Growth and Yield Monitoring: A Discussion Paper

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Growth and Yield Monitoring Task Force

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Executive Summary

This report was commissioned by the Growth and Yield Monitoring Task Force to provide a basis for discussion and the development of growth and yield monitoring objectives. The report focuses on the important issues surrounding growth and yield monitoring with the intent of providing a common understanding and starting point for those involved in the development of growth and yield monitoring programs. The key points discussed are:

1. Defining and distinguishing between different types of monitoring.
   - Forest monitoring is primarily an inventory function, that occurs at local, national and global scales. The main objectives focus on tracking the distribution, types and growth and yield of forests.
   - Forest management monitoring is the process of ensuring forest management practices meet existing legislation and standards. It occurs at all levels of management.
   - The Growth and Yield Monitoring Task Force defines "growth and yield monitoring" as: *"…the process of observing the growth and yield of a forest and comparing this with the predicted growth and yield of that forest to assess risk and uncertainty around predictions."* It may be more suitably called "checking growth and yield estimates and predictions".
2. Table 1 (page *) summarizes expressed growth and yield needs at the management unit and provincial level. It is proposed that research, not monitoring be the primary source of new information to meet these needs.
3. Existing programs that fit the definition of growth and yield monitoring include:
   - Inventory audits. This program is designed to answer the question "How good is the current inventory?".
   - Volume, decay and waste equation validation. New equations have been developed by BEC zone; these are currently being checked to ensure their applicability to specific areas of the province.
   - The Northern Interior Vegetation Management Association (NIVMA) has developed a monitoring protocol called TRENDS (Treatment Regime Evaluation - Numerical Decision Support). The overall goal of the TRENDS monitoring protocol is "… to provide an objective measure of the response of trees and stands to the silviculture prescriptions applied on the range of sites being managed." (NIVMA 1995). Strictly speaking the TRENDS protocol does not fit the current definition of growth and yield monitoring. The primary focus of this program is to obtain new growth and yield information. However, it could be argued that TRENDS, by providing feedback on current policies and guidelines, does meet, at least indirectly, the definition of growth and yield monitoring.
4. Related issues identified in discussions of growth and yield monitoring include:
   - The need to define the required accuracy for growth and yield estimates. Determination of acceptable error levels should be based on their impact on management decisions.

- It is important to distinguish between growth after treatment and response to a treatment. Growth after treatment is simply as stated. Response to a treatment is the difference between growth after treatment and how the treated stand would have grown without the treatment (it is the incremental difference). Information on growth after treatment can be obtained by sampling treated stands. Obtaining treatment responses requires controls and randomization and replication of treatment application.
- A growth and yield monitoring program should be viewed as one component of an overall growth and yield information system. As such steps should be taken towards the development of a coordinated growth and yield strategy that specifies what information is needed and how it is going to be obtained.

5. What growth and yield information should be monitored? In order to answer this question we need to determine where having incorrect growth and yield information would have the biggest impact. Examples include:
   - Information used to determine allowable cuts. The inventory audit procedure provides a check of existing inventory information. A next step could be to develop a program to check projections of analysis units used in timber supply analysis.
   - Site index is the major driving variable in most growth and yield models. Changes in site index can have large implications in terms of growth and yield projections.
   - Ensuring that operational stands are growing as expected, particularly following significant expenditures on treatments.
   - Information used to project the growth of partially cut and mixed species stands.

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1. Introduction

1.1. Background

The Growth and Yield Monitoring Task Force, formed in May 1996, has been charged with the development of a provincially coordinated growth and yield monitoring program. In order to complete this task the first major step required is the development of an agreed upon set of objectives for a growth and yield monitoring program. In order to reach this step the Task Force must first identify and understand the many issues surrounding the topic of growth and yield monitoring. With well-defined objectives in place, the Task Force can then proceed with the second phase of its mandate, the development of a framework for a provincially coordinated growth and yield monitoring program.

1.2. Objectives

The goal of this report is to provide information on the issues surrounding growth and yield monitoring. This is done to form a basis for the development of growth and yield monitoring program objectives. Specifically this will be done by meeting the following objectives:

1. Illustrate how growth and yield monitoring, as currently defined by the Task force, differs from other types of monitoring.
2. Summarize growth and yield information needs at a management unit, provincial, national and global scale to:
   a) Show the linkages between growth and yield information needs within and between the various levels of management.
   b) Identify the needs that could possibly be met with a growth and yield monitoring program.
   c) Identify the needs that can not be met with a growth and yield monitoring program.
3. Identify existing programs that:
   a) a new growth and yield monitoring program could potentially have linkages to, and/or
   b) fit the current definition of growth and yield monitoring.
4. Identify the issues raised in discussions of growth and yield monitoring.

2. Monitoring Defined

The verb "monitor" is a widely used and ambiguous term. Therefore, in any discussions on monitoring, it is imperative the monitoring objectives are well defined and clearly understood. The following section outlines the numerous ways the term "monitoring" is used in forest management. The aim is to clarify and make clear the distinctions between different types of monitoring.

Webster's dictionary defines the verb "monitor" as:

- "to watch, observe, or check especially for a special purpose"
- "to keep track of, regulate, or control the operation (as a machine or process)".

Within forest management there are two general ways in which the term monitoring is used. These are:

a) forest monitoring, and
b) forest management monitoring.

2.1. Forest Monitoring

Forest monitoring is primarily an inventory function. This occurs at local, national and global scales. The main objectives focus on tracking the distribution, types and growth and yield of forests. The data collected is used for forest management planning, decision-making and policy development.

IUFRO (1994) has developed international guidelines for forest monitoring. The purpose of the guidelines is to promote standardized or compatible collection of certain data that will allow the development of a common data base for research and management. IUFRO (1994) provided the following definition of forest monitoring:

> "*The periodic measurement or observation of selected physical, chemical, and biological parameters for establishing baselines and for detecting and quantifying changes over time*."

Under this definition, forest monitoring is done to provide information for land management, timber production, energy use, carbon balance, and ecosystem management. It is stressed that at any level of forest monitoring the information needs assessment should be the first step. It is critical to establish the purpose of the monitoring, what needs to be inferred from the collected information and who will use the results.

Note that the IUFRO definition is very broad in scope and at a local level could conceivably encompass all growth and yield data collection. The question becomes whether or not the "*periodic measurements*" are done within a sampling design or an experimental design. In most instances, forest monitoring is done via the sampling of a specified target population. It is done to determine the current state of the population and to track its changes over time.

