A Review of

Operational Growth and Yield Monitoring

in British Columbia

A Report to the
B.C. Ministry of Forests
Inventory Branch

Major Service Contract No. 19525

Prepared by:

Eleanor R.G. McWilliams, M.Sc., R.P.F.
James S. Thrower, Ph.D., R.P.F.

September 1994

EXECUTIVE SUMMARY

The Ministry of Forests, Inventory Branch maintains two programs to monitor the growth and yield of operationally treated stands: the Intensive Forestry Program and the Silviculturally Treated Program. Establishment of plots under these programs was recently suspended because of concerns the programs would not meet their objectives. Specific concerns included the subjective selection of stands, subjective location of plots within stands, and the lack of treatment replication and randomization. The objective of this report was to review these programs and determine if objectives are being met, assess the current utility of the objectives, and to examine the potential utility of the data for current and future needs. This was achieved by reviewing all available internal documentation of these programs, and through discussions with knowledgeable persons from Government, Industry, Consulting firms, and the University of British Columbia. Recommendations were then made on the future of these programs and how to best meet current and expected future needs for growth and yield monitoring.

Growth and Yield Monitoring Defined

The first step in the review was to clearly define what information is needed from a Growth and Yield Monitoring program. Early discussions with knowledgeable persons and a review of the forestry literature demonstrated a wide variety of definitions for this term. This reflects the varied information needs to make a wide range of forest management decisions. A critical examination of the various ideas led us to develop a clear definition of growth and yield monitoring as:

> *Growth and Yield Monitoring is 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 implies that a prior expectation of growth and yield must exist before it can be monitored. Thus the objective of growth and yield monitoring should be to check existing growth and yield predictions - not to develop new predictions.

The Intensive Forestry Program

The objective of the Intensive Forestry Program was: *"to monitor and periodically measure the growth responses of selected stands treated under the Silviculture Forestry Program."* The intent was to provide information about the average response of stands treated under operational conditions with juvenile spacing, fertilization, and other silvicultural treatments. Other expectations of the program were that estimated responses would be representative of large areas such as Forest Regions and the Province. The installations were established by locating a cluster of 5-10 fixed-radius plots in a treated portion of a subjectively chosen stand, and an equal number of plots in an untreated portion of the stand. The intent was to compare tree growth between these areas to estimate treatment response.

We concluded that the majority of these installations cannot be used to estimate the growth response of operationally applied treatments at the stand or forest level. Furthermore, this

program does not meet the criteria of a Growth and Yield Monitoring program under our definition. This is primarily because the subjectively chosen stands do not provide a representative sample of all treated stands, and the installation design does not provide assurances that the treated and untreated areas were similar in site and stand characteristics before treatment. Thus observed differences in growth could be due to treatment, site differences, or stand structure, and these effects cannot be separated.

1. We recommend that the Intensive Forestry Program be discontinued and additional plots are not established under this program. However, remeasurement of existing plots should continue until all have been evaluated for the potential to show treatment response or for use in special studies. This should proceed immediately to avoid allocating further funds to the remeasurement of plots that will be abandoned.

The Silviculturally Treated Program

The Silviculturally Treated Program had four related objectives: *1) "to sample recognized populations in treated stands, to establish rates of growth, mortality and changes in stand structure from establishment to maturity or cutting age"; 2) "to provide treated stand growth and yield data to calibrate growth models of various resolution"; 3) "to assess operational growth response due to intensive forestry practices and provide guidance in the allocation of funding stand tending and pest management programs, and"; 4) "to provide data suitable for special investigative studies."* The original design was a cluster of three fixed-radius plots located at a random starting distance along a subjectively chosen line through subjectively chosen stands. This was later changed to establishing a single plot with the same selection methods.

We concluded this program does not meet the first and third objectives, and does not meet the criteria of a Growth and Yield Monitoring program under our definition. These plots can be used to estimate "rates of growth, mortality and changes in stand structure from establishment to maturity or cutting age", but only for subjectively chosen portions of individual stands. Thus these plots do not represent the population of all treated stands. These plots were established after treatment, therefore, cannot "assess operational growth response due to intensive forestry practices", or to "provide guidance in the allocation of funding stand tending and pest management programs". The program can meet the second and fourth objectives of providing data for the development and calibration of some forms of growth and yield models and for special studies.

2. We recommend the Silviculturally Treated Program should continue with clarification of the program objectives and potential use of the data.

Future Monitoring Systems

The Intensive Forestry and Silviculturally Treated programs do not meet the objectives of a Growth and Yield Monitoring program under our definition. Thus a new program should be

developed to periodically check growth and yield predictions to ensure they are within a reasonable margin of error of actual growth and yield in the operational forest.

3. We recommend that a new Growth and Yield Monitoring program be designed, tested, and implemented as soon as possible. This program should provide data representative of the areas and at the resolution that the growth and yield estimates are used in forest management and planning.

Related Issues

This review identified several closely related issues that should be addressed in conjunction with the development of a new Growth and Yield Monitoring system.

4. We recommend that a program be developed to estimate Operational Adjustment Factors (OAFs) to ensure predicted growth and yield reflects that achieved in the operational forest. This should be done at the level and resolution that the predictions are used in forest management and planning. This could be fully integrated with a monitoring program; however, the objectives of each should not be compromised in efforts to combine the programs.

5. We recommend that the issue of observing response to operational treatments be addressed by a committee ofsilviculturalists and researchers. Discussion should focus on the pros and cons of observing treatment response in operational stands versus relating research results through operational adjustment factors.

