWG report provided the foundation for the current Vegetation Resource Inventory (VRI) with the highlights explained in the executive summary as follows:

> *"The design of the inventory has been finalized, tested, and is ready for the first full scale operational implementation in 1995. The design covers the entire land base of BC with a standard suite of measurements from the disciplines of timber, ecology, range and soils. The design is simple, reasonably efficient and is statistically and technically defensible. The results offer an excellent set of measurements for research, resource identification and large scale planning. In addition, it provides an unbiased basis in sampling for any future information needs."*
>
> *"An initial estimation of vegetation polygons provides location-specific information which also increases efficiency. Relocatable ground measurements will adjust these to form an unbiased set of estimates for vegetation and ecological characteristics in the province. To offer flexibility in scheduling and future re-inventory, the units are inventoried separately until the province is covered. After each inventory is processed, adjusted information for every vegetation polygon will be individually available. The same sampling procedure can also be used to do a quick, less precise check of the province as a whole."*
>
> *"More information will be gathered than has ever been available previously, and the methods have been coordinated with several resource groups to ensure consistency of definition and procedure. The overall project is described generally in one video, and a second video for technical specialists covers the details of field measurements. Manuals have been written, tested and are now being prepared in their final draft."*
>
> *"Integration with other groups will use databases and Geographic Information Systems based on the TRIM mapping base. New features include a method to unbiasedly update the information based on local work, new decay procedures, direct growth information, statistics to indicate data reliability and an outside audit to add credibility to the system."*
>
> *"A wide variety of individuals and organizations has been involved, and the process has been worked out in considerable detail over several years. General recommendations are available in the full report, with technical details available in field manuals."*
>
> *"Discussions between Ministry, industrial and academic committee members has been frank, productive and remarkably successful. This report is the final set of recommendations of this committee, augmented by the field procedures and detailed processes developed by the committee."*

The committee went on to emphasize that the inventory was founded on ground sampling so as to ensure that the sum of the (area weighted) attributes at the polygon scale would match with the ground based estimates of the total. They provided an example of how this works using stand height, noting again that when this is completed, "… then the total of the adjusted estimates will be correct." Furthermore, the measurements at the "integrated plot centres" provided measures of, "… biodiversity, plant species, tree volumes, growth capacity, range values, soil information, and many other characteristics."

There were 66 recommendations concerning application of the VRI procedures that included, for example, matters of quality control, reporting, etc. One recommendation focused on inventory update:

> *"Changing the inventory due to significant changes in individual polygon values or land base changes can be made at any time, since they will normally be a small part of the Vegetation Inventory." (56)*[40]

Three recommendations were identified under training:

> *"Training of field staff is a serious concern, and should be given high priority." (60)*

> *"The committee recommends that a permanent group of 4-6 people be maintained within the MoF in Victoria who are fully experienced, and qualified to carry out Vegetation Inventory field work. In addition, we recommend the development of a stable group of people within the contracting community to carry out the necessary field work." (61)*

> *"The Ministry of Forests should insure permanent internal expertise in photo work, sampling, field measurements and data compilation within Resources Inventory Branch." (62)*

Two more recommendations addressed inventory projection:

> *"The adjusted inventory estimates should be modified over time by standard projection models." (58)*

> *"Growth prediction and model building should be done as a process separate from the Vegetation Inventory." (59)*

One recommendation dealt with external quality control:

> *"To assure the public that the inventory is correct, the Province should employ an independent agency to do an audit." (63)*

There were four final recommendations that addressed inventory implementation:

> *"The committee believes that the new procedures should be phased in at a rate consistent with the numbers of trained people available for this work." (64)*

> *"The provincial commitment to this project should be clear." (65)*

[40] Number in parenthesis refers to the number associated with the recommendation in the original document.

"A Provincial Inventory Technical Council should be established." (66)

"The value of information collected on the Vegetation Inventory should be periodically evaluated." (67)

"The province should continue to develop the Pre-Inventory Analysis (PIA)." (68)

At this stage of the discussion it is necessary to back up to discuss further developments in growth and yield. In 1986, an interior Forest Productivity Council was formed, and then merged with the Coastal Council in 1995. This was composed of representatives from industry, government, and consulting. In 1996, the Chief Forester redesigned the council, "… to encourage a more active role by private sector managers." The design was implemented in 1997 with the following stated objectives:

"Growth and yield data are an integral part of the provincial forest inventory system. Models using this data simulate growth and future yield of second-growth stands, and impacts due to insects and disease."

"The primary interest of the council is forest productivity. Emphasis is on acquiring and evaluating models that can simulate the growth of natural and treated stands. These models must meet the requirements for use in the B.C. forest inventory database and assess the implications for wildlife habitat and other non-timber values."

"The council encourages development of effective and continuing processes for acquiring, sharing and applying growth and yield information between a number of agencies and co-operatives."

In the 1989-1990 fiscal year the Ministry of Forests inventory budget was established at approximately 8 million dollars (Canadian Inventory Committee, 2001), almost all of which was provided by the BC Government. Between April, 1991 and March 1995, funding was at or above 15 million dollars with the majority of funds being provided by the Government. During this time there was a substantial amount of work being done on developing and testing new Vegetation Resources Inventory (VRI) procedures. Some Tree Farm Licenses (TFL's) had completed inventories using initial drafts of these procedures as early as 1995 (Ministry of Sustainable Resources Management, 2004). A number of inventory audits were also carried out to verify the reliability of inventories in various Timber Supply Areas (TSA's). In 1995, it was envisioned that the entire province would be re-inventoried within 7 to 10 years.

Between April, 1995 and March, 1997 inventory funding rose to over 26 million dollars, with much of the funding being provided by the Provincial Government, administered through Forest Renewal BC. By the 1999-2000 fiscal year the budget had dropped to 6 million dollars, with a slight increase at the end of the 2001-2002 fiscal year. As of 2004, only 13 out of 43 Forest Districts had been re-inventoried, along with 2 Innovative Forest Practices Agreement Areas (Ministry of Sustainable Resources Management, 2004).

In 2001, the BC Government introduced their "New Era" reform agenda (Hoberg and Paulsen, 2005). This agenda was driven by "… budget cuts and associated core review, the softwood lumber trade dispute with the Americans, and forces of nature affecting forest health." As part of the agenda, the responsibility for forest inventories was transferred to the new Ministry of Sustainable Resources Management (MSRM). A new Forest and Range Practices Agreement (FRPA) was passed as means of shifting from a prescriptive legislated agenda to an outcomes-based agenda (Rayner and Howlett, 2009). Bill 40 was passed under the Forests Statutes Amendment Act, in 2002, wherein the Chief Forester's responsibilities for forest inventories were revoked and transferred to MSRM. This reorganization was done in an effort to centralize all resource inventory functions (Ministry of Forests and Range, 2005a). In the meantime, resource inventory operations had been "downsized." Between 1992 and 1995 there were approximately 188 Ministry of Forests inventory related jobs, helping the Chief Forester make informed decisions (Parfitt and Garner, 2004). In 2000, this number fell to 105 jobs. By 2004, there were 28 "inventory" jobs in the Ministry of Forests. Similar "downsizing" occurred within MSRM (Ministry of Forests and Range, 2005b).

During this same period, the Forest Productivity Council continued to operate albeit the level of activity was somewhat curtailed. One of its primary responsibilities was shifted to setting priorities for growth and yield to be administered under Forest Renewal BC (FRBC) and undertaking project proposal adjudication for funding by this same organization. The 2000 to 2005 plan for the Council had established the following vision (Ministry of Forests and Range, 2002):

> *"To be able to consistently and accurately predict the productivity and quality of BC's forests under any resource management regime to support better and more informed decision making."*

… with the following priorities:

> *"To achieve the vision, FPC has identified 5 priority areas for work that need the most attention over the next 5 years. The following list of the 5 priorities, ranked in decreasing order of importance, will be utilized in considering potential projects."*

1) Complex stand work including (no order is implied by the following bullets):
    a) developing tools for assessing and projecting stand structures,
    b) modeling for forest level applications,
    c) assessment of response to management practices,
    d) determination of yield projections, and
    e) determination of site productivity.
2) Wildlife/ Habitat/ Biodiversity - Forest Measurement Linkages
3) Forest Resources Inventory Projection Tools
4) Site Productivity Tools and Measurement
5) Forest Health

> *"BC's 50 million hectares of forest land are comprised of a wide array species growing over widely divergent biogeoclimatic zones and managed under a variety of forest practices. This diversity means that no one set of tools will satisfy all the needs for productivity estimates throughout the province. Instead, a selection of*

tools that can be applied in an appropriate manner for a selected forest type must be developed and applied for accurate projections of timber supply or assessing silvicultural investment options. It is also important to remember that data collection is central to development of these forest productivity tools and as with the tools themselves, no one set of data will satisfy all needs."