Experimental designs are used to determine how a certain population responds to treatments. Sampling is used to estimate population parameters. Problems can often arise when trying to infer treatment effects by sampling treated and untreated portions of the population. This is because: a) operationally treatments are not applied randomly so growth after treatment is confounded with site and initial stand conditions; b) there are high levels of variability in the operational forest; and c) in most cases pre-treatment measurements, critical to understanding the effect of the treatment, are not obtained. As a result, sampling or monitoring of a specific population will often not be the best way to obtain information on treatment response.

The remainder of this section provides an overview of some existing forest monitoring programs.

2.1.1. British Columbia Vegetation Resource Inventory

The new B.C. Vegetation Resource Inventory can be considered forest monitoring. The inventory has two major objectives:

1. To determine how much of a given characteristic (e.g. volume of trees or coarse woody debris) is within B.C.
2. To determine where exactly this material exists (Resources Inventory Committee 1995).

The inventory will provide information for research, resource identification and large scale planning.

The new inventory procedure consists of two phases. In the first phase, polygons are delineated on aerial photographs and polygon values are estimated. In the second phase a sample of polygons is selected with probability proportional to area and re-locatable ground plots are established at randomly chosen grid points within the chosen polygons. A relationship is then established between the photo estimates and ground sample information. This relationship is then used to adjust photo estimates so that the totals of all the adjusted polygon estimates will be correct. Over time the inventory values are projected forward to keep them current. Eventually a re-inventory is done when existing projections and updates of the inventory are deemed unacceptable.

2.1.2. B.C. Forest Damage Appraisal Strategy

Quantification of forest damage is a critical component in the accurate estimation of forest productivity. Monitoring the damage incidence, severity and intensity of pest damage is an integral part of monitoring the state of the forest. The Forest Damage Appraisal Strategy for B.C. was endorsed by the Forest Productivity Councils in January 1995. The goals of the strategy are as follows (Beale 1994):

"A. Develop and maintain a forest pest inventory to the resolution required for intensive forest resources management.

B. Develop pest risk and stand hazard rating systems.

C. Develop pest damage appraisal methods, and a network of monitoring installations.

D. Develop forest growth models to predict forest productivity responses to pest damage under various management regimes, and to predict pest damage responses to stand level management regimes.
E. Develop inputs for forest modeling procedures in which the effects of pest inventory, risk and hazard, and damage are considered in the allocation of forest resources."

Exactly what objectives would be met by a network of monitoring installations (goal C) has not yet been clearly defined. Stated objectives referencing this goal include development of a pest-damaged treated PSP matrix for stand and pest treatments. It is recognized that the type of pest-damaged PSPs and the size of the matrix are dependent on the model development strategy envisioned or already underway. Two modelling approaches currently used are stand growth models (e.g., Prognosis) and tree growth models (e.g., TASS - TIPSY).

2.1.3. Ecological Monitoring and Assessment Network (EMAN)

EMAN is a network run by Environment Canada to monitor and assess the environmental changes that are taking place in Canadian ecosystems.[1] It acts as a coordinating body bringing together universities, industry, non-government organizations and other government agencies. Its operating goal is to coordinate the monitoring and research activities at a network of specific sites across the country.

EMAN has considering getting into long term (and possibly extensive) monitoring activities. They define research and monitoring as follows:

Research is the endeavour to discover new knowledge or to reinterpret existing data, by critical study.

Monitoring is a system of continuous observation, measurement and evaluation for defined purposes.

Monitoring and research are generally iterative processes.

2.1.4. Proposed new national forest inventory - criteria and indicators for sustainable development

The National Forest Strategy, endorsed in 1995 by the Canadian Council of Forest Ministers (CCFM), commits the country to sustainable forest management. In order to document Canada's progress in achieving sustainable management, the CCFM agreed to report on six ecological, economic and social benefit criteria using 83 associated indicators (CCFM 1995). (Note that this is commonly referred to as the C&I initiative.) For example, one ecological criterion is ecosystem diversity and one indicator of this is the percentage and extent of area by forest type and age class. An example socio-economic criterion is contribution to the national economy and one indicator of this is the total employment in all forest sectors.

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[1] Reference: http://www.cciw.ca/eman-temp/

The criteria and indicators are intended to provide a framework for describing the state of Canadian forests and forest management. They can also be used to demonstrate that sustainable forest management is being practiced. The indicators are intended to provide information on trends or changes in the status of forests and related values over time. The information collected is not intended to assist in sustainable forest management at a local level, it is intended to provide a national overview.

A proposed new national inventory design has been developed that will provide information on several of the criteria that describe the state of Canadian forests. In other words, this inventory will monitor Canada's forests. (Information will also be collected by other methods for criteria that cover such things as the forest products industry, recreational use of the forest, sustainability of forest communities, and aboriginal and treaty rights.) Previously, the Canadian Forestry Service prepared a national report on Canada's forests ever five years by summarizing inventory data available from provincial, territorial and federal sources. However, it was very difficult to detect changes over time with this procedure. Successive reports varied due to changing standards, areas inventoried, and the time of inventories. (CFIC 1996).

The proposal is to base the national inventory on a two phase design. The first phase would consist of a grid of aerial photo plots across the country, possibly at a 20 km spacing. This could be re-photographed following a predetermined schedule to determine changes in vegetation cover. The second phase would be ground plots established at subsample of the first phase sample points. Vegetation volume and biomass data would be collected on the ground plots.

To coordinate national and provincial efforts, the current thinking is to use the national phase two sample points falling within B.C. as additional provincial phase two sample points. Depending on the design of the national plots, either data from them can be added to the provincial data or if it is not suitable, a provincial plot can be established at the same time at the same centre point. In either case, the plots established will be re-locatable.