6. *We recommend that standards be developed to define the quantity and quality of data for model development and that a program is implemented to ensure the collection of these data.*

7. *We recommend that a program be developed to estimate the severity of pest impacts on growth and yield and how they interact with silvicultural treatments. This should be done in conjunction with existing programs at Forestry Canada.*

ACKNOWLEDGMENTS

We gratefully thank those persons who spent time discussing the Intensive Forestry Program, the Silviculturally Treated Program, and the expectations and perceptions of these and other programs. These persons include from *Inventory Branch:* Joe Braz, Rob Drummond, Carlos Martins, Sam Otukol, Ken Richardson, Ulf Soderberg, Jon Vivian, and Barry Wilson; *Silviculture Branch:* Frank Barber, Jeff Beale, Ralph Winter, and Mike Wyeth; *Research Branch:* lan Cameron, Phil Comeau, Jim Goudie, Mik Kovats, and Ken Mitchell; *Resource Planning Branch:* Darrell Errico and Barry Philips; *Cariboo Region:* Hal Giles, Ray LeDuc, and Craig Sutherland; *Kamloops Region:* Ron Gray, Bob MacDonald, and Alan Vyse; *Nelson Region:* Bernie Peschke and John Pollack; *Prince George Region:* Larry Badowski, Jim David, Les Herring, Dick Nakatsu, and Richard Reich; *Prince Rupert Region:* Boyd Brown; *Chilliwack District:* Les Andersen; *Cranbrook District:* Denis Petryshen; *Kalum District: Pat* Smith; *Williams Lake District:* Jerry Chapman; *Industry*: John Barker, Reid Carter, and Larry Promnitz; *Consultants:* Kim lles and Don Reimer; *University of British Columbia:* Val Lemay and Peter Marshall.

We also thank those who reviewed an earlier draft of this manuscript: Peter Marshall and Don Reimer who provided excellent comments that helped us revise this document, and Louise DeMontigny, Jim Goudie, Ken Mitchell, Gordon Nigh, Sam Otukol, Ulf Soderberg, and Jon Vivian. We also thank A.Y. Omule who did a great deal of preliminary work reviewing these programs, and Martin Watts who cleaned and performed the preliminary analysis of the Intensive Forestry plot data.

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1. INTRODUCTION

1.1 Background

The B.C. Ministry of Forests, Inventory Branch maintains two programs to monitor the growth and yield of operationally treated stands:

- the Intensive Forestry (IF) program and
- the Silviculturally Treated (ST) program.

The IF program was implemented in 1979 with the objective of observing growth response of silviculture treatments applied under operational conditions. The design was to establish one cluster of permanent sample plots (PSPs) in a silviculturally treated stand and another cluster in a nearby untreated portion of the stand. The intent was to observe growth response of a variety of treatments applied across a range of stand types. The ST program was initiated in 1985 to provide general growth and yield information about operationally treated stands. It was implemented using a cluster of three PSPs located in silviculturally treated areas and changed in 1989 to using a single plot.

Recent discussions and reviews in the Ministry of Forests and the Forest Productivity Councils of the overall collection and use of growth and yield data in the Province have raised many questions about these programs. Major concerns were the subjective location of plots and the lack of replication within stands would not provide data capable of meeting programs objectives. It was also questioned if the original objectives are appropriate for current and future needs. As a result, further installation of new plots under these programs was suspended'; however, scheduled remeasurements continue.

1.2. Objectives

The objective of this report was to review the Ministry of Forests IF and ST programs and make recommendations whether they should be discontinued, reinstated, modified, or replaced with one or more new programs. A review of the forestry literature, internal reports, memos, and manuals regarding the IF and ST programs, and discussions with Government, Industry, University and Consulting foresters showed varied interpretations and uses of the term Monitoring. Thus it was necessary to developed a clear definition of *Growth and Yield Monitoring* before making recommendations regarding the future of these programs.
This report contains seven major Sections. Following this introduction, Monitoring and related terms are defined and discussed in Section two. A proposed definition and the key elements of a Growth and Yield Monitoring program are given in Section three. The objectives and history of the IF and ST programs are outlined in Section four, and an evaluation the original objectives, and the current and potential utility of the data is given in Section five. This is followed by recommendations in Section six for the future of the IF and ST programs, the development of a new Growth and Yield Monitoring Program, and the need to address several other related issues.

2. DEFINITIONS AND PERCEPTIONS OF MONITORING NEEDS

A major source of confusion in discussing Monitoring programs is the ambiguity of the term. 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)".*

The term is frequently used without reference to what is being monitored or for what purpose. A review of the literature and interviews with Government and Industry foresters presented in the following section illustrates the varied use and different perceptions of its meaning.

2.1. Monitoring as Defined and Used in the Literature

The term Monitoring is widely used throughout the forestry literature to describe the process of checking or regulating some defined activity. For example:

- remote sensing is used to monitor changes in forest cover;
- insect and disease surveys are used to monitor the state of forest health;
- projected timber yields are monitored for accuracy;
- herbicide and pesticide applications are monitored for compliance with guidelines;
- the implementation of plans are monitored to ensure objectives are met;
- stand development is monitored to check growth; and
- changes in vegetation are monitored following site disturbance.