During this period growth and yield activities were largely conducted under the direction of the Research Branch. The exception to this approach was with respect to the Variable Density Yield Projection system that was the responsibility of the inventory group, at that time under MSRM. The Ministry of Forests had submitted a substantial proposal to FRBC involving the following activities:

1) To develop methods for estimating site productivity in complex stands, with one option including the use of site index (Thomas and Nigh).[41]

2) To develop and validate height-age models and growth intercept models for estimating site index in young stands (Thomas and Nigh).

3) To develop juvenile height growth models to estimate years to "greenup" from breast height (Thomas and Nigh).

4) To develop site index, Biogeoclimatic-Ecosystem (SIBEC) relationships (Mah and Thomas).

5) To maintain and enhance of the Variable Density Yield Projection System, VDYP7 that had been under development for 5-years (Bartram and Drummond).

6) To continue development of the Tree and Stand Simulator (TASS II) with extensions into the ICH (paper birch and larch), MS and IDF, and BWBS (aspen) zones and extensions involving estimation of product yields and financial returns. This proposal included use of TASS to forecast the yields of pure and complex stands (Mitchell[42]).

7) To expand the range of Prognosis^{BC} that had been adapted from the US in partnership with UBC starting in 1998 (Snowdon, Zumrawi, Marshall, and LeMay).

8) To support permanent sample plot establishment and re-measurement (Braz).

9) To maintain managed stand installations, some of which dated back to 1929 (de Montigny, Johnstone, Brockley, and Thomas).

10) To develop methods and provide data to assess how forest health factors impact stand level growth and yield (Muir).

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[41] The purpose of indicating the proponents is to draw attention to where in the forest service funds were being directed. The individuals involved were also associated with specific programs that were in existence at that time, some of which are still in place, and some not.

[42] Dr. Ken Mitchell was hired by the BC Ministry of Forests in 1980 to develop the Tree and Stand Simulator building on his thesis work on white spruce (Mitchell, 1969) and subsequent work on Douglas-fir at Cowichan Research Station (Mitchell, 1975).

11) To undertake growth and yield extension (Di Lucca).

12) To support the activities of the Forest Productivity Council (Vivian).

13) To characterize complex stand structures (Winter and Scott).

This list indicates the scope of government activity in growth and yield during that time. The total proposed funding to implement these proposals was $8.3 million over a 3-year period, or $2.8 million per year. Total related FRBC funding of these projects prior to submission of the proposals was $16 million, most of which would have been spent in the years leading up to the proposal since it took a number of years for the FRBC program to become fully functional. The largest amount solicited was with respect to measurement of managed stand installations (Item number 9; $1.6 million over 3 years or $522,000 per year). This involved measurement and/or establishment and measurement of 3,579 plots produced at an average cost of $437.72 per plot. Over 6 million ($6.7 million) had been allocated to this work by FRBC in previous years.

The second largest project from the list above involved $1.3 million for further development of Prognosis^{BC} (Item number 7; $421,000 per year). This involved a combination of field work, data management, and computer model development. According to the proposal, the development of Prognosis^{BC} had been initiated in 1997 as tool for dealing with complex stands, this being a high priority for the Forest Productivity Council. The proponents also identified that one UBC research associate and three Masters students were funded by the project. This work continued to receive funding until sometime after 2010 (See Statland, 2010), but eventually a decision was made by the Ministry of Forests to put an end to support for the development and application of Prognosis^{BC}. Just over 1.3 million FRBC dollars had supported development of Prognosis^{BC} prior to the FRBC proposal.

The third largest proposal involved establishment and re-measurement of growth and yield plots (item 8), at an estimated cost of $770,000 over 3 years ($257,000 per year). This amount was to be allocated for purposes of training, data management, software update, and development of a 10-year strategy. It did not include the cost of ground plot establishment and re-measurement beyond that associated with training. Just under $3.4 million dollars of FRBC dollars were contributed to this program prior to submission of the proposal.

Forest Renewal BC was a Crown Corporation established between 1994 and 2002, that was replaced under a new Liberal government regime in 2002 by the Forest Investment Account (Wikipedia, 2018), albeit the transition took some time to unfold. Funding was secured for the FRBC program through a "Super Stumpage" where licensees paid on a dollar per cubic metre harvested rate. The FRBC process illustrates the emphasis on transparency and third-party engagement in awarding funds for program activity, with third party control over the direction that the funding takes. The concept of FRBC was also to put both government and non-government (private industry) project proposals on an equal footing.

Funding of forest inventory, growth and yield, and related activities, and the mechanisms for delivering funds, have been a permanent feature of the BC policy debate, particularly as it relates to Provincial and Federal contributions, and as it relates to Government versus Industry responsibilities. Resolutions to these questions have also been impacted by the placement of US tariffs on Canadian wood products due to purported subsidies. Questions of how much funding is needed and who benefits also become paramount, particularly as it relates to whether the outcomes are strategic or operational in nature. In relation to the development and implementation of forest inventory products and services, to what extent does the creation of this split between these different kinds of outcomes impact on the broader concern for ensuring the sustainability in the production of forestry related goods and services? Is there something we should do in relation to inventory, growth and yield, to better ensure that strategic ends meet with operational outcomes, and so too, vice-versa?

In 2005 responsibility for forest inventory was returned to the Ministry of Forests and Range. Forty-seven resource inventory positions and 3 systems support positions were transferred back into the Ministry (Ministry of Forests and Range, 2005b). "The current inventory section has fewer resources now than in 2001, but has responded by streamlining the business process, staff consolidation, reliance on third party data collection and dropping some activities that were not sustainable." The Ministry of Forests and Range (2005b) stated the purpose of the resource inventory program as:

- forest and visual inventories are (to be) maintained to the best possible standards in partnership with agencies and the forest industry; and
- spatial data are (to be) made available for purposes of key business processes in support of Compliance and Enforcement, BC Timber Sales, tenures, fire protection, forest health and silviculture strategies.

This year (2005) also marked the last year of operation of the Forest Productivity Council.

While the inventory had been restored to the BC Ministry of Forests and Range, legislation to assign responsibility to the chief forester for purpose of developing and implementing forest inventory was still lacking after having been revoked in 2001. This is contrast to recommendations made previously by the Forest Resources Commission (Peel, 1991; Pp. 25-27):

> *"The Provincial Forester will take on an expanded role, a role seen critically important by the Forest Resources Commission. The Provincial Forester position, currently known as the Chief Forester, was initially introduced in 1912 as a high-level advisor to the Chief Commissioner (Minister) of Lands and Forests on all matters of forest management. The independence of the Chief Forester and the ethic that the Forest Service developed provided an important balance between the government, the industry and the public interest in forest management and conservation."*

> *"But over time, the Chief Forester's stewardship responsibilities have gradually been eroded to the point where the post is essentially a staff position with powers only to recommend. The vacuum ultimately created has led to many requests to the Forests Resources Commission for the establishment of an independent forest ombudsman. The commission has concluded that in replacing the Chief Forester,*

the position and responsibilities of Provincial Forester should be structured so that the Provincial Forester is seen to be impartial, and to represent all values in forest management on all Crown lands."

"Therefore, the Commission has concluded that the Provincial Forester should be required by legislation to make annual reports direct to the legislature on the state of the forests. In essence, the Provincial Forester must have a position that will be seen by all to be unbiased and trustworthy."

"In order to ensure that the Provincial Forester can fulfill this role, the Provincial Forester's office should also guarantee access to all inventory information developed by the Forest Resources Corporation, as well as by other forest land base tenure holders, and be responsible, where required, for maintaining the quality of inventory information on all other Crown lands."

These remarks also stand out in an environment where the Province had migrated to a "results-based approach" to forest management under the Forest and Range Practices Act (FRPA) introduced in 2004. This was intended to reduce overhead related to the implementation of government review and approval processes. Ultimately this approach would be further extended to include the notion of "Professional Reliance."

While all of these changes were taking place, nature was also taking its turn at the helm. In 2003 there two large urban interface fires, one in the Okanagan (25,600 ha) and one in the McLure, Barriere and Louis Creek (26,420 ha) areas that spawned a Provincial Review (Filmon, 2003). It was recommended that cities and towns develop plans for reducing the risk of fire within the urban-wildland interface. The forest inventory provides a starting point for this activity and then further advanced through the use of ground surveys to assess stand conditions and the distribution of fuel types. Large fires continued to manifest in 2009, 2010, 2014, and 2017 (See BC Government, 2018).