2.1.5. Canadian Forest Service Forest Health Network

The Canadian Forest Service (CFS) is charged with reporting on, and predicting the future status of, the health of Canada's forests. The Forest Health Network (FHN) was established to monitor the health of Canada's forests and conduct research on the effects of threats such as climate change, air pollution, and loss of biodiversity (CFS 1996). In doing this the FHN will provide information necessary to support the C&I initiative. The mission of the FHN is

> *"To be the national focus for research, monitoring, interpretation, and reporting of changes in the health of Canada's forests."*

The aim is to accomplish this by having a national monitoring system and research program that is coordinated with other provincial, national and international ecological monitoring and research networks (for example B.C. Forest Damage Appraisal Strategy and EMAN). A stated milestone is to "Determine the number of plots required and establish an enhanced and expanded national forest health plot network to monitor and predict changes in forest health by March 1999." (CFS 1996). This work will be done in collaboration with the development and establishment of the proposed national forest inventory. It is expected that a portion of the FHN plots will be co-located with national inventory plots and that selected forest health indicators will be measured at all inventory plots.

ARNEWS (Acid Rain Network of Early Warning Sites) is now part of the Forest Health Network. This intent is to enhance this system to address issues such as biodiversity and climate change.

2.1.6. USDA Forest Service Forest Inventory and Analysis Program

The role of the USDA Forest Service Forest Inventory and Analysis Program (FIA) is often stated as inventory, analysis and monitoring. Their mission is to improve the understanding and management of the U.S. forests by maintaining a comprehensive inventory of the status and trends of the diverse forest ecosystems, their use, and their health.[2] This is forest monitoring. They observe and record changes in the U.S. forests via a large network of PSPs that are re-sampled on an on-going basis.

2.1.7.VEGETATION Programme

This new program is managed by the Joint Research Centre of the European Community. It is expected to be operational at the end of 1997 or beginning of 1998. It is an example of global forest monitoring. Its objective is daily monitoring of the state of terrestrial vegetation cover through remote sensing, at regional and global levels. With a resolution of 1 km it will not provide information for local management.[3]

2.2. Forest Management Monitoring

Forest management monitoring is the process of ensuring forest management practices meet existing legislation and standards. It occurs at all levels of management. For example, a B.C. registered professional forester must monitor the work of his or her staff to ensure that it is carried out to specified standards. At the other end of the spectrum, the Canadian federal government has committed Canada to sustainable forest management and must monitor the overall management of the nation's forests. The following are examples of forest management monitoring systems.

2.2.1. B.C. Ministry of Forests Quality Assurance Framework

This framework has been designed to meet the needs for an internal Forest Practices Code compliance assessment and to determine the effectiveness of the ministry in discharging its

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2 Reference: http://rredc.nrel.gov/biomass/forest/forest_ov/forest.html

3 Reference: http://www-vegetation.cst.cnes.fr:8050/vgthmpg.htlm

regulatory obligations. Four broad expectations have been identified for the quality assurance framework (MOF 1996):

"1. Act as an incentive and, to some extent, a deterrent for obligation holders to conduct forest practices in accordance with the legislated requirements;
2. Facilitate the improvement of forest practices, including the regulatory framework governing these practices;
3. Provide the primary record of exercising due diligence by the ministry, and
4. Facilitate prediction of the future status of the forest resource based on the past level of success."

2.2.2. B.C. Forest Practices Board

The Forest Practices Board was created to monitor forest management practices in B.C. The Forest Practices Code of British Columbia Act requires that the Board undertake periodic independent audits to ensure forest practices are consistent with requirements under the code[4].

2.2.3. Canadian Standards Association's Sustainable Forest Management System Standards

The Canadian Standards Association Sustainable Forest Management (SFM) System Standards include requirements for conserving biological diversity, maintaining and enhancing forest ecosystems, conserving soil and water resources and providing multiple benefits to society. The goal of the SMF system, as stated in the Z808 standard, is to "maintain and enhance the log-term health of forest ecosystems, while providing environmental, economic, social and cultural opportunities for the benefit of both present and future generations."[5]. The SMF standards are consistent with ISO's generic 14001 Environmental Management System and additionally include requirements for:

1. adherence to the six ecological, economic and social benefit criteria for sustainable forest management presented by the Canadian Council of Forest Ministers
2. significant public input
3. development of local sustainable forest management criteria and indicators
4. independent audits to check field performance

Defined Forest Areas (DFAs) can be certified following the development of a comprehensive forest management plan and a successful independent audit by qualified and accredited auditors.

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[4] Reference: http://www.fpb.gov.bc.ca

[5] Reference: http//www.csa.ca

2.2.4. Operations Monitoring

At an operational level monitoring of practices takes place all the time. Examples include check cruising, water quality monitoring before, during and after fertilizer and herbicide applications, monitoring fertilizer applications, and post-treatment surveys to check the quality of the treatment application.

2.3. Link Between Forest Monitoring and Forest Management Monitoring

Ultimately the success or failure of forest management practices are reflected in the state of the forest. As a result, forest monitoring serves two roles. Firstly it provides information to base management decisions on, and secondly it provides a measure of the success of forest management practices.

2.4. Growth and Yield Monitoring

The Growth and Yield Monitoring Task Force defines "growth and yield monitoring" as:

"The process of observing the growth and yield of a forest and comparing this with the predicted growth and yield of that forest to assess risk and uncertainty around predictions."

Instead of growth and yield monitoring it may be more suitably called "checking growth and yield estimates and predictions".

Regardless of what it is called it is probably best referred to as a form of forest management monitoring that is carried out by monitoring the forest. Perhaps this is the root of the confusion surrounding growth and yield monitoring. It is not forest monitoring per se, because the primary objective is not to describe the state of the forest but rather to check existing estimates and predictions about the state of the forest.

The primary objective of a growth and yield monitoring program should be to identify growth and yield estimates with an error level large enough to significantly impact management decisions.

In the McWilliams and Thrower report (1994) growth and yield monitoring was defined as:

"The process of observing the growth and yield of a forest or stand and comparing this with the predicted or expected growth and yield of that forest or stand."

This definition was purposely narrow in scope to make clear the distinction between:

a) developing growth and yield estimates, and

b) providing an independent check of existing growth and yield estimates.

What was not made clear in this report is that following their initial use as an independent check, data from a growth and yield monitoring program could be used as interim measure to adjust growth and yield estimates and could be used as part of an augmented data set to develop new or modify existing growth and yield estimates. This point was made by Ian Moss in his review of the report (Moss 1994).