Other examples use Monitoring in the context of specified activities. For example, Promnitz (1991) discussed monitoring as an activity to compare plans to actual performance and compared it to pilot plants or test marketing used in other industrial situations. He gave examples of monitoring for efficiency of guidelines in site selection, efficiency of operations in quality control, and measuring stand response for behavior to operational treatments. He suggested that monitoring should be considered as transition between research and operations in measuring treatment response.

Barnard (1990) described monitoring as the repeated recording or sampling of pertinent data for comparison to a reference system or baseline. Bruce and Wensel (1987) suggested definitions for several terms used to describe developing, adjusting, and testing empirical growth models. They defined monitoring as continued checking of system outputs to detect shortcomings of the model.

Reid Collins & Associates Ltd. (1986) reviewed methods for operational monitoring of managed stand growth and yield and identified five basic *perceptions* of growth monitoring:

1. For calibrating growth models, where calibration means adjusting differences between operational stands and the PSPs used to develop the models (i.e., the development of Operational Adjustment Factors).
2. To quantify the impact of silviculture treatments (i.e., to estimate treatment response).
3. To supply basic growth data for new growth models.
4. To supply global estimates of growth, mortality and standing volumes for large geographic areas, such as compartments, treatment class, or forest type to quantify the impact of pests and provide an independent audit of the Ministry's stand based inventory.
5. To supply operational feedback on the performance and development of individual silviculturally treated stands, primarily to identify problems in stand development resulting from specific treatments applied under different conditions.

The many uses of the term *Monitoring* in the literature demonstrates the need to clearly state the objectives of a Monitoring program. Without specific reference to program objectives, the use of this term will likely result in misunderstanding and confusion.

2.2. Perceived Needs for Growth and Yield Monitoring in British Columbia

The term Monitoring is widely used in the forest industry to describe activities that check procedures and expectations. Phrases such as *Operational Monitoring, Operational Growth and Yield Monitoring,* and *Growth and Yield Monitoring are* used in reference to observing the growth and yield of operational stands. We interviewed several Government, Industry, University, and Consulting foresters with administrative, operational, and research backgrounds. They explained their perceptions and expectations of monitoring programs, and specifically *Operational Growth and Yield Monitoring.* The following examples illustrate the range of expectations and perceptions:

- *"Operational monitoring should provide feedback information that allows for adjustment of processes or systems. Data collection should be broad based and independent of the data used to develop the processes or systems being monitored. With respect to growth and yield prediction, operational monitoring should provide operational adjustment factors to alter model predictions. Operational monitoring should have a global perspective, i.e., it should not be restricted to silviculturally treated stands."*
- *"Operational monitoring is tracking the growth and losses of operational forests. The collected data should be used in model development or for adjusting model outputs to reflect real world situations. Data should provide a feedback mechanism to check growth projections."*
- *"Operational monitoring is the establishment of plots in operationally treated stands to provide data for rough comparisons of treatments. The data is used to identify trends; it is not intended to be suitable for growth and yield modeling or to provide estimates of absolute treatment responses. The data provide much needed information where formal research trials are lacking."*

- *"Monitoring is describing the 'state of the nation'; it is not detailed research. Knowing about changes of state is important to operational planning. One can conceptually refer to all silviculture surveys as monitoring; every survey is in a sense a monitoring of past activities. Such monitoring is required to support business decisions."*

This wide range of responses highlights the varied use of the term for different objectives. This was similar to the perceptions found by Reid Collins & Associates Ltd. (1986). The common element of these examples is they include the collection and analysis of growth and yield data from operational stands.

Different ideas and objectives exist because the need for growth and yield information from operational stands varies greatly. The type and resolution of information required depends on the specific decisions that must be made. For example, managed stand yield tables used in timber supply analysis must be adjusted to reflect average conditions in the planning unit. This is more detailed information than needed to prioritize silviculture treatments for application across large areas.

The following sections document growth and yield information needs perceived by the Ministry of Forests and Industry as possible to address with a monitoring program.

2.3. Program Specific Needs for Growth and Yield Monitoring

2.3.1. Inventory Branch

Inventory Branch implements the IF and ST programs and is responsible for the development of sampling plans, installation and measurement of plots, collection, editing, and storage of data for these and other programs. The Branch currently does not directly use information from the IF and ST programs.

The Branch is also responsible for the prediction of growth and yield of natural stands using the Variable Density Yield Projection system (VDYP). This system gives the average volume of forest polygons at different ages predicted from forest cover attributes. It was constructed using data from temporary sample plots (TSPs) collected for provincial inventories from the mid-1950s to 1980s and PSPs located under other programs.

The Inventory Branch Volume and Decay program develops volume and taper functions for estimating the volume of commercial tree species (Munro 1992). This program also relates internal decay and external indicators. The resulting volume equations and loss factors are used to compile tree volumes for all TSPs and PSPs maintained by Inventory Branch. Consequently, this program affects all uses of the inventory data, including estimation of forest-cover polygon volumes, development of VDYP, and timber supply analyses.

Inventory Branch has developed an audit procedure to estimate forest inventory accuracy. This program compares the volumes predicted using VDYP with that obtained from ground measurements in randomly selected polygons in specific planning units (TFL or TSA).[1] The results can be used to assign priorities for re-inventories and may be used as a temporary measure to adjust the existing inventory (Ministry of Forests 1992).

Inventory Branch staff identified the primary purpose of a Growth and Yield Monitoring program as providing feedback to check growth and yield prediction systems. They noted that the data used to development these systems should be collected independently of that used to monitor or check the systems. The predicted growth and yield for both managed and natural stands should be monitored to ensure it reflects the actual growth and yield in the area of application. Branch staff also suggested that data from a Growth and Yield Monitoring program could be used to develop Operational Adjustment Factors (OAFs). These would be used to adjust predictions for specific areas where actual yields differ from predicted yields.