Wildfires were not the only source of catastrophic events. The Mountain Pine Beetle epidemic was well underway in 2005 after breaking out of the Chilcotin Plateau starting in 2001 (BCFLNRO, 2012). At the start of 2005, over 300 million cubic metres of commercially valuable pine were estimated as being dead. By the end of that year another 140 million cubic metres were added as "red-attack." During this time Chief Forester, Jim Snetsinger, RPF issued a report on "Strategies for Forest Inventory and Monitoring in Mountain Pine Beetle Areas," prepared by Reimer et al. (2005). In the cover letter Snetsinger cites Melanie Boyce, then Director of Forest Analysis Branch, as having drawn the following conclusions from the report:

- Leadership and communication
  - There is an urgent need to collect new data, with coordination through a new Technical-Business Advisory Group to ensure an efficient and effective inventory strategy is created. The group should communicate with a broad audience and develop an accessible list of all relevant inventory activities.
- Standards
  - A new approach to forest inventory should be developed that allows for different sampling plans and different standards, which are responsive to

the dynamics of the MPB infestation. For example, some new data sets should be developed that can capture updated information on a yearly basis.

- Strategies for Business requirements
    - Four areas must be examined to ensure all business needs are considered:
        - The location and extent of mortality.
        - The volume and value of attacked stands.
        - Corporate decisions such as AAC uplifts, which areas should be harvested or not, and silviculture strategies.
        - Technical matters such as database structures and modelling requirements.

Implementation of these "action items" had already begun and were cited as follows:

- A new adaptive VRI pilot in the Quesnel TSA.
- Testing a new dataset in two areas to report mountain pine beetle mortality (year of red attack and severity) using yearly satellite imagery.
- A small task group was established to hold high-level discussions regarding strategies to consider how various types of imagery might be applicable to the strategy.
- An inter-agency was established to coordinate forest inventory related activities, with intent of developing technical working groups to work in "various areas."

This eventually resulted in annual updates by the Ministry using Landsat and the method of change detection as a means of estimating the proportion of polygon area impacted by Mountain Pine Beetle. When combined with consideration of the "shelf life" of trees following mortality the information could be used to estimate the impacts on mid-term timber supplies, and so too for investigating impacts on hydrology[43], wildlife habitat (See McCann et al. 2011), and the potential for increasing the numbers and sizes of wildfire events.

In that same year (2005) Michel Charon published a Canadian Parliament review, with the provocative title, "Sustainable Forest Management in Canada: Clear Policy – Questionable Practice." Charon began as follows with a definition of Sustainable Forest Management or SFM (citing the Canadian Forest Service, 2001):

> *"Management that maintains and enhances the long-term health of forest ecosystems for the benefit of all living things while providing environmental, economic, social and cultural opportunities for present and future generations."*

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[43] Schnorbus (2011) provides an excellent overview on this topic. With respect to forest inventory he wrote (p. 23), "Hydrologic modelling is an effective means of extrapolating relationships obtained at the stand scale to larger landscapes, where hydrologic response to disturbance is also influenced by variability in such factors as climate, forest structure (e.g., height, density, and canopy cover), tree physiology (e.g., age, transpiration rate), topography (e.g., slope, aspect, relief and elevation), and basin topology (e.g., drainage density and stream order). Hydrologic modelling is necessary to understand and predict effects of forest disturbance over large regions and at locations downstream from the disturbance area." With respect to long term watershed monitoring he specifically identifies the need for (p. 23), "An inventory of secondary structure in lodgepole pine stands."

The Canadian Council of Forest Ministers (CCFM) announced in that same report that a steering committee would be established to develop a National Forest Information System (NFIS) for purposes of reporting on forest sustainability for purposes of meeting national and international commitments. Referring to this and previous state of the inventory reports, Charon (2005) had this to say.

> *"A forest inventory that tracks the SFM indicators is an essential tool for successful monitoring and reporting on forest sustainability. The federal government produced Canada Forest Inventory (CanFI) reports in 1986, 1991, 1994, and 2001. The provincial governments, as managers of the natural resource within their jurisdiction, regularly collect the data and each generates its own inventory. The Government of Canada collects data for federal forests such as those of the Department of National Defense or First Nations lands, and consolidates the data from each province and territory to create the national reports.[44] CanFI's shortcomings are well-known: it is a "snapshot of different-aged information, collected according to different standards";[45] it does not include information on rate or nature of change; and it cannot be used to make projections into the future or as a benchmark against which to capture future inventories.[46,47] These limitations greatly diminish the availability and quality of the data for assessing the sustainability of Canada's forest management."*

Charon (2005) then turned to the discussion of provincial inventories in the context of sustainable forest management, including British Columbia:

> *"The British Columbia government takes pride in the province's North American leadership role in sustainable forest management certification (CSA, ISO, Forest Stewardship Council, or other). In January 2003, British Columbia reported nearly 70% of the timber harvested in the province came from operations that met ISO or other third party standards.[48] The next year, the government published, "The State of British Columbia's Forests, 2004," as the first in a series of three reports designed to comprise a complete assessment of forest sustainability in the province.[49] The 2004 report suggests that the current state of forests in the province is sustainable from an environmental point of view, although pressures are threatening future diversity. The government assesses that the timber harvest is currently managed in a sustainable manner but there will continue to be great local variability in sustainability resulting in potential booms in some areas and buts in others. The report highlights the fact that Aboriginal involvement in forest management has not been sufficient in the past but is now improving. Finally, the*

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[44] Charon (2005) noted that the data was sourced from 45 different agencies including provincial and territorial governments, federal departments, First Nation groups, private land owners, and timber harvesters.

[45] Gillis et al. 2003.

[46] Barker et al. 1996.

[47] Gillis et al. 2003.

[48] Charon (2005) noted that: "The Suzuki Foundation states that the only ecologically credible certification is the certification offered by the Forest Stewardship Council, as all others are funded by industry. The majority of certified forests in British Columbia are ISO- or CSA-certified.

[49] British Columbia Ministry of Forests (2004).

government assesses its own legislation on sustainable forest management as good and improving, basing this assessment largely on proposed and already implemented simplifications of the regulatory and administrative burden for industry."

The notion of sustainable forest management and whether it is being obtained is tied back to the inventory as a source of information regarding past, present, and future. As pointed out by Charon, the question of sustainability may draw different assessments and conclusions at different scales. The process of allocating forest management rights and responsibilities is also informed by the inventory, as is legislation for the purpose of managing for all resource values.

Charon (2005) identifies that there are some organizations, particularly Non-Governmental Organizations that have often chosen to conclude that in fact sustainable forest management is not being practiced. The work of Global Forest Watch Canada (2000) is summarized in relation to the following categories and items of concern:

- Forest Condition and Change Trends:
    - Rate of deforestation.
    - Level of fragmentation, particularly in species rich forests, amount of road development.
    - Loss of species habitats.
- Forest Industry:
    - Level of harvesting versus reforestation.
    - Impacts on employment and income, and the associated number of communities.
- Commitments and Legislation
    - Managing forests for environmental benefits, not just timber.
    - Level of confidence in the process, particularly as it relates to reliance on self-policing and reporting to monitor compliance.

Forest inventory provides a reflection of these trends, outcomes, and initiatives, and as such, provides a guide for adjusting course in relation to these at the same time. Global Forest Watch Canada (2000) drew a few more conclusions specific to this commentary:

- Lack of publicly available forest information hinders accountability and informed decision making.
- As a result of cost-recovery policies government datasets are often prohibitively expensive to noncommercial users.
- National datasets on productivity limitations, land ownership, aboriginal forest use, threatened and endangered species distributions, and compliance with management laws are either outdated or not systematically collected.
- There is no systematic monitoring of changes in forest condition- for example, where primary forests are being converted to secondary growth, which is useful for gauging the environmental tradeoffs development entails.

In 2006 the Association of BC Forest Professionals (ABCFP) undertook a review of the status of forest inventories in BC (Moss et al. 2006). This review included the VRI, Terrain Resource Information Mapping (TRIM) and Terrestrial and Predictive Ecosystem

Mapping (TEM and PEM). The reviewers developed a set of criteria for assessment, and then undertook a survey of users and producers of forest inventory with respect to those criteria to determine the potential strengths and weaknesses of the inventory program. With a few revisions, these same criteria were adopted for use by this Panel as identified elsewhere in the report. The primary recommendations from the ABCFP report are summarized below:

1) Secure *multi-year funding* sufficient to support annual inventory costs should be sought – preferably from the BC Treasury Board.