This does not mean however, that it is not important to distinguish between collecting data to develop growth and yield estimates and collecting data to check growth and yield estimates. This distinction is important because it can translate into different data collection strategies. For example, to establish the amount and distribution of timber volume we have developed detailed sampling procedures within the new vegetation inventory. To check existing timber volumes we have the inventory audit procedure. These are two different sampling strategies to answer two different questions. It is also important to recognize that after the audit plots have served their initial purpose they can be added to the set of inventory ground sample plots. Another way to recognize the distinction is to realize that alone, the audit plots are sufficient to answer the audit question, but alone they would not be sufficient for inventory purposes. They initially serve as an independent check and then subsequently can be used as part of the database for updating inventory information.

It is also important to note that a monitoring program should be designed to check the applicability of growth and yield estimates for a particular population, not to directly check the methodology for producing the estimates. This is because the populations that estimates are generated for are continually changing. The group of forests or stands for which we are trying to estimate growth and yield continually change with silviculture treatments, harvesting, pest impacts, and land withdrawals. The same methodology may work in one area, but not in another. For example one can not immediately assume that a model does not work because it produces incorrect estimates for a given area. The model likely works well in other areas and it is only the application of the model to a particular area that is inappropriate.

Other items to consider when developing a growth and yield monitoring program are the hypotheses as to why there may be problems in the systems being monitored. In doing this it may be possible to collect data that could help pinpoint where the problems are.

3. Growth and Yield Information Needs

The initial mandate of the Growth and Yield Monitoring Task Force is to identify and group provincial growth and yield needs to clearly illustrate what falls under the umbrella of growth and yield monitoring and what does not. In addition, Task Force members indicated they would like to have an overview of growth and yield needs at the global, nation and local (management unit and provincial) levels and potential linkages between these information needs.

3.1. Global, National and Local Needs

Growth and yield information is used at all levels of forest management for decision making and policy development. As the issues to be dealt with differ at the various management levels, so do the types and precision of growth and yield information needs. The following are examples of global, national and local forest management issues (IUFRO 1994).

Global issues: Commercial and non-commercial benefits, biodiversity, carbon cycles, bio-productivity, forest health, site protection, climate change, hydrology and water cycles.

National issues: Sustainable management, carbon cycles, rates of change of forest cover, forest quality and health.

Local issues: Commercial and non-commercial use of the forests, forest quality and health, management influences, growth rates of specific stand types.

The information needed to address these issues can be obtained by forest and environmental monitoring, by research programs, and by models developed to provide projections of future conditions.

In theory local data can be summarized to meet national information needs and in turn national information can be summarized to meet global needs. In practice this is often difficult to do for two reasons. First, local data is collected at different times and with different methodologies across the country making comparisons and compilation difficult. Second, information required at a higher level is not collected at the lower level. For example, information on climate change is not generally collected at a local level. For these reasons separate systems have often been developed to collect local, national and global information. This is not to say however that when developing new systems that any potential linkages should not be investigated. On the contrary, given the high cost of data collection, it is prudent to determine if any collaboration can be obtained. A good example of this is the proposal to use the new national inventory ground plots as ground plots within the new provincial vegetation inventory.

In developing a new growth and yield monitoring program in B.C., the national information needs to be aware of are those required to address the criteria and indicators agreed to by the Canadian Council of Forest Ministers. Several of these are being addressed by the proposed new national inventory so any linkages are likely to come via linkages to the new national inventory.

3.1.1. Provincial (B.C.) Growth and Yield Information Needs

Expressed growth and yield information needs at the management unit and provincial level are summarized in Table 1. It is purposed that growth and yield monitoring should not be the primary source of information to meet any of the needs listed in Table 1. In addition to the needs in Table 1, there have also been expressed needs for:

a) Improved methods of data storage and summary, so that collected data is more accessible to more people. For example, easier access to accurate and detailed stand history information, and better linkages between silviculture and inventory attributes.
b) Better communication between those developing growth and yield tools and those using the tools.

The information needs identified in Table 1 are those of the practitioners. The researchers or people charged with developing growth and yield information and tools also have information needs. These are primarily centered around data collection. To this end, growth and yield monitoring data should not be the primary source of data used to develop growth and yield information and tools to meet the needs identified in Table 1. Growth and yield monitoring data, after being used to check existing predictions, could be added to databases used to develop or modify information, but it should not be considered a primary source.

In order to meet any of the needs identified in Table 1 the following general steps are taken:

(The term "model" in the following is used in its broadest sense to represent anything from a single equation to an inventory design.)

1. Any existing information and models are reviewed to determine their utility.
2. A model is chosen.
3. Data required to develop the model is collected from existing sources and new sampling and/or experimental designs.
4. The model is developed.

Once a model exists the estimates or predictions from it can be monitored to determine if they are truly representative of the population of interest. In other words, once information exists to meet any of the information needs in Table 1, then growth and yield monitoring can be used as an independent check of the application of the growth and yield information.

Table 1. Summary of *expressed* growth and yield information needs at the management unit and provincial level.[6] Growth and yield monitoring data should not be the primary source of information to meet these needs, it may however be subsequently added to databases used to meet these needs.

Tree	Stand	Forest
1. Volume and taper equations that reflect: a) losses due to decay, waste and breakage, b) form changes due to varying treatments.	1. Accurate estimates of site quality. This includes: a) SI estimates from BEC b) SI estimates from growth intercepts, c) adjustment of old growth site indices d) site / height curves for all species	
2. BEC based stratification of volume and taper equations. 3. Net volume adjustments	2. Response to the full range of: a) stand establishment scenarios, b) incremental silviculture treatments, and c) harvesting options, including interactions between treatments, sites, species, timing of treatments and prior treatments. 3. Pest impacts on stand growth and yield including interactions with stand establishment, tending and harvesting treatments. 4. Economic analysis of stand management scenarios including analysis of wood quality and product recovery. 5. Information on all of the above incorporated into stand growth models. 6. Stand models that can grow from bare ground or user defined inputs. 7. Estimates of OAFS for stand models (localization of stand models). 8. Quantification of the difference in treatment response under research and operational conditions.	2. Management level inventory 3. Models to update inventories between re-inventories. 4. Long-term inventory projection models, including projections of successional change. 5. BEC based stratification of growth and yield projection. 6. Indices of habitat quality and biodiversity. 7. Growth and condition of non-commercial vegetation. 8. Quantity and distribution of coarse woody debris. 9. Predictions of stand attributes related to non-timber resources. 10. Projections of long-term cyclical damage caused by pests and fire. 11. Projections of long-term climatic influences.