2.3.2. *Silviculture Branch*

Silviculture Branch implements and administers stand establishment and tending programs. This includes setting and administering policy for the prioritization of silviculture treatments, selection of stands for treatment, and monitoring the application of the treatments. Monitoring the application and response of treatments were both identified as important needs. Treatments must be monitored to ensure they are applied at the desired rate and achieve the desired objectives. For example, planting operations are monitored to ensure the desired number of trees are planted in the correct locations, and juvenile spacing operations are monitored to ensure the desired number, species, and quality of trees are left after treatment. This is needed for payment of contractors and to ensure that stand management objectives are achieved.

Monitoring treatment response was identified as important to ensure the effects are as predicted, and to provide basic information on stand performance. There was also interest in estimating the difference between the responses observed in research trials and operationally treated stands. Most research trials attempt to control the variation in some factors that affect growth such as site quality, stand structure, and treatment application, thus do not reflect the natural variation usually found under operational conditions.

The Forest Health section of Silviculture Branch needs data on the severity of forest pests. For example, data are needed on pest populations to determine if they are increasing or decreasing over time, and how these populations interact and are affected by silvicultural treatments.

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[1] The statistical audit of the inventory can be considered a monitoring program. This brings up the question of the difference between Auditing and Monitoring. Most consider an audit to be at one point in time while monitoring is an ongoing process. The distinction becomes less clear when audits are performed routinely over time. If the objectives of an audit or monitoring program are clearly stated confusion can be minimized.

2.3.3. Research Branch

Research Branch develops managed stand yield tables using TASS (Mitchell and Cameron 1985, Mitchell 1975). This model was developed primarily using data from research installations, PSPs, and stem-analysis. These tables reflect the potential yield that may be observed on small parcels of forest land. Therefore, the estimates are adjusted downward using OAFs to approximate the yield that is expected on average over large land areas typical of planning units used in timber supply analyses. Branch staff identified a potential role of a monitoring program as providing data to check projections of managed stand growth and yield. Ideally, the data would be of sufficient resolution to identify the components of potential differences (operational falldown).[2]

Another need is to check managed stand yield tables where the model has been extrapolated to conditions where research data are limited. An example is plantations established at low densities. Monitoring data could be used for interim model calibration where significant differences were detected until more detailed research data were available.

Research Branch has developed a Vegetation Management Monitoring System (Comeau et al. 1993) to:

> "... *provide both short-term and long-term information on the effects of vegetation management treatments on crop performance (survival, free-growing status, growth, and yield) and on the characteristics (composition and structure) of plant communities, and to provide a database for modeling crop responses to competition and brushing treatments."*

This is proposed as an alternative to costly, extensive research installations. The program is intended to estimate the effects of vegetation control efforts, the effects on biodiversity and wildlife habitat, and interactions with the general plant community.

2.3.4. Resource Planning Branch

One of the ultimate end-uses of growth and yield information is timber supply analyses. This is conducted by the Resource Planning Branch for all Government managed TSA's. The Branch estimates harvest forecasts for planning units based on predicted stand volume growth considering a number of assumptions, constraints, existing policy, and legislation. The growth curves for these analyses are provided by Inventory Branch for natural stands (VDYP) and by Research Branch for managed stands (TASS). The application of these growth curves assumes they are representative of the area to which they are applied (currently TSAs or TFLs). Resource Planning Branch relies on Inventory and Research Branches to provide accurate information.

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[2] The difference in yield observed in the managed forest, on average over many stands, compared to the (usually) higher yields shown for the same forest type in managed stand yield tables developed from research installations and PSPs is called Operational Falldown (Bruce 1977).

2.3.5. *MOF Regions and Districts*

Regional and District staff responsible for prescribing stands specific treatments indicated a need for a greater quantity and quality of growth and yield information to make these decisions. Examples are information to: check managed stand yield tables and localize model projections; to indicate how stands are performing (feedback on management activities); and to show the magnitude of treatment responses to guide silviculture investment decisions. There is concern that research lags behind current operations, thus efficient methods are needed to collect data for stand conditions where there is little information. They suggested that many of these needs could be meet by monitoring the growth and yield of operationally treated stands.

2.3.6. *Industry*

Most forest companies use the growth and yield information supplied by the Ministry of Forests for silviculture decisions and forest-level planning. Companies that use their own growth and yield information must show that it accurately reflects their management area. Industry foresters stated that monitoring should provide data to check model projections and calculate OAFs. They also indicated a need to check the predicted growth response of stands treated under operational conditions.

2.4. Summary of Identified Growth and Yield Information Needs

Government, Industry, and Consulting foresters identified several information needs possible to address with a Growth and Yield Monitoring program. These are summarized as:

1 . To provide data for an independent check of inventory and growth projections to ensure that accurate estimates are used in planning.

2. To provide data to check the predicted growth of operationally treated stands. This provides a check on models used to prioritize silviculture treatments and provides feedback to silvicultural foresters.

3. To develop OAFs for adjusting model projections to reflect observed stand growth in specific planning units. This includes estimating the difference in treatment response under operational and research conditions.

4. To estimate treatment response for conditions where research trials are not available.

5. To provide new data for model development and calibration.

6. To provide data on the incidence and severity of pest impacts on growth and yield, and interactions with silvicultural treatments.