2) *Responsibility for the forest inventory* should be *returned to the Chief Forester* under the Forest Act.

3) Higher priority should be placed on obtaining *current, complete coverage of all lands, using VRI standards* at least at a basic level of forestry inventory information. The basic level inventory information should be sufficient for the Chief Forester's mandate of sustainable forest management at the provincial level. (Note that this recommendation recognized that, "Detailed information for every hectare of forest in BC is simply not economically feasible.")

4) For all areas currently under development, complete and current inventory information at *a more detailed level should be available* that will allow the Chief Forester to minimize the risks of decisions at a management unit level. (Examples given were TFLs, TSAs, and community forests. It was identified that there is need for high quality stand-level data that could be easily used as inputs into growth and yield forecasting models, and that geo-referenced ground plots would be required to make this connection.)

5) Inventory information requirements for specific, local areas requiring a high level of spatial resolution and detail should be outside of the base funding for the inventory program.

6) We *endorse the formation of a vegetation inventory council* and encourage this group to play a major role in strategic planning for the forest inventory as well as providing general advice on inventory issues. (This recommendation refers back to the 2005 Snetsinger letter referred to above).

7) *A program to forecast inventory attributes* for strategic planning and decision making under a variety of stand conditions should be part of the BC Forest Inventory Program and included in the strategic plan. (At this time Prognosis^{BC} was being supported and TASS III was not yet under development. Specific reference is made to, "… include growth and yield models at the tree, stand, or aggregate stand level, and models to forecast other attributes." i.e. attributes beyond those included in traditional growth and yield models.)

8) The program to *maintain and measure a system of repeatedly measured ground plots* (permanent sample plots) must be continued and augmented as a part of the BC Forest Inventory Program to support the development of forecast models and to

monitor stand dynamics. (This included the installation and re-measurement of experimental plots as part of the recommendation.)

9) *Public access to summarized inventory products* should be supported. (This recommendation distinguished between base products and data tables that would be available versus more detailed datasets that would be withheld and available upon request, in part to address privacy concerns associated with private lands).

10) *Historical records of past inventory data*, procedures and standards should be archived to the greatest possible extent. (This recommendation was for the purpose of addressing issues of sustainability, climate change and management based on natural disturbance, i.e. maintaining landscapes within an historical range of variation.)

11) A component should be included in the *baseline inventory budget to support research* into possible uses of new technologies and methods that could be used to improve inventory procedures. (Examples given were: "1) the use of multiple sources of data to provide the basic information for the entire province, and 2) the use of imputation methods to provide details for a variety of variables at lower costs and facilitate the connections of forecast models to inventory data).

In 2006, B.C. completed installation of its portion of the National Forest Inventory (NFI) plots (2,414 photo samples established on a 20 km grid; 268 of these also have ground plots, BCFLNRORD, 2018). The Ministry reported that, "Over time, NFI re-measurements will strengthen the statistical foundation for SFM reporting."

In 2010 the Ministry of Forests, Mines and Lands (MFML) completed the third edition of, "The State of British Columbia's Forests" (MFML, 2010). Under the category of "Knowledge" they addressed the question, "How current and complete are B.C.'s inventories?" To start with it is highlighted that, "Like other Canadian jurisdictions, B.C. relies primarily on map-based forest inventories derived from photo-interpretation and inventory field plots." The government database was found to cover 90% of B.C. The remaining 10% included parks, private land, and tree farm license areas. The majority of the forest inventory was based on photo interpretation dating from 1953 to 1995. As of the 2010 report, 26% of B.C. was re-inventoried to the current VRI standard. The inventory maps and databases were described as being updated, "… every few years to reflect predicted growth, human made disturbances (e.g., harvesting), and natural disturbances (e.g., fire, insects, and disease)." The State of the Forest Report also acknowledged the existence of a number of inventories, including: ecosystems, recreation, terrain, traditional Aboriginal territories, transportation, visual quality, and watersheds. "In some cases, this information was found to be less current than the forest cover inventory."

In 2011, Resource Practices Branch completed their report on, "A new silviculture framework for British Columbia: Options and recommendations report." The report was initiated in a 2009 discussion paper entitled, "Growing opportunities: A new vision for silviculture in BC." The aim of this discussion paper was to develop a new framework to help guide silviculture investments and make British Columbia a world leader in growing trees.” (Resource Practices Branch, 2011). In the final report, inventory is highlighted as the biggest information gap. The gaps are further described (paraphrased) as follows:

- Following the attainment of free growing based on a free growing surveys, there are no further ground surveys (scheduled for the foreseeable future).
- There is a serious information gap regarding post-free-growing stand growth (and development).
- The reliability of site productivity estimates is a concern.
- Inventory maps are being used operationally in ways they were never intended and don’t provide the level of detail required for silviculture planning.
- Gaps exist relating to other forest values.

These issues were revisited under the theme of Research with the need for secure funding and staff so that they might be addressed. There was a focus on concern for issues related to tree improvement, growth and yield, the application of different silviculture techniques, and so too, the management for different objectives (e.g., timber, wildlife habitat, etc.). It was also mentioned that there were many gaps related to disease resistance and silviculture treatment effectiveness. This would be best accomplished through the acquisition of better growth and yield data using ground plots, “… whether temporary or permanent plots, in addition to formal monitoring plots in stands from age 20 – rotation.” In relation to this last item, they described a concept of stand development monitoring (SDM) for post free growing stands as follows:

> *“SDM is being designed to assess timber productivity of free growing stands after they have been declared free growing, check for changes to the inventory label attributes (e.g., species, age, site index, number of free growing and well-spaced trees, total density) and update those attributes to obtain a new inventory label. SDM will also be useful for refining stand yield prediction that is used in the Chief Forester’s Timber Supply Review process. Changes to free growing and total density can be an indication of comprised forest health.”*

In December, 2011 the Association of BC Professionals initiated an update to the 2006 ABCFP review (Moss, 2011). The report is prefaced with remarks concerning the turbulence that had occurred during this time. This occurred due to the 2007 subprime mortgage crises severely affecting forest industry production and government revenues. Then came reorganization starting in 2010 when the Ministry of Forests was split into the Ministry of Forests, Mines and Lands, and the Ministry of Natural Resource Operations. The distinction separated strategic considerations under the first ministry versus operational activities (e.g., issuance of permits and compliance and enforcement) under the second ministry. In March, 2011, these were two organizations were combined in a Ministry of Forests, Lands and Natural Resource Operations after Mining was reassigned to Energy, Mines and Petroleum Resources. As part of the last reorganization, Research Branch was closed with staff reallocated to various other branches. In particular, the “TASS” growth and yield research and modelling group was transferred to the “Resource Analysis and Inventory Branch” and continues to operate under this unit today.

While all of this re-organization continued, FLNR was still dealing with the fall-out from continuing MPB and wildfire impacts on the landscape and so too inventories that predated 1980. They applied risk management (triage, in effect) and in so doing gave increased priority to Phase I (photo interpreted) over Phase II (adjusted photo interpreted) inventories. They were also focused on making data more accessible to the public along with deploying quality control and "Change Management" procedures to ensure inventory was meeting current demands. An example of the latter would be inclusion of the identification of dead wood as a new attribute, separate from live tree components.

The main deficiency that was identified in the 2011 ABCFP report was with respect to adequate funding. The funding for the 2011-2012 year was $8.5 million. Fifteen million was identified as the long-term average level of funding, and as a result, as being the necessary annual level of funding to maintain a program sufficient to keep inventories current and up to date. It was also highlighted that no Permanent Sample Plots had been re-measured for a period of two years leading up to the report and that the maintenance and measurement of these plots was critical to growth and yield forecasting of reasonably possible future forest and stand-level conditions.

The question of whether or not the inventory was sufficient "for the Chief Forester's mandate of sustainable forest management at the provincial level" could not be fully addressed in the 2011 ABCFP review. This was felt to be an important question that should be addressed at some time in the future, "… in a more comprehensive review."

The 2011 ABCFP report included some commentary concerning the importance of the forest inventory to forestry professionals (here used in the broad context to include agronomists, biologists; wildlife, water management, recreation, and landscape design specialists). Three uncertainties that pose threats to the efficient and effective use of forest inventory for the purpose of better ensuring sustainability of social, economic, and environmental goods and services:

1) Continued indecision about the allocation of private versus public rights and responsibilities and the questions who benefits, who pays, and by how much?

2) The impacts of climate change on forest dynamics.

3) Continuing fluctuations in forest revenues, and subsequent allocations to forest inventory and management.