6 Sources include the MOF Growth and Yield Program Strategy (Anon. 1995), McWilliams and Thrower 1994, and discussions with government, industry, and consulting foresters.

3.2. Overview of the Development and Uses of Growth and Yield Information at the Management Unit or Provincial Level and the Various Types of Monitoring

An overview of the development and uses of growth and yield information at the management unit or provincial level is shown in Figure 1. Management decisions can occur at the forest level (e.g., AAC determinations) and at the stand level (e.g., treatment selection). Each part of the process illustrated in this figure can be "monitored":

1. Inventory information, obtained via forest monitoring, can be checked to determine if it is accurate. (Inventory audits - a form of growth and yield monitoring.)
2. Data and inferences drawn from research installations can be checked for accuracy and applicability. This is done by reviewing the experimental design, the data analysis, and the interpretation of results. The peer review process, prior to funds being granted for research, and subsequently prior to publication of any information, is the primary way this is accomplished.
3. Prior to being used to develop growth and yield estimates and predictions, literature and published data can be reviewed to ensure its accuracy and utility.
4. Those using the growth and yield information in the decision making process can be checked to determine if they are using it correctly. Objective 3 (b) of the Growth and Yield Program Strategy states: "… ensuring that users use growth and yield information correctly and consistently across the ministry… This objective requires an internal audit process that provides mechanisms for monitoring the application of growth and yield information. " (Anon. 1995). Users outside the ministry can also be checked. This is a form of forest management monitoring.
5. The decision makers can be checked to determine if their decision making process follows legislation and established guidelines. (Forest management monitoring, e.g., Forest Practices audits, Ministry Quality Assurance Framework, CSA Sustainable Forest Management System Standards)
6. Management actions can be checked to determine if they were carried out as specified in all levels of planning documents. (Forest management monitoring, e.g., post - treatment silviculture surveys to check for contractor compliance, forest practices auditing or monitoring)
7. Operational data and observations can be checked to determine if they are accurate. (Forest management monitoring, e.g., auditing of silviculture surveys, check cruising)
8. Stand and forest level growth and yield can be measured to determine if it is being accurately represented by existing growth and yield estimates and predictions. (Growth and yield monitoring)

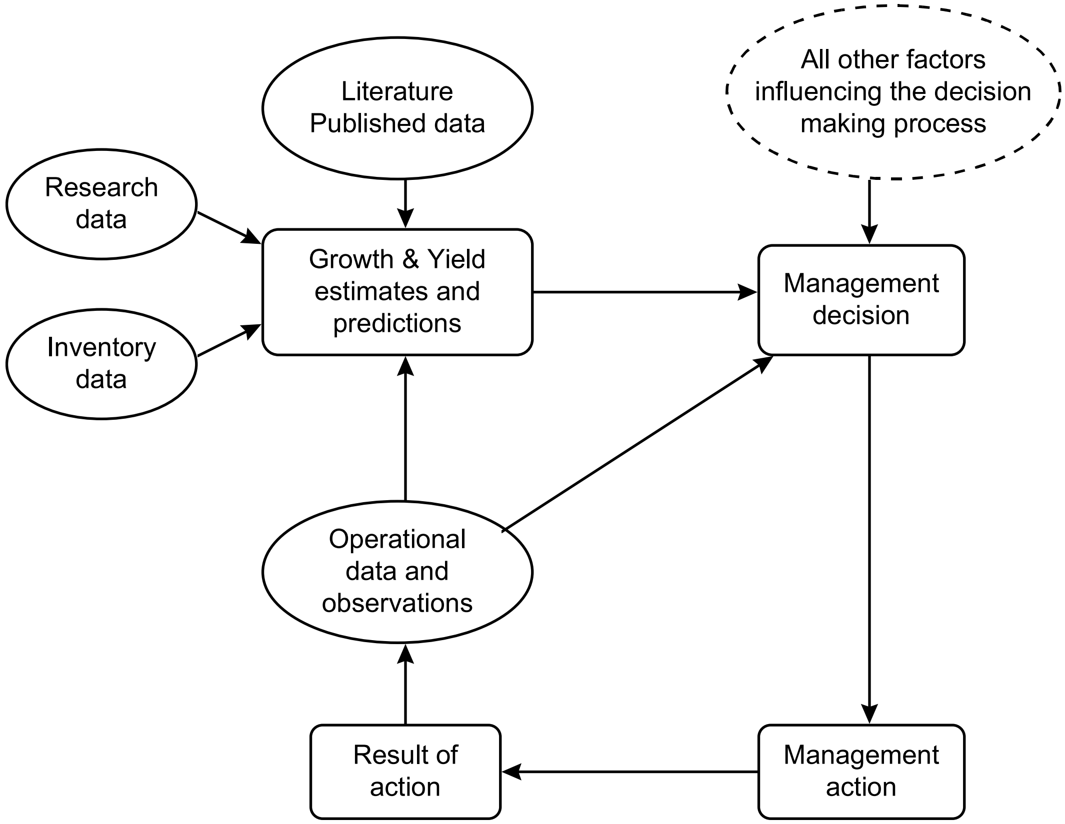

Figure 1. Overview of the development and uses of growth and yield information within a management unit or at the provincial level.

4. Existing Programs Referred to as Growth and Yield Monitoring

4.1. Inventory audits

The inventory audit procedure fits the Task Force definition of growth and yield monitoring. Inventory audits were designed to answer the question “How good is the current inventory?”. The objective is to assess the reliability of the inventory volumes by comparing them to ground measured volumes. Target populations are typically portions of TFLs or TSAs with the sampling units being polygons. A number of polygons are randomly selected and then within each of these a cluster of ground sample plots are randomly established to determine stand volume. The ground measured volumes (audit volumes) are then compared to the inventory volumes for the selected polygons. This sampling procedure allows an estimate of the reliability of the inventory volumes for the entire target population to be determined.

4.2. NIVMA TRENDS

The Northern Interior Vegetation Management Association (NIVMA) is an industry cooperative which has been assessing vegetation management effects on plantation performance since 1989. Cooperative members use a common monitoring protocol to allow for the development of a common database. Their original protocol was the Unified System of Silvicultural Monitoring (USSM). The main focus of this system was the measurement of crop tree survival and growth in relation to other vegetation. Between 1989 and 1995, 850 USSM installations were established by NIVMA members.