This information is needed for specific components of an overall forest management system. However, it may not be appropriate to address all these needs with a Growth and Yield Monitoring program. The following sections give a proposed definition of Growth and Yield Monitoring, and suggestions for the key elements of a program.

3. GROWTH AND YIELD MONITORING DEFINED

3.1. Proposed Definition

We propose the following definition:

> *Growth and Yield Monitoring is 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 is narrow in scope to make clear the difference between the development of predictions and expectations of growth and yield, and the monitoring of these predictions and expectations. A clear and concise definition supports the development of a focused system and increases the chance of success in achieving stated objectives. A Growth and Yield Monitoring system using this definition may be developed as a stand-alone program or as part of other programs. For example, an empirically based growth and yield inventory projection system that is regularly updated and checked may have a built in monitoring system.

3.2. Key Elements of a Growth and Yield Monitoring Program

The above definition identifies three key elements of a Growth and Yield Monitoring program:

1 . A prediction or expectation of the growth and yield of a forest or stand *must exist* before it can be monitored. This is consistent with programs designed to monitor for change detection as are often used in forest health and environmental programs. These programs often consider the current state-of-affairs as the baseline from which deviations or changes are measured.
2. The data must be representative of the area to which the growth and yield predictions are applied (i.e., must be collected using an unbiased process).
3. The observed growth and yield must be compared to an existing prediction or expectation. Without this comparison the process would be quantification of existing growth and yield.

This definition indicates that growth and yield monitoring can occur at different levels of resolution and is repeated over time. A single observation for checking the current state-of-affairs could be considered an audit.

Growth and yield activities generate information to quantify:

- The current state of the forest, and
- How the forest changes over time (with and without intervention).

Growth and Yield Monitoring programs should provide an independent check of the accuracy of growth and yield predictions. Differences between the predicted and actual growth and yield may be addressed through refinement in the application of the prediction systems, or may require

application of new systems. A growth and yield prediction system may provide accurate estimates in one area but not another.

The statistical audit procedure recently implemented by Inventory Branch provides a check on the current state of the forest inventory. This can be considered monitoring estimates of the current state of the forest. The challenge is to develop a system to check estimates of how the operational forest changes over time. These are not independent because current inventory estimates (state of the operational forest) are based on both past inventories and projections of growth. Omule (1992) suggested a linkage between inventory audits and stand growth monitoring. This is likely a feasible and sound option.

We propose that the first and second of the six information needs listed in Section 2.4 are addressed in a growth and yield monitoring program. The others are aimed at providing new or improving existing information; they are not directed at providing an independent check of current information.

The objective of a monitoring program applied to operationally treated stands is to check the predicted average growth and yield of these stands - not to estimate treatment response. Treatment response is the difference between the growth of a stand after treatment - and the growth that would have occurred in the same stand if it had not been treated. Treatment response must be estimated from repeated measurements of randomly assigned treatments to ensure that observed difference are due to the treatment and not to differences in site quality and stand structure. Operational treatments are not randomly applied within or among stands. Therefore, the component of growth due to treatment (i.e., response) cannot be separated from other factors. Thus a monitoring program should be used only to check the predicted growth of treated stands and not to estimate the response to the treatment.

3.3. Suggested General Use of the Term 'Monitoring'

We suggest that *Monitoring* is not used to describe any process or program without specifically stating what is monitored and for what purpose. The term *Monitoring* is similar to *checking,* or *observing,* in that without a more descriptive phrase it is not possible to determine the intent of the action. The Forest Productivity Councils (1990) also suggested that the term *Monitoring* is not used alone in reference to forest growth and yield to avoid the confusion historically associated with this term.

The difference between the verbs measure, quantify, observe, and others that are commonly used interchangeably with monitor is they do not imply the process of *checking the results with a predetermined baseline, benchmark, or standard.* Thus monitoring is watching, observing, or checking something for comparison against a pre-conceived idea.

4. OBJECTIVES AND HISTORY OF THE INTENSIVE FORESTRY AND SILVICULTURALLY TREATED PROGRAMS

4.1. The Intensive Forestry (IF) Program

4.1.1. Objectives

The Intensive Forestry Program (Silviculture Forestry Program) initiated in 1978 resulted in a tremendous increase in the area treated with what is commonly called incremental silviculture. The largest component of the program was juvenile spacing of interior lodgepole pine stands (Ministry of Forests 1979a). Other treatments included fertilization, pruning, brushing, weeding, and herbicide application. In 1979 an *Operational Monitoring Program,* also called the Intensive Forestry (IF) Program, was initiated to track the growth of these treated stands. The objective of the IF program was:

> *"to monitor and periodically measure the **growth responses** of selected stands treated under the Silviculture Forestry Program, ..."* (Ministry of Forests 1979b).

The intent was to compare the growth of trees in treated and adjacent untreated plots to estimate the *growth response* that could be attributed to the silvicultural treatment.

4.1.2. Implementation

The IF program was implemented through Inventory and Silviculture, Regional and Branch staff. Plots were installed in subjectively chosen areas to represent current treatments under the direction of the Regional staff with varying involvement at that District level. Some installations were also established by Industry under Section 88 of the Forest Act.