In 2012 the Auditor General conducted, "An audit of the Ministry of Forests, Lands and Natural Resource Operations' management of timber" (Auditor General of British Columbia, 2012). It was recommended that FLNR:

1) Develop a plan for directing forest stewardship that establishes clearly defined timber objectives and stewardship principles to guide decision-making, actions, time frames and assessment of results.

2) Ensure that its investments in silviculture are sufficient to achieve long-term timber objectives, and that they align with stewardship principles and are cost-effective.

3) Ensure that restocking activities result in the establishment of forests that are consistent with its long-term timber objectives.

4) Ensure that its information systems reflect actual forest conditions in priority management areas.

5) Ensure that the collective and individual components of its oversight framework are sufficient to ensure the achievement of long-term timber objectives.

6) Develop and implement appropriate performance measures to demonstrate progress towards achieving long-term timber objectives and report publicly on the results.

With respect to recommendation number 4, FLNR responded as follows:

1) To periodically re-inventory all forest lands to ensure that information on stands is up-to-date in the period between free growing and harvest;

2) To implement the ground sampling program that is used to validate forest inventory estimates that have been derived from aerial photography;

3) To reduce the backlog of submissions to the ministry's information system (RESULTS) that have not been integrated into the inventory;

4) To test and refine the growth and yield projection models;

5) To implement programs to monitor young stand growth, yield, and condition.

6) To provide publicly accessible information on the accuracy of forest inventories, to carefully set inventory priorities and focus investment on areas with the greatest need, and to report on the performance of the Forest Inventory Program.

In April, 2013 the auditor general evaluated the progress made in implementing their recommendations. In particular with respect to recommendation number 4:

> *"The ministry self-assessed that they had fully or substantially completed this recommendation, whereas we found that the recommendation was partially implemented. In our 2012 audit, we noted concerns with the ministry's forest inventory information, used to forecast timber supply and determine the allowable annual cut, particularly in areas affected by disturbance. Since our 2012 audit, the ministry has focused on initiatives to improve its forest inventory for mountain pine beetle areas where data is the most out-of-date and consequences for communities are the greatest. The ministry has developed a 10-year Forest Inventory Strategic Plan and is working towards its implementation, as well as developing a monitoring and reporting framework."*

> *"The ministry has also initiated a quality assurance program for data submitted by licensees that is achieving encouraging results, with the ministry reporting that the incidence of data quality issues for recently harvested areas has decreased from 11.3% to 1.4% over the last two years. These results are reflected in FLNRO's new performance measure that assesses improvement in the quality of data used for resource stewardship decisions."*

"We are encouraged by government's intent to fully implement this recommendation through its ongoing commitment to the 10-year plan."

The BC Special Committee on Timber Supply (2012) reported the results of their investigation into mid-term supplies had this to say about inventory updates:

"The dynamic changes taking place in the forest as a result of the mountain pine beetle epidemic are difficult to capture and account for in a cost-effective manner at the best of times. However, the task is made even more difficult during periods of budget instability."

"As noted earlier, several concerns about declining inventory efforts were expressed to the Committee during its consultations. Some of the concerns were simply characterized as being about the level of expenditure while others were more clearly focused on how weaknesses in the inventory create uncertainty about the overall state of the forest and about how to plan and account for changes to the forest. For example, as discussed above, what areas are no longer satisfactorily restocked and require treatment? Or, how can the Province accommodate emerging economic interests, such as the growing bio-economy sector, when there is uncertainty about how much of the forest is dead versus alive?"

"It is recognized that the forest inventory is used to establish or bring perspective to a broad range of important social, environmental, and economic forest management goals. Given that the mountain pine beetle epidemic is coming to an end, it is now vitally important to update the inventory in a cost-effective and timely manner to: support important decisions such as new allowable annual cut (AAC) determinations; to plan reforestation efforts; to assess the attainment of environmental and social objectives; and to evaluate new licenses that support demands from the forest sector, the emerging bio-economy sector and other fibre-based initiatives."

More specifically, the Committee recommends to the Legislative Assembly that the Ministry:

- *a) Prepare a position paper that:*
    - *a. States the purposes, uses and objectives of the forest inventories and the many important decisions that it supports; and*
    - *b. Assesses the strengths and weaknesses of the inventories in meeting their objectives, including their current utility in supporting management priorities and strategic forest-level management decisions that need to be taken in response to the beetle epidemic.*

- *b) Review and establish forest inventory priorities for the areas affected by the mountain pine beetle and develop realistic, cost-effective budget projections required to meet them.*

The Committee further recommends that based on the Ministry's review, the Province ensure that sufficient funding is provided to support the preparation of a five-year provincial inventory action plan that details how the program will meet provincial priorities, including consideration of the urgent issues emerging in the mountain pine beetle areas.

Many of the recommendations made in the report involved the use of forest inventory, including those related to land use monitoring, quantification of different forest types, allocations of wood supplies, growing more fibre and generating more value through silviculture practices, reducing fuels in the wildland-urban interface, assessing and classifying stands impacted by mountain pine beetle, rehabilitating and reforesting mountain pine beetle impacted stands, continuing the practice of Chief Forester AAC determination and harvesting of un-salvaged losses to facilitate harvesting in response to mountain pine beetle impacts. This demonstrates the importance of forest inventory to sound forest management in British Columbia.

In February, 2013, FLNR introduced its Forest Inventory Strategic Plan, this being the strategic plan under which it currently operates. The inventory program mission is stated as follows:

"The mission of the ministry's Forest Inventory Program is to produce reliable forest inventories and stand growth models so that natural resource management in British Columbia is informed by credible information on forest condition."

The plan identifies the following applications:

"The data and models produced by the Forest Inventory Program are used to characterize current, and forecast future, forest condition. This information is used in many settings including the analysis of fibre supply, evaluation of tenure options and business opportunities, simulation of forest carbon dynamics, design of silviculture regimes, timber harvest planning, state of forest reporting, habitat mapping, wildfire risk assessment, management of visual resources, biodiversity assessment, and much more."

The dominant factors affecting the development of the plan include:

- MPB and climate change: introducing uncertainty into growth rates, particularly of young stands in relation to mid-term timber supplies.
- The potential use of airborne Light Detection And Ranging (LiDAR), combined with other sources of imagery, including high resolution digital aerial photographs as a means of updating inventory production processes and content.
- Currency: One quarter of the data was less than 13 years old; another quarter was over 35 years old.
- Workforce and budget: It was noted that the budget increased from \$3.5 million in 2010/11 to \$7.5 million in 2012/13. A shift in funding source from the Forest Investment Account (FIA; managed under contract by Price Waterhouse and Coopers) to the Land Base Investment Program (LBIP) added substantial new project management responsibilities to the program. This was in addition to an

aging workforce, and the added workload associated with making a transition through retirement and recruiting and training processes.

- Program reviews: These influenced the course of development of the strategic plan.

The strategy then refers to an expanded vision (paraphrased):

1) Natural resource management is informed by reliable forest inventory and stand growth models.

2) Forest inventory that is current, complete, reliable, accessible, and relevant that provide information on the status, trends, and condition of BC's forests as well as the capability to forecast future condition under alternative scenarios.

3) The ministry's Forest Inventory Program engages and communicates with stakeholders, and collaborates with partners in project delivery. It is efficient, effective, high performing, innovate, and adopts new technology and methods.

Strategies are identified for obtaining the vision. These include continuing the risk-management approach for determining those forest inventory areas that are the highest priority for attention as a basis for underwriting forest management decision-making. Specific 5- and 10-year targets were set to obtain 9 different goals within 10-years:

1) Update the inventory for all depletions and disturbances.

2) Produce new VRI for MPB-affected areas and other priority areas.

3) Ensure all forest inventory is less than 30-years old.

4) Provide interim inventory information on demand for critical areas.

5) Use low cost, innovative methods to provide forest inventory information for appropriate areas.

6) Monitor stand growth and change throughout the province.

7) Ensure that forest inventory is verified and supplemented with ground sample plots.

8) Reliable stand growth models for all significant conditions.

9) Complete the forest inventory coverage province wide.

The plan cites the need for four new staff to reach a complement of 32 inventory program staff, and an average of $8 million per year for the 10-year duration of the strategy. It committed the ministry to monitoring its own performance relative to the actual targets identified in relation to the 9 goals mentioned above.

As of 2014, the status of British Columbia's forest inventory is summarized as follows (BCFLNRO, 2015; this report includes maps of the various coverages):

- Twenty seven percent of the inventory was less than 10-years old, 74 % less than 30-years old, and 17% greater than 41-years old, with the oldest inventories representing the Cassiar and western Fort Nelson TSAs.
- Considering the Timber Harvesting Land Base (THLB), 60% of the area conforms to the VRI standard.
- Gaps in coverage represent approximately 5% of the area and progress was being made in closing these gaps.
- Areas were highlighted where inventory was produced with the aid of Landsat or LiDAR illustrating innovation within the Program.