In the past year NIVMA has developed a new monitoring protocol. This work reflects new information needs such as determining years to breast height, free growing and green-up and monitoring attributes such as biodiversity and longer term site productivity. The new monitoring protocol is called TRENDS (Treatment Regime Evaluation - Numerical Decision Support). The overall goal of the TRENDS monitoring protocol is “… to provide an objective measure of the response of trees and stands to the silviculture prescriptions applied on the range of sites being managed.” (NIVMA 1995).

Strictly speaking neither the USSM nor TRENDS protocols fit the current definition of growth and yield monitoring. The primary focus of both these programs was and is to obtain new growth and yield information to be used for future decision making and also to be used to check existing policies and guidelines. In that current policies and guidelines are based on existing growth and yield information, or at a minimum some general assumptions about stand growth, it could be argued that the TRENDS protocol does meet, at least indirectly, the definition of growth and yield monitoring.

The stated objectives for TRENDS are as follows (NIVMA 1996):

"1. Quantify the years to breast height for Timber Supply Planning purposes.
2. Describe the years to free growing for silviculture policy purposes.
3. Provide a basis for reviewing the definition of free growing.
4. Quantify the impacts of various levels of site disturbance on years to breast height as a basis for reviewing soil conservation guidelines.
5. Provide a basis for reviewing the expected years to green-up.
6. Provide a basis for reviewing the efficacy of silviculture practices.
7. Identify common successional patterns in given ecosystems following disturbance regime.
8. Quantify the potential impacts of abiotic factors (damage) and pest incidence on years to breast height and stand development."

Using the TRENDS protocol the population being monitored is the land in northern B.C. and Alberta required to be reforested by Association members. Installation sites are randomly selected from this population. Association members are required to establish a specified number of installations each year. This number is proportional to the member's AAC. Each member randomly selects with replacement and probability proportional to size the specified number of cutblocks from their list of blocks they plan to harvest the following year. In each chosen cutblock an installation or installations are established by randomly choosing the installation centre point. Each installation is a 30 x 30 m square plot divided into 4 quadrants and containing 4 subplots, 36 grid points and 2 transect lines. Measurements taken before and several times after harvest include site description, ecological classification, site disturbance, vegetation, crop and non-crop trees, cone crop rating, pests, and coarse woody debris.

The proposed analysis and reporting of the data includes using an Oracle database and producing tree annuity tables. The latter essentially being insurance tables for trees. These tables will, for example, show the probability of a tree reaching free to grow in a specified time frame given some early measurement such as leader growth.

4.3. Volume, Decay and Waste Equation Validation and Calibration

New volume, decay and waste equations have been developed by BEC zone. All TSPs and PSPs will be re-compiled using the new equations. Because the old equations were based on forest inventory zones and PSYUs there is a desire to check the applicability of the new equations to specific areas. This process of checking equations fits the definition of growth and yield monitoring.

One example of where this has been done is in the Queen Charlotte Islands (J.S. Thrower & Associates 1996). There were initial concerns that the volume, decay and waste equations may not be appropriate for this area as the sample of trees used to construct the equations was not taken specifically for the Queen Charlotte Islands. To check the existing equations an unbiased sample of trees was selected. These trees were felled and stem analysis was used to measure volume and decay. Volume and decay were then also estimated using the equations. A comparison showed that in general volumes for the immature trees were over-estimated and volumes for the mature trees were under-estimated. As a result, the data collected was used to develop a linear regression equation to adjustment the estimates produced by the volume and decay equations.

Currently under the timber supply review process, if inventory audits, old growth site index adjustments, land withdrawals, etc. have a large impact on the AAC then these areas are being given top priority to check the new individual tree equations. They are checking to make sure the equations are representative of the local area.

5. Issues

5.1. Required Accuracy of Growth and Yield Estimates

What level of accuracy do our growth and yield estimates need to have? What order of magnitude do errors need to be before they have a significant impact on management decisions? The answers to these questions should impact both the development of new growth and yield estimates and the priorities for checking existing estimates. The costs of obtaining information must be considered relative to the impact the information has on management decisions. The answers to these questions can be obtained initially by educated guesses and assumptions, and subsequently, if warranted, by formal sensitivity analyses. What level of management decision making is involved? One has to consider the costs of obtaining information and the impact certain error levels have on the decision making process. There is a need to determine what information is important and how accurate it needs to be. Some would argue that just because we have the expertise and technical ability to address most of our growth and yield information needs does not necessarily mean we should do so if the increase in knowledge is not justified by the costs of obtaining it.

5.2. Using Growth and Yield Monitoring Data For Model Development and Calibration

For any given growth and yield information need there are several model forms that could be chosen to address the need. The type of data required to develop a given model will depend in part on the model form. In designing a growth and yield monitoring system the primary objective should be to check existing growth and yield estimates. A secondary objective could be to collect data to provide interim corrections to model estimates, or even further, to add the monitoring data to existing data sets that would then be used to modify models so that they produce acceptable output. The key points to consider here are:

a) if monitoring data is added to the data set used to develop models it no longer can be used as an independent check; and

b) in order to be able to add the growth and yield monitoring data to the data set used for model development and modification, the type of data required must be known and the monitoring program must be designed to collect it. If there are any indications that current models may be replaced by new ones, then the type of data required for the development of the new models must be known.

5.3. Growth After Versus Response to a Treatment

There needs to be a clear distinction between “growth after a treatment” and “response to a treatment”. Growth after a treatment is simply as stated, it is the growth of a stand following treatment. Response to a treatment is growth after treatment minus the growth that would have occurred if the stand had not been treated. The types of sampling or experimental designs required to estimate these two quantities are different. Growth following a treatment can be estimated using a sampling design that includes establishing plots in treated stands and taking repeated measurements. Note that these could be PSPs or TSPs at different points in time, with PSPs providing a more accurate measure of growth. To determine treatment response, controls are needed to estimate how the treated stands would have grown without treatment. This requires some sort of experimental design.

Theoretically, a growth and yield monitoring program could take one of two approaches:

a) Observe growth after operational silviculture treatments and compare this to the predicted or expected growth. This would be done by randomly establishing plots in a defined population of operational stands.
b) Observe treatment responses on a random selection of treated sites. Sites would have to be chosen prior to treatment from a list of blocks scheduled for treatment. Within each chosen site a control area would be randomly defined prior to treatment and plot(s) would be established within treated and control areas. The control area must be a randomly chosen part of the block originally scheduled for treatment, not an adjoining area excluded from treatment for other reasons.