4.1.3. Plot Design and Sampling Methods

The installation design used a series of 5-10 plots established in the treated portion of a stand and an equal number of plots in an adjacent untreated portion of the stand[3] (Ministry of Forests 1979b). The plots were located in a grid or linear configuration in areas considered representative of the treatment. Plot sizes in the treated area were adjusted to include a total of about 100 trees. Plots in the treated area were generally about double the size of plots in the untreated area and usually had different diameter limits (FORCOMP Forestry Consulting Ltd. 1993). There have been at least 164 installations located throughout the Province under this program with about 86% of these in juvenile spaced stands (Table 1).

The measurements taken on the sample plots changed several times in the early stages of the program (Ministry of Forests 1981a). The original methods included tagging and measuring all trees in the control and treatment plots, and stem-mapping all trees in the treated plots before treatment. All plots were to be remeasured every five years. Two significant changes occurred in

[3] This untreated portion of the stand was called the 'control' area for the treatment. However, these areas cannot be considered as controls as used in experimental designs.

1980 when trees in control plots were not tagged, but only tallied by diameter class, and trees in the treated plots were not tagged until after treatment. The effects of these changes were that individual tree growth in the control plots could not be tracked over time and the pre-treatment stand conditions could not be determined. In 1980 the methods also changed to include measuring three, six, and nine year pre-treatment height-growth increments of sample trees in both the control and treatment plots. However, this was abandoned because of the perceived difficulty of identifying annual branch whorls in lodgepole pine. Changes in 1981 included elimination of stem-mapping, inclusion of a sub-plot to tally trees below the tagging limit, and changing the tagging limit from 0.3 m in height to 1.3 m. No significant changes were made after 1981.

Table 1. Number of Intensive Forestry (IF) installations by treatment and Forest Inventory Zone (FIZ) (from FORCOMP Forestry Consulting Ltd. 1993).

FIZ	Spaced	Spaced & Fertilized	Fertilized	Space & Weeded	Weeded	Unknown	Total
A	12					1	13
B	12	1					13
C	10						10
D	24	2	1				27
E						2	2
F	9						9
G	13	5	2	1	2	1	24
H	39	2				1	42
I	12	1					13
J	9						9
K							0
L	1				1		2
Total	141 (86%)	12 (7%)	3 (2%)	1 (<1 %)	3 (2%)	5 (3%)	164 (100%)

4.1.4. Recent Developments and Concern

In 1985 questions were raised about the ability of the IF program to achieve its objectives. Reid, Collins and Associates Ltd. (1986) reviewed operational growth and yield monitoring in the Province and concluded that is should be aimed at: a) providing information for calibrating growth and yield models; b) quantifying the impact of forest pests on growth and yield; and c) to provide an independent audit of the Provincial forest inventory. They concluded that the IF plots should be considered research installations to quantify treatment response, thus a separate system was needed to monitor the growth of operationally treated and natural stands.

During this time many questions were raised by operational staff about the ability of the program to provide information on operational growth response and why there had not been any analysis and interpretation of the data. Their concerns focused primarily on potential differences in site between the control and treated plots and the high variation between plots within the treated and untreated areas. Despite these concerns, the general consensus was that the objectives were being met and the program was proceeding as planned.

Questions about the Ministry's monitoring programs (IF and ST) continued at all levels with much discussion in the Forest Productivity Council's Technical Advisory Committee (TAC). This

resulted in the Ministry issuing a statement through the TAC reconfirming the objectives of the monitoring program as:

- *"to develop operational growth data to calibrate growth models; and"*
- *"to estimate global (BA level or other appropriate geographic area) growth, mortality/growth loss and volume to offer guidance for the allocation of funding stand tending and pest management programs, and supply an independent audit of the present audit."* (Ministry of Forests 1987a).

Discussion continued in the TAC and Ministry with serious concerns about the statistical validity of the data from the IF and ST programs. In 1988 this resulted in suspension of further installation of plots under the IF program pending a review of the program and the data. The concerns noted by the Ministry were (Ministry of Forests 1993a):

1 . "*The permanent sample plots are located in stands that are subjectively located."*
2. *"The plot locations are conspicuous; there is a tendency to treat stands with plots differently from neighbouring stands without plots. "*
3. *"For the IFM [IF] plots, the control plots were located subjectively; furthermore, for analytical comparisons, the initial stand conditions of the control plots and the treated plots were not identical in most cases."*

A preliminary analysis of the IF installations data assessed the utility of the information for quantifying growth trends (FORCOMP Forestry Consultants Ltd. 1993). The analysis noted several deficiencies in the design and data including:

- High variability among plots within installations.
- Improper recording of ingrowth.
- Plot sizes too small to capture stand variation.
- No measure of site quality in younger stands.
- No method to determine if stand conditions in the treated and untreated areas were different before treatment for many installations.

The report contained several recommendations including:

1 . The installations should be established before treatment.
2. Documentation of the treatments should clearly state objectives.
3. Site productivity should be assessed using some method that is not affected by treatment.
4. The variability among plots must be reduced and the residual number of trees must agree with the treatment objective to relate results to a specific level of treatment.
5. Ingrowth trees should be numbered.
6. Plots should not include veteran trees.

7. Plots are generally too small; they should be large enough to represent stand variation when compiled separately.
8. Diameter limits for tagging and measuring trees should be the same between plots in the treated and untreated areas of an installations, and should be standardized for all installations.
9. Height measurements should be collected to allow comparison of height growth between treated and untreated areas.

The report stated that the data could not be used for developing inventory projection models. However, it identified potential use of the data for some modeling efforts if ingrowth trees were properly recorded and measured.