With respect to ground sampling the following activities were highlighted:

- Since the development in the mid-1990s, 6778 five-point VRI phase II ground samples were established under 89 VRI ground-sampling projects.
- In the mid-2000s, 268 National Forest Inventory (NFI) ground samples were established on a subsample of the 20 km x 20 km grid.
- Two hundred and forty-six (246) Change Monitoring Inventory (CMI) plots were added to the 20 km x 20 km grid; these fixed radius plots are the same as NFI plots, but without soil sampling and other detailed, non-timber measurements. Additional sampling was scheduled to complete coverage across the central and southern interior of BC.
- Seven hundred and thirteen (713) Young Stand Monitoring plots were established to date.

With respect to the acquisition and use of imagery:

- In a typical year three to four million hectares of new photography is required.
- Each year the inventory program downloads, processes and makes available Landsat satellite imagery for the entire province. The imagery is used to update the provincial forest inventory for wildfire, detect newly harvested areas, assist with ground sample planning, and provide quality assurance on silviculture data as it is integrated into the provincial inventory.

With respect to special products the following were identified:

- Harvest change detection: this is done in combination with satellite imagery (Landsat) and can provide an early indication of where harvesting has occurred prior to receiving records from licensees.
- Site index mapping: This is made of Terrestrial Ecosystem Mapping (TEM), Predictive Ecosystem Mapping (PEM), and Site Index Biogeoclimatic Ecosystem Classification (SIBEC) that provides a database that establishes a relationship between site series and site indices associated with various species growing in those site series.
- NFI photo samples: There are 2414 2x2 km photo samples established on a 20 km grid that were established in the mid-2000s. Each year, the ministry transfers the new aerial photography that it has purchased to the federal government for updating the NFI photo-sample database.

Conclusion

The forest inventory is more than a dataset that can be used to help plan and manage BC forests. It is the central piece of information that enables us to exert an influence on forest landscapes and in so doing, obtain certain benefits. It provides feedback to determine if we are on the right track, if we succeeded in obtaining the desired outcomes, and if not, what to do about it. It is a tool to help anticipate reasonably possible future forest conditions, and in so doing make better decisions with respect to the potential for reward versus regret. It is also a central piece of information necessary to help the Chief Forester make AAC determinations with consideration for the management of all resource values associated with each forested landscape. Finally, it is critical to the conduct of good professional practice precisely because it is so difficult to see the forest for the trees, particularly when we are standing amongst them when doing our work in the field, and in so doing be able to consider the potential and probable impacts of our decisions at multiple scales.

One of the lessons of history is that the inventory has not always been attended by equal regard. People have despaired that it is too expensive to obtain the levels of reliability needed in an inventory to support the conduct of forest operations, except on the broadest of scales. One solution has been "to cut the baby in half" with one half – the inventory half – allocated for strategic purposes, and the other half - cruising and silviculture surveys - for operational purposes. This solution is done with a high level of faith that what is done operationally, will indeed match with what we said should be done from a strategic point of view.

The other lesson is that there are at least some who think the first lesson is wrong. This is particularly so when it comes to considerations of investments in silviculture, and/or the need to better account for species habitat; or where stands are so complex that we have difficulty comprehending landscapes even when we have been associated with them for a long time. The "baby cannot be cut in half." The belief that the sum of the parts will add up to the whole is mere faith unsubstantiated by data, and there is a sense that this form of dyslexia may be (if it is not already) driving us to place where we do not what to be – "into a cul-de-sac with no easy way out."

Those with more level heads might think it somewhere in between. It can be difficult to resolve the situation under these circumstances. We are often confronted with a state of ignorance. We can choose to try to resolve it, or not.

These two extreme views of the inventory world have found their way into various forest commissions and reviews of forest management practice and policy review over the years, sometimes raised up to crescendo in demands for more and better outcomes, and sometimes falling to pianissimo, perhaps with an opening that can be exploited by particular interest groups, when people are worn out with the discussion and attention is redirected toward other, more fruitful (sometimes misleading?) endeavors.

The real answer probably lies at both extremes and somewhere in between depending on where we are on the map. In some areas we really do need better information to help make informed decisions given the level and variety of demands and the rapidly changing nature of the forest and stand conditions that we see. There are also new opportunities that might help us find our way, including the use of LiDAR and the increasing availability of various kinds of satellite imagery. Still these are not solutions in of themselves; we need to continue to observe, measure, and evaluate ground-level changes in stand characteristics with time, because reality is stranger than fiction. To make maximum use of remote sensing tools we need to connect what we see on the ground with what can be seen within the forest-as-a-whole. Where there is demand for better, more reliable, and perhaps more expensive solutions, we need to have access to adequate resources, tools, and training so that we can meet those demands.

The challenge for the panel is to provide some guidance as to what the demand is, where the priorities are likely to be found, and to make some recommendations to ensure that this inventory ship is on an upright keel and headed in the direction we wish to go.

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Appendix 6: Improving Communications and Training

A component of the FAIB vision is:

> *"The ministry's Forest Inventory Program engages and communicates with stakeholders, and collaborates with partners in project delivery."*

Confidence in the forest inventory and achieving the vision requires:

- Users and interested parties (e.g., public laypersons) to be aware of the available data and information and have knowledge regarding how it can be used and its limitations,
- Government and external to Government decision-makers to be acutely aware of the importance of the inventory in decision-making across Government, industry and Crown Corporations, and
- Forest practitioners to be informed, through comprehensive training, of the various parts of the inventory and how to use it.

Current situation

The overall FAIB resourcing is at a low level. Consequently priorities need to be established and although communications and training are recognized as being important, they tend to be limited to the absolute minimum resourcing to deliver on the FAIB goals. This has resulted in communications consisting mainly of posting inventory data and information on the FAIB website and in some cases making interested parties aware of the posting(s). Frequently, no formal follow-up occurs other than through the limited training sessions conducted by FAIB and/or the Association of BC Forest Professionals (ABCFP). However, FAIB does respond to specific requests, provided resources are available to do so.

Lack of public understanding of the inventory appears frequently to be the reason for questioning the reliability of the inventory. This is usually associated with the Forest Inventory Program critics questioning the inadequacy of the accuracy of the inventory and thus the products (e.g., TSR, yield projections) that use the inventory data. It appears the public is not aware the inventory has been developed for strategic level decision-making and not to address operational issues which tend to be of most interest to them.

FAIB provides technical training in several areas as resources allow, including:

- Contractors, licensees and staff regarding inventory methods,
- Forest professionals, in collaboration with the ABCFP, regarding the content of the inventory and its uses, and

- Internal capacity to accommodate attrition and succession.

FAIB communicates with the public regarding the inventory as part of the delivery of processes and products that utilize inventory data and information. There is little or no direct communications with the public to assist them in understanding the inventory, its uses and limitations.

FAIB provides public and user access to the inventory but with some instances restrictions are involved as required under data sharing agreements with the owner of the inventory data.

User input

Overall, communications and data access was the sixth highest issue identified through the Panel interviews and submissions. This is an important issue for users and the public both from the perspectives of usefulness of the inventory data and analysis and the program credibility with the public.

Training was identified as the tenth highest issue. Although this issue is not a top priority from a user perspective, it is a major factor in maintaining a forest inventory of high value in achieving well managed forests. Internally within FAIB, this is a critical issue relative to succession and incorporation of new technologies, given the projected number of retirees over the next several years and the expectation of incorporating new technologies into the FAIB programs.

The Panel interviews and submissions identified a greater need for:

- Standardization of forest inventory terminology and communicating it to forest and other professional users and the public,
- Increased opportunity for forest professionals and interested public in the understanding what is in the inventory, its uses and limitations,
- Clarity among FAIB staff as to how each job contributes to the Branch's vision to build pride in the organization, and
- Improved access and transparency to all inventory data and information.

Proposed improvement actions

- Increase resourcing for communications and training to meet user and public needs by:
    - Increasing government decision-makers awareness of the importance of the inventory as part of many decisions across government, industry and Crown corporations and the associated economic, environmental and social benefits,
- Improve communications with forest and other professional users and the public by:
    - Announcing availability of new or updated products on social media, and

    - Improving access and transparency to the inventory data and information through making previously constrained data and information accessible on-line for use by the public and forest and other professional users
- Improve public education regarding the forest inventory by:
    - Developing a short (<3 minute) video for laypersons to explain the inventory program and its uses,
    - Developing, with Partner K-12 student education organizations, a short (<2 minute) video explaining forest inventory and its uses to build general knowledge capacity, and
    - Developing brochures for public distribution at events that explain each component of the inventory.
- Maintain and increase a qualified workforce by:
    - Focusing on training for an internal (FAIB) and contractor community workforce to address attrition and succession in the workforce,
    - Building and implementing, in partnership with the ABCFP, industry and other professional inventory users, a comprehensive forest professionals training package that includes understanding what is in the forest inventory, its uses and limitations, and
    - Continuing to provide professional accreditation training for staff, contractors and user professionals.