The first approach answers the question: are stands growing as we expect them to after treatment? This is likely most appropriately done across the full range of treated areas to ensure that average growth projections are accurate for planning purposes. This approach will not provide estimates of operational treatment response even if both untreated and treated areas are sampled. The primary reason for this is that in silviculture operations treatments are not randomly applied. Randomly assigning treatments to each of several areas avoids the biases introduced via site-treatment and stand-treatment interactions.

In theory, the second approach could provide an estimate of the operational response to treatment. However, whether or not it is:

a) logistically possible to implement such a procedure operationally; and
b) possible to obtain sufficient sample sizes to obtain a reasonable error level,

is open to considerable debate.

If it is possible to implement, the information obtained will be of relatively low precision and should not be viewed as a replacement for trials designed to quantify treatment responses. At best, the information will simply ensure that, on average, across several areas of application that treatment responses are as expected. For the following reasons, it should not be viewed as an opportunity to obtain new information on treatment responses where such information is lacking:

1. Under operational conditions there are high levels of within stand variability making treatment responses difficult to observe. Stand growth is a function of the site, stand age, density and structure as well as treatment. Unless site, stand age, density and structure are relatively uniform their variability can mask treatment responses. This is why under experimental conditions an attempt is made to minimize the within stand variability.
2. It is extremely important to establish plots and take measurements prior to treatment to provide pre-treatment information. While this is not impossible to do under operational

conditions, historically it has not been done due to cost and logistical considerations. If the pre-treatment information shows differences then adjustments can be made to treatment response estimates to reflect these pre-treatment differences (i.e., using covariance or regression techniques). If no pre-treatment information is available the only way to proceed is to assume that there were no pre-treatment differences. Experience with analyzing data from silviculture trials has shown that even under experimental conditions where an effort is made to minimize stand variability, pre-treatment differences almost always exist.

5.4. Differences in Data Quantity and Quality Between Management Units

The differences in data quantity and quality between management units should be considered prior to the development of a growth and yield monitoring program. The need to check growth and yield estimates may be a high priority in one area where information exists, but in another where there is little information to base decisions on a higher priority will likely be to obtain baseline information. This is an important consideration in the prioritization of funding.

5.5. Operational Adjustment Factors (OAFs)

Growth and yield monitoring has been suggested by some as a possible source of data for the development of OAFs (McWilliams and Thrower 1994). However, data collected with the primary objective of checking existing growth and yield estimates will not on its own provide the data necessary to develop OAFs. At best it will provide an interim estimate of the appropriate OAFs to use for a given area.

To review, there are two categories of OAFs.

Category 1: Factors that cause a reduction in the productive land base.

- Rock outcrops, small swamps, any areas where trees did not or can not grow.
- The impact of these factors depends on their size and frequency. Several small unproductive areas may have little impact while 1 large area equal in size to the sum of the smaller areas may have a fairly large impact.
- May be thought of as proportionately lowering the potential yield curve.

Category 2: Factors that cause a reduction in the productivity of the trees, or death of trees, and that change (usually increase) in probability over time.

- Non-catastrophic insect attack, root rot, other diseases, climatic factors such as ice and snow storms, blowdown.
- This category does not include the catastrophic losses from fire and insects already accounted for in the planning system.
- May be thought of as changing the shape of the potential yield curve.

OAFs are needed to adjustment estimates from the model TASS (TIPSY). This is because TASS predicts potential growth and yield. The development of TASS is done in two iterative phases; first, biologically oriented functions based on detailed stem analysis data are developed, and second the model output is compared with PSP and research installation data for calibration. The potential yields of the subjectively established PSPs provide an important bench mark for calibration - they are the most stable as they are free of the many extraneous factors (OAFs) that affect growth and yield. In other words, PSPs are subjectively located to minimize variation. Without a reliable bench mark, where the effects of extraneous factors are minimized, it would not be possible to reliably estimate stand growth and yield without a complete understanding of the many factors contributing to operational falldown.

One can think of operational falldown (difference between PSPs and the average yield of same type of stand) as bias. TASS projections of potential growth and yield are positively biased relative to average growth and yield. As a result they must be adjusted downward to reflect average conditions. The long term strategy for developing OAFs is to identify the specific agents that cause falldown and learn how best to incorporate into the modeling process. This may be by adjusting yields after the fact or by allowing inputs to the model that sufficiently describe the operational conditions prior to estimating yield.

5.6. Permanent Sample Plots - Will They Represent the Target Population Over Time?

If the target population is defined in geographic terms, for example, the area within a specific management unit, then a random network of permanent sample plots will continue to represent the population over time. If the target population is a specific stand type which changes in area and distribution over time, then a random network of PSPs established today will often fail to represent the target population over time. With a changing population, to keep a representative sample, plots will have to be dropped and added over time.

5.7. The Role of Growth and Yield Monitoring Within the Overall Growth and Yield Strategy

The current growth and yield program strategy is a major step forward in the coordination of efforts and the identification of growth and yield needs and priorities. However, what is lacking is an overlying vision of where we are headed with our growth and yield information systems, something that ties all the proposed projects together. Before embarking on the development of a growth and yield monitoring program, a minimum step should be to develop some basic assumptions of where we will be 10 plus years from now with our growth and yield information. This is important because a growth and yield monitoring program should be viewed as one component of an overall growth and yield information system. It is also important to be forward looking whenever contemplating the establishment of permanent sample plots given their expense is typically justified by the projected return of long term valuable information.

6. What Growth and Yield Information Should be Monitored?

In theory all the growth and yield information that is used for decision making can be monitored. In practice this is likely not feasible and therefore priorities need to be developed. It is purposed that priorities be based on the significance of the decision that the growth and yield information is used to make. In other words where would having incorrect growth and yield information have the biggest impact? The following sections outline three types of information commonly suggested as that which should be monitored.