4.2. The Silviculturally Treated (ST) Program

4.2.1. Objectives

The ST program initiated in 1985 was to provide information about the growth and yield of silviculturally treated stands in the Province. Treatments included planting, brushing and weeding, conifer release, juvenile spacing, fertilization, rehabilitation, sanitation spacing, mistletoe control, and commercial thinning. The original objectives were to sample treated stands to:

> *"monitor the rates of growth, mortality, changes in stand structure and stand development to rotation."* (Ministry of Forests 1985a).

These objectives were further clarified by Inventory Branch (Ministry of Forests 1990a) for the Forest Productivity Council TAC as to:

1. *"sample recognized populations in treated stands, to establish rates of growth, mortality and changes in stands structure from establishment to maturity or cutting age"*
2. *"provide treated stand growth and yield data to calibrate growth models of various resolution"*
3. *"assess operational growth response due to intensive forestry practices and provide guidance in the allocation of funding between stand tending and pest management programs, and"*
4. *"provide data suitable for special investigative studies."*

4.2.2. Implementation

Stands were subjectively chosen for the ST program by District Silviculture and Inventory Resource Officers to represent current treatments. Stands were not considered if site and species composition varied greatly, if they were too old for a minimum of two measurements (at 10 year intervals), or if they were too small to accommodate a sample (Ministry of Forests 1985a, 1989a).

Plots were located in suitable treated stands along a line projected through the middle of the stand at a distance between 30-200 m, depending on the size of the area, with the distance for the first plot chosen from a random number list.

4.2.3. Plot Design and Sampling Methods

Initially a cluster of three PSPs was located in each stand after treatment (Ministry of Forests 1985a). The original intent was to combine the ST program with the multi-phase inventory sampling program introduced at the time. This program included air photo measurements at phase one, ground sampling for inventory at phase two, and ground sampling for growth and yield at phase three. The intent was to superimpose the three ST plots over the six inventory variable-radius plots. Plots two, four and six would be converted to PSPs under the ST program and plots one, three, and five would be destructively sampled for volume and decay studies. Other ST plot clusters were located independently so they could be combined with multi-phase inventory samples at a future time. One hundred twenty-five clusters of three plots were located between 1985 and 1988 using these methods (Table 2).

The methodology changed in 1989 from using three plot clusters to establishing a single plot in the sampled stands. This change was based on recommendations from the Forest Productivity Council's TAC. In addition stands were to be chosen according to the Forest Productivity Council's matrix for treated stands.

Table 2. Approximate number of plots established under the Silviculturally treated (Pers. Comm., Joe Braz, Feb. 1, 1994; Bob MacDonald, Feb. 21, 1994).

Year	Cariboo	Kamloops	Nelson	Prince George	Prince Rupert	Vancouver	Total
1985				5			5
1986				6	10	3	19
1987	8		1	7	31	2	49
1988	2		3	11	36		52
1989			2	7		4	13
1990		2	12	13	21	32	80
1991	25	24	17	24	12	27	129
1992	24	31		31	31	6	92
Total	59 (13%)	57 (12%)	35 (7%)	104 (22%)	141 (30%)	74 (16%)	470 (100%)

4.2.4. Recent Developments and Concern

The objectives and methods of the ST program were also questioned around 1985-86 with the IF program. The concerns were that *"the current monitoring plots have limited analytical value because of the inherent bias in the design of the sampling plan",* and specifically that:

1. *"The permanent sample plots are located in stands that are subjectively located"*
2. *"The plot locations are conspicuous; there is a tendency to treat stands with plots differently from neighbouring stands without plots."* (Ministry of Forests 1993a).

The main use of the data from these plots was identified as (Ministry of Forests 1993c):

1 . *"Providing feedback on the performance of treated stands under operational conditions; and"*

2. *"Quantifying the incidence, frequency, probability and dynamics of extraneous factors (e.g. pest damage) that reduce potential stand yield."*

The main concerns were that the data would not meet these needs and did not represent the average growth of stands under operational conditions (Ministry of Forests 1993c). This resulted in suspension of plot establishment under the ST program in 1993 pending a complete review (however, remeasurement of existing plots was to continue).

5. EVALUATION OF THE INTENSIVE FORESTRY AND SILVICULTURALLY TREATED PROGRAMS

5.1. The Intensive Forestry (IF) Program

5.1.1. Meeting Stated Objectives

The objective of the IF program was to:

> *"monitor and periodically measure the **growth responses** of selected stands treated under the Silviculture Forestry Program".*

We conclude that data from most installations established under this program cannot estimate silvicultural treatment response - thus the program does not meet the original objectives. These installations provide data to "monitor and periodically measure the growth" of subjectively located portions of treated stands and subjectively located portions of adjacent stands; however, this is not the objective of the IF program.

Most of these installations cannot provide response information because the initial conditions of the treated and untreated plots are unknown. Thus differences in growth between treated and untreated plots could be due to differences in site quality, initial density, spatial distribution of trees, and many other factors in addition to the treatment. These effects are usually removed in experiments through randomization and replication. Some of these effects of site and stand differences may be removed through covariance analyses using a pre-treatment measure as a covariate. However, pre-treatment stand conditions are known for only some installations.

An additional problem is the original objective of the IF program is not clear. The objective states that the growth response in 'selected stands' will be monitored and periodically measured; however, what these stands represent and what inferences are possible is not clear. Estimates from a subjectively chosen stand only provides inference to that stand. Estimates from selecting many stands from a group allows inference to made about the entire group.