Appendix 7: Forest Inventory Collaborative Support Groups

The Chief Forester has the responsibility to advise government and inform the public on Sustainable Forest Management. Users identified a desire to have more say in the inputs and outputs of the Forest Inventory Program necessary to meet their needs. Officially integrating support groups in key areas into the policy, planning and program implementation of the FAIB would address this issue.

It is proposed there be three (3) cooperative support groups created to ensure the FAIB inventory program meets user, including government, needs but with the FLNR maintaining the overall responsibility for Crown lands.

1) Independent Forest Inventory Review
2) Forest Inventory Technical Advisory Group
3) Growth and Yield Partnership

Independent Forest Inventory Review

The proposed concept is the *Forest Practices Board* (FPB) mandate be expanded to include providing independent advice regarding:

- FAIB progress to delivering a strategic plan that addresses user issues and progress in meeting user needs, and
- Resourcing (staffing and funding) required to deliver the FAIB strategic plan.

The FPB would conduct assessments based on audits, review recommendations from the *Forest Inventory Technical Advisory Group* and the *Growth and Yield Partnership,* and include periodic review of inventory protocols and requirements.

This model would capitalize on the FPB's positive public reputation of an independent voice and their audit expertise. Government would benefit from the administrative infrastructure costs already within the FPB and the FAIB would benefit from the independent advice.

Forest Inventory Technical Advisory Group

Although it is proposed government retains the responsibility for establishing the standards for each type of forest inventory data collection, the proposed concept is a *Forest Inventory Technical Advisory Group,* reporting to the Chief Forester, be established under a Memorandum of Understanding (MoU) between the primary users of the forest inventory, including FLNR. The MoU would be based on a jointly held view and commitment of delivering a forest inventory that meets the current and projected future needs of users and the Province. Meeting the forest inventory criteria and government adopted recommendations outlined by the Forest Inventory Review Panel would be the basis for evaluating proposed actions and decision-making. The MoU would include the principles of operation, meeting timing and frequency, etc.

Mandate

The mandate would be to provide advice to FAIB in:

- Developing and implementing an innovative Forest Inventory Program that delivers, at a high and innovative level, the required information and data to meet user needs within the criteria outlined by the Review Panel,
- Establishing forest inventory data collection standards to meet government and user forest inventory needs,
- Identifying areas of the Province where the quality of the forest inventory requires upgrading to better underwrite the level of inventory decided upon by FAIB,
- Establishing inventory data collection and management programs to provide information to respond to natural disturbances and climate change,
- Identifying opportunities to integrate silviculture surveys and standards with the requirements of data collection to efficiently and effectively support the forest inventory and Growth and Yield programs,
- Identifying new technologies that would assist in improving efficiencies and effectiveness in data collection, distribution and analysis,
- Conducting communications to interested parties (professionals and laypersons) regarding the forest inventory,

- Establishing and implementation of forest professionals' training programs for priority aspects of the forest inventory data collection, analysis and applications, and
- Acquiring expert advice on topics identified in delivery of the mandate items above.

Membership

The membership would include forest inventory expertise representation from:

- Government, including FAIB, BCTS and Ministry of Environment users,
- The forest industry, including a member from each of the coastal and interior TFL licensees and each TSA Association,
- The perspective of First Nations forest companies,
- The forest mensuration and biometrics research community (academia and government),
- The perspective of the forest inventory consulting community.

The funding and secretarial support for the *Technical Advisory Group* and the required actions to deliver the mandate would be borne by government throughout the life of the *Technical Advisory Group*. An accomplished facilitator with a reputation of independence and knowledge about the forest inventory should be retained to facilitate the *Technical Advisory Group* discussions and meetings.

Growth and Yield Partnership

A sound and innovative Growth and Yield Program is critical in the ability to provide the forecast projections essential for well-managed forests. A *Growth and Yield Partnership* should be considered. The concept includes government taking a leading role in investigating and establishing, if supported by key parties, such a partnership. The conceptual framework for the *Partnership* is intended to:

- Be sustainable over the long-term,
- Encourage companies or organizations to participate,
- Be organized with the principles of cooperation,
- Focus on user and provincial needs,
- Support the FAIB Growth and Yield Program,
- Encourage the understanding of growth and yield as a foundation for forest management, and
- Provide the necessary multi-year funding for sustainability of Growth and Yield research and projection model development.

Growth and Yield programs are long-term and need to be established to provide sustainability. This can be best achieved if the key Parties (i.e., government and forest companies) are committed and actively involved in the Program and the resourcing mechanisms can withstand economic environmental changes.

A BC Growth and Yield Program is a critical component in realizing the full benefits of the forest asset to the government, communities and industry over the long-term. It takes leadership by both key Parties to work as a team, create and be committed to the essential mechanisms. The following is a proposed *Partnership* concept to achieve the benefits.

Mandate

The Partnership is not a Collaborative but adopts the concept of collaboration to assist FAIB in:

- Providing support for the Growth and Yield Program,
- Providing stable Growth and Yield Program funding including capitalizing on leverage funding opportunities for developing priority growth and yield model development, and
- Establishing a mechanism that demonstrates the Province and industry see value in a long-term Growth and Yield Program.

The *Partnership* mandate would be to report to the Chief Forester and work as a team with a focus on current and long-term specific user and provincial issues and associated priority needs, including:

- Identifying specific issues and priority user and provincial needs requiring research and model development to address the issue(s),
- Receiving input from the *Forest Inventory Technical Advisory Group* and results arising from the independent Forest Practices Board reviews as they relate to the Growth and Yield Program,
- Working in collaboration with the *Forest Inventory Technical Advisory Group* to efficiently and effectively develop and implement a growth and yield data collection and projection system that is responsive to user needs, natural disturbances and climate change,
- Developing a strategic research plan to address the user issue(s) and needs,
- Prioritizing Growth and Yield research projects with an emphasis on:
    - User and provincial issues and needs,
    - Obtaining the required field data to conduct the priority research,
    - Obtaining funding leverage,
    - Stand projection model development, and
    - Testing of new technologies for data collection,
- Soliciting advice from Growth and Yield experts regarding priorities and other matters requiring their expertise,

- Developing a peer review proposal process that involves experts, not involved in BC Growth and Yield research and model development,
- Requiring project proposals to include a plan to communicate results, interpretations and training to users and interested parties, and
- Recommending to the Chief Forester projects requiring government funding.

Funding

The Growth and Yield research and projection model development funding is expected to come from three (3) primary sources:

- Government – stumpage allocation,
- Industry – company specific contributions, including in-kind data acquisition contributions, and
- Research funding organizations – leverage funding.

The proposed model would include government increasing stumpage as a means of acquiring the necessary funding for the *Partnership* program. Industry costs associated with Growth and Yield data collection, research and model development that benefit government and industry as a whole would be eligible for stumpage credits against the company stumpage contribution up to a maximum based on AAC allocations. The maximum per cubic metre of AAC would reflect the benefits of the Growth and Yield Program to the companies. In instances where a company is not prepared to invest in the research, the full stumpage increase would be borne by the company. Company Growth and Yield activities that are specific to a company's management and thus other companies and government would not benefit, would not be eligible.

The increase in stumpage would be legislatively directed to the Growth and Yield research, data collection and model development to ensure sustainability of a program that has its greatest benefits involving long-term programs. The methodology would need to be consistent with the requirements of the Canada-US Softwood Lumber Agreement.

The magnitude of the stumpage increase would be determined by:

- Assessing the base level of long-term funding required to sustain the movement toward providing the necessary data and information required to achieve well managed forests in BC,
- Identifying the funds required to meet the priority research conducted by FAIB and the *Partnership*,
- Identifying the expected industry credits to stumpage, and
- Identifying the funds to obtain the data and information required to implement a strategic plan required to move toward achieving well-managed forests in BC.

The government funding would be provided to the Chief Forester for allocation based on recommendations from the *Partnership*.

The Growth and Yield and model development research proposals would be encouraged to use existing funding provided by the government as a lever to acquire additional funding from research funding organizations.