6.1. Growth and Yield Information Used in AAC Determinations

AAC determinations are obviously significant decisions that require growth and yield information. The inventory audit procedure provides a check of existing inventory information. A next step could be to develop a program to check projections of analysis units used in timber supply analysis. One possible way of doing this would be to use the new vegetation resource inventory ground sample plots (and possibly additional national inventory plots). These plots could be re-measured to obtain growth information. Plots falling within a given timber supply area could be post-stratified into analysis units and average growth compared to the growth projections used in timber supply analysis. In addition, even prior to comparing expected and realized growth, the average values input into the models to project growth could be checked. In other words, initially confirm that existing models are being applied as appropriately as possible. Sample sizes required would have to be considered. In addition, this type of program is not going to give immediate feedback similar to the inventory audits. Checking existing yield predictions can be with a single measurement, checking growth projections requires data to be collected over time.

6.2. Site Indices

Other significant growth and yield information includes the results coming in from the old growth site index project. Major changes to site index and therefore growth and yield expectations are indicated. As a result there will need to be an independent way to check this information. It is purposed that this could be accomplished via inventory audits and the implementation of the new vegetation resource inventory. Under both these programs site index information is collected.

6.3. Expected Growth Following Silviculture Treatments

Another often asked question that fits under the realm of growth and yield monitoring is "are operational stands responding to treatments as we expect them to?". This presupposes that: a) acceptable levels of growth and yield information exist; b) based on this information silviculture programs are in place; and c) it is deemed prudent to check that growth following treatment is as expected. If acceptable levels of growth and yield information do not exist, then the question becomes one of obtaining information, not checking existing information. This distinction is important because it will change the way in which data are collected and utilized.

Before any program is designed to check that operational stands are responding as we expect them to, we need first to answer the question "what level of information is required?". In other words, will it be sufficient to know that for timber supply analysis we are on average projecting the growth of treated stands accurately? Or, at the other extreme, do we want to know if we can accurately predict the growth of an individual stand? Or, do we want to be somewhere in between?

The desire for feedback on operational stand performance has been expressed by many silvicultural foresters. Unfortunately in B.C. the majority of foresters do not spend their careers working in one area building up local knowledge. As a result, many silviculture foresters would like an information base to draw upon which documents the success or failure of previously applied treatments in the area in which they are currently working. ISIS and MLSIS provide a history of what has been done to stands but do not include feedback information on how stands have grown after treatments. This is a key issue that most silviculture foresters would like to see addressed.

In the instances where growth and yield information regarding a silviculture treatment does not exist, growth and yield monitoring should not be considered a primary source of new information. As growth and yield monitoring is done via sampling operational stands it is only possible to summarize the observed growth in treated and untreated stands. Assuming that the difference between these observations represents a treatment response requires making the assumptions that treated and untreated stands were similar in all respects (site, age, structure, density, and species composition) prior to treatment application. This is rarely the case as the choice of which stands to treat is based on these very factors. The only way to ensure that the observed response is due to treatment and not several other factors is with a design that has replicates and random application of treatments including a control.

7. Summary

The term "monitoring" is used in many different ways in forest management, therefore it is critical to clearly define the objectives of any monitoring program. Within forest management, two broad categories of monitoring can be defined, these are forest monitoring and forest management monitoring. Forest monitoring is primarily an inventory function, with the main objectives focused on tracking the distribution, types and growth and yield of forests. Forest management monitoring is the process of ensuring forest management practices meet existing legislation and standards.

Growth and yield monitoring, as defined by the B.C. Ministry of Forests Growth and Yield Monitoring Task Force is:

"The process of observing the growth and yield of a forest and comparing this with the predicted growth and yield of that forest to assess risk and uncertainty around predictions."

It may be more suitably be called "checking growth and yield estimates and predictions". As such it may be regarded as a form of forest management monitoring that is done by monitoring the forest. It is not forest monitoring per se, because the primary objective is not to describe the state of the forest but rather to check existing estimates and predictions about the state of the forest. The primary objective of a growth and yield monitoring program should be to identify growth and yield estimates with an error level large enough to significantly impact management decisions. Examples include information used to determine individual tree volumes, information used to determine silviculture spending priorities, and information used to determined allowable annual cuts.

Growth and yield information is required for individual trees, stands and forests. When discussing growth and yield monitoring it is critical to realize that its primary role should be to check existing growth and yield information that has been used to make significant management decisions. It should not be viewed as a primary method for obtaining new growth and yield information. This distinction is important because the methodology used to collect the data will differ. In the broadest sense growth and yield monitoring consists of sampling operational stands. This differs from designed experiments that include control plots and randomization and replication of treatment applications.

8. References

CCFM (Canadian Council of Forest Ministers). 1995. Defining sustainable forest management: a Canadian approach to criteria and indicators. Can. For. Serv., Nat. Res. Can.

CFIC (Canadian Forest Inventory Committee). 1996. A new national forest inventory. Unpubl. proposal prepared by the mensuration subcommittee (D. Morgan chairperson).

CFS (Canadian Forest Service) 1996. Canadian Forest Service science and technology networks, forest health network. September 1996. Unpubl. memo.

Beale,J. (chair). 1994. A forest damage appraisal strategy for British Columbia. A report to the Forest Productivity Councils of B.C. Technical Advisory Committee by the Pest PSP Matrix Subcommittee. December 9, 1994. Unpubl.

IUFRO 1994. IUFRO international guidelines for forest monitoring. R. Paivinen (ed.). IUFRO world series Vol. 5. 102 p.

McWilliams, E.R.G., and Thrower, J.S. 1994. A review of operational growth and yield monitoring in British Columbia. Contract Rep., B.C. Min. For. Inv. Br., Major Service Contract No. 19525. Unpubl.

MOF (Ministry of Forests) 1996. Ministry of Forests, British Columbia Forest Service, Briefing note. Prepared for: Gerry Armstrong, Deputy Minister. Issue: Ministry quality assurance framework. May 10, 1996.

Moss, I.S. 1994. Report review: McWilliams, E.R.G., and Thrower, J.S. 1994. A review of operational growth and yield monitoring in British Columbia. Contract Rep. B.C. Min. For. Inv. Br., Major Service Contract No. 19525. Unpubl.

NIVMA 1995. TRENDS monitoring protocol background manual. July 1, 1995. Unpubl.

NIVMA 1996. TRENDS field manual. May 31, 1996. Unpubl.

Resources Inventory Committee. 1995. Final report from the Vegetation Working Group on a proposed new inventory. March 30, 1995. Victoria, B.C.

J.S. Thrower & Associates. 1996. Queen Charlotte Islands volume, decay, and waste equation validation and calibration. Contract Rep. B.C. Min. For., Resources Inv. Br. DRAFT.