***Partnership* Composition**

The *Partnership* would be composed of Growth and Yield experts reflecting perspectives of:

- FAIB
- Forest companies
- First Nations forest managers
- Federal Government research organizations
- Universities and Colleges
- Climate change research organizations
- Forest professionals
- Consulting foresters

Members will be asked to commit to:

- Working collaboratively as a team of partners and not competitors to move toward providing data and information to support well-managed forests based on the criteria provided by the Forest Inventory Review Panel,
- Participating as an active member in the fulfillment and implementation of the mandate, and
- Determining the user and provincial priority issues and topics to drive the research.

Administration

The intent of the model is to keep administration of the Program at a minimum by the Chief Forester's office providing the following administrative support:

- Retaining an independent Chair of the *Partnership* with knowledge about growth and yield,
- Contract administration associated with successful proponent research organizations recommended by the *Partnership*, and
- Funds and secretarial support for the operations of the *Partnership*.

Appendix 8: Clarification Examples relative to User Input

The following are examples where the user comments do not reflect other relevant information or facts. The Panel has taken into consideration the user input but also the type of additional input into developing the recommendations.

Growth and Yield model issues

Participating users were in **major agreement** that either the model parameters or the scope associated with TASS, TIPSY or VDYP needs review or improvement. The most common concerns included:

User feedback:
Models provide inadequate projections for complex stands (multi-species, deciduous/coniferous, or uneven aged) and miss or substitute many species:

- *Especially for spruce-aspen mixes, and birch stands (northeast) and stand dynamics in the Interior Douglas Fir BEC Zone (IDF).*

Panel consideration:

- The Mixedwood Growth Model (MGM) has been developed for use in Alberta and has been applied in NE BC (see for example, Kabzems, R. and Delong, C. 2011. Will minor spruce components of boreal broadleaf stands replace themselves after clearcut harvesting? B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 063) https://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/TR063.pdf [accessed October 11, 2018]
- PrognosisBC is calibrated for use in Douglas-fir for many site series within the IDF, and is available through ESSA. https://essa.com/explore-essa/tools/fvsprognosis/ [accessed October 11, 2018]

User feedback:

- *Tree species may have site curves that have a biogeoclimatic dissimilarity.*

Panel consideration:

- It is recognized that site index can to some extent be explained by differences in site series (e.g. SIBEC). Given that this is the case, this statement may be interpreted to mean that the shapes and scales of top height versus age curves are expected to be different in relation to differences in BEC zone, and/or other levels of site differentiation (e.g. site association).

Attribution issues

Participating users were in **major agreement** that inventory attributes need to be improved, including issues related to the integrity of data inputs into the inventory. The most common concerns included:

User feedback:
Concern regarding age class breaks and definitions

- *Age is a significant attribute used in a wide variety of analyses (wildlife, biodiversity, hydrology, wildfire risks etc.), the data may be poorly populated (i.e. there are missing data) in some units.*

Panel considerations:

- Regarding age attributes, the VRI standard estimates age of the stand to the nearest year relative to the time of origin. See P. 65 of the 2018 VRI photo interpretation procedures. The previous Forest Cover (FC) inventory standard assigned ages based on 20-year age classes up to 140 years, with the remaining classes as follows: 141-250, and 251+ (defined in terms of age classes 1 to 9). Stand age is a very difficult number to assess at the best of times, even when standing in the field in stands other than those that would be classified as "plantation" (for example, see Wong, C.M. and Lertzman, K.P. 2001. Errors in estimating tree age: implications for studies of stand dynamics. Canadian Journal of Forest Research, 31:1262-1271.)

User feedback:

- *Many attributes are not populated, too difficult to reliably populate, not needed for users, are based on other mapping programs and consequently not updated (e.g., BEC mapping), or there are surrogate and independent products (e.g., SNR/SMR from ecosystem mapping).*

Panel considerations:

- Regarding outdated attributes, sometimes a classification has been updated but corresponding changes to mapping have not been made, and as a result, there is uncertainty as to what version of the classification was used to produce the map, increasing the likelihood of misinterpretation. This can be significant, for example, when using site series classification to assign site indices.

User feedback:

- *Biomass estimations from VDYP7 are not based on measured stand conditions and are therefore less useful for fuel management planning.*

Panel considerations:

- Regarding biomass estimations, VDYP7 is a model that was developed using ground plot data for calibration and testing purposes. The statement implies that the estimates derived from the model, in combination with the Vegetation Resource Inventory polygon attributes are not sufficiently reliable for use in fuel management planning.

Continue to develop and refine enhanced forest inventory methods

Participating users were in **major agreement** that the province should broaden its use of proven technology and methods to enhance the forest inventory. The most common solutions included:

User feedback:
The Forest Inventory Program should develop baseline acquisition standards for LiDAR.
Panel considerations:
See GEO BC (2017) specifications for LiDAR for the Province of British Columbia; https://www2.gov.bc.ca/assets/gov/data/geographic/digital-imagery/geobc_lidar_specifications.pdf [accessed October 11, 2018]

Communications/Data access

Participating users were in **moderate agreement** there are issues related to the dissemination of information from the Forest Inventory Program. The most common comments included:

User feedback:

- *There is limited documentation and/or extension for the access, intended use and limitations of the forest inventory or analytical products from the program.*

Panel considerations:

- See Sandvoss, M., McClymont, B., and Farnden, C. 2005. A user's guide to the Vegetation Resources Inventory. Timberline Forest Inventory Consultants, Prince George, BC. https://www.for.gov.bc.ca/hfd/library/documents/bib106996.pdf [accessed October 12, 2018]

Update issues

Participating users were in **moderate agreement** that there were problems with the annual inventory updates. The most common concerns included:

User feedback:

- *Generalization of silviculture records (RESULTS) when brought into the inventory:*
    - *Blending polygons to the block level (versus "standard unit" level) introduces avoidable errors such as generalizing species composition, over/under estimating species components, losing complex stand structural data such as mature retention areas being recorded as depleted, or depleted units being recorded as mature.*

Panel considerations:

- The current procedure used by FAIB is to assign the attributes associated with the largest stratum in RESULTS to each cutblock as a whole. This was deemed necessary due to difficulties in reconciling RESULTS stratum-level linework with cutblock boundaries identified in the inventory (pers. Comm., FAIB Staff, 2018).

User feedback:

- *Effects from natural disturbance, namely Mountain Pine Beetle and fire, are too slow for effectual planning (volume recovery) responses.*

Panel considerations:

- With respect to the 2017 fires, see the February, 2018 assessment of "Impacts of 2017 fires on Timber Supply in the Cariboo Region." https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/impacts_2017_fires.pdf [accessed October 11, 2018] The importance of rapid response has at least recently been recognized by FAIB, particularly where events have occurred on a large scale.

Uncertainty in innovation

Participating users were in **minor agreement** that a lack of certainty in technological advancements impedes the BC Forest Inventory Program. Some common concerns included:

User feedback:

- *LiDAR provides a basis for more reliable estimation of heights, basal area, volume, and biomass but the general consensus is that it does not, by itself, provide reliable information on ages or species composition.*

Panel considerations:

- For a comprehensive review, see White, J.C., Coops, N.C., Wulder, M.A., Vastaranta, M., Hilker, T., and Tompalski, P. 2016. Remote sensing technologies for enhancing inventories: A review. Canadian Journal of Remote Sensing, 42: 619-641.

User feedback:

- *New remotely sensed technologies (such as digital air photogrammetry) should contribute to computer-aided interpretation standards or automatable attribution, but there is seemingly reluctance among interpreters and policy makers to make the changes.*

Panel considerations:

- This statement deserves a rejoinder as to at least one possible reason as to why this might be. The introduction of change takes dedicated time, money, training, resourcefulness, and a deliberate sense of where the organization wants to be, by when, in order to introduce substantive change. It requires a methodical approach that ensures steady progress, rather than charging ahead with perceived solutions to one set of problems, only to discover new ones that more than offset any benefits accrued. It requires that inventory be maintained as system while changes are being introduced. VRI took approximately 4-years and substantial additional resources to develop as a substitute for the previously established Forest Cover (FC) inventory protocol. Additional development and changes in infrastructure continued long afterward to better streamline the production, maintenance, and delivery processes.

User feedback:

- *There is such a wide range of new remotely sensed data, kinds of sensors, data processing and analysis techniques, and data applications, such that no one system configuration can be identified as being preferred in all situations.*

Panel considerations:

- What may be required is the ability to construct and maintain a toolbox that is capable of deployment in terms of rapid data processing, analyses, validation, and comparison of results in an effort to get to the best product for the purposes intended and in an effort to employ continuous improvement along the way.