5.1.2. Expectations

In addition to the stated objective, other expectations of the program were that it would provide data to:

- localize model projections;
- check Managed Stand Yield Tables; and
- provide a general check on how operational stands are growing.

These expectations indicate misunderstanding of the intent and objectives of the program. It also indicates the need of operational foresters for additional growth and yield information and attempts to use any potential source of information to supply this need.

5.1.3. Current Use of the Data

We are not aware of any analytical use of data from plots installed under the IF program. However, data from fertilized plots installed under a local program using the same design have been analyzed in the Kamloops Region (Newhouse 1993)."[4]

5.1.4. Potential Use of the Data

Plots established under this program may have potential use in special studies of the response of trees and stands to silvicultural treatments. However, each installation must be evaluated individually to determine the use for specific purposes. Other special studies could focus on individual tree responses, wood quality, or site quality issues.

5.2. The Silviculturally Treated (ST) Program

5.2.1. Meeting Stated Objectives

There are four stated objectives for this program:

1 . *"sample recognized populations in treated stands, to establish rates of growth, mortality and changes in stand structure from establishment to maturity or cutting age"*

The data from the ST program do not provide information about the population of all silviculturally treated stands. This is because the plots were located in subjectively chosen stands and therefore inference cannot be made beyond the sampled stands. Furthermore, the plots were located within the stands in a manner that excluded edges of treated areas from possible sampling. Choosing a random point along a subjectively chosen line is not a random sample of the stand. Thus the data from the ST program do not provide an unbiased estimate of the intended population of all treated stands. The degree to which the data are biased may be small but the magnitude unknown.

[4] This report noted the major limitations of the design as lack of randomness in selecting sample stands and the lack of replication in treatments.

2. *"provide treated stand growth and yield data to calibrate growth models of various resolution"*

   Data from the ST program can be used for model development and calibration for stands that are *similar to the plots included in the program.* This is not the same as using the data to represent the population of existing stands. The challenge remains of linking the data from these subjectively chosen plots to the population of interest which is all silviculurally treated stands. Thus in other words, the data can be used to develop and calibrate models for specific stand conditions, but these conditions may not represent the intended target population.

   The major drawback in the ST program for providing model development and calibration data is that pre-treatment information was not collected. Thus the data cannot be used to develop and calibrate models for stands of a given pre-treatment condition.

3. *"assess operational growth response due to intensive forestry practices and provide guidance in the allocation of funding stand tending and pest management programs"*

   Data from the ST program cannot be used to assess operational growth response. These data do not include pre-treatment information and do not have controls for comparison. Thus it is not possible to determine what component of observed growth is due to the treatment and what is due to differences in site quality, stand structure, and other factors that affect tree growth. Accordingly, it would be difficult to use these data for guidance in allocation of funds.

4. *"provide data suitable for special investigative studies."*

   The data from the ST program have potential for use in a wide variety of special studies. For example, there is potential for conducting non-destructive stem-analysis of trees in selected plots to determine the growth patterns of the residual trees.

5.2.2. Expectations

In addition to the stated objectives, other expectations of the ST program were that it would provide data to:

- develop operational adjustment factors (OAFs);
- localize model projections; and
- provide a general check on how operational stands are growing.

The data from this program cannot be used for these purposes because of the subjective selection of stands and plots. These expectations also indicate misunderstanding of the original objectives of the program.

5.2.3. Current Use of the Data

We are not aware of any analytical use of the data collected under the ST program. This is primarily because the first remeasurements are not scheduled until 1995 and thus only first measurements are currently available.

5.2.4. Potential Use of the Data

Data from these plots can be used to calibrate growth and yield models for stands with conditions similar to the plots (item 2 in Section 5.2.1 above) and for special studies (item 4 in Section 5.2.1 above).

6. RECOMMENDATIONS

6.1. The Intensive Forestry (IF) Program

1 . *We recommend that the IF program be discontinued and additional plots are not established under this program.*

1a. Each installation should be evaluated to determine if treatment response can be estimated and for other potential use of the data.

1b. Scheduled remeasurements should continue until installations have been evaluated.

1c. Only installations meeting criteria for showing treatment response should be considered for demonstration areas.

Rationale

The most notable deficiencies of the IF installations are:

- the subjective selection of stands;
- the subjective location of the 'control' and treated areas within stands; and
- the lack of randomization and replication.

The combined effect of these deficiencies is that unknown effects are introduced and confounded with the treatment. This makes it impossible to determine what component of the observed difference in growth is due to treatment and what is due to differences in site conditions or initial stand structure.

Implementation Strategy

i. Discontinue the IF program. Notify all concerned parties that new installations will not be established under this program but scheduled remeasurements will continue until all installations have been evaluated. The technical reasons why the design does not meet the desired objectives should be made clear.

ii. Implement a process to evaluate individual installations for: a) type and quality of data; b) homogeneity of site and stand conditions between the control and treated plots; c) potential for using covariance analysis to account for differences in pre-treatment conditions; and d) the possible suitability for use in special studies. This should begin immediately to minimize the expense of future measurements of plots that have no potential value for growth and yield information.

iii. Recommendations should be made for each installation to be maintained to observe treatment responses, maintained for special studies, or abandoned. These recommendations should be clearly justified, documented, and presented to all parties concerned. Reasons for abandoning specific installations should be discussed and agreed to by Regional and District staff.

iv. Installations considered to have potential for observing treatment response or having high potential for special studies should continue to be remeasured by Inventory Branch.

6.2. The Silviculturally Treated (ST) Program

2. *We recommend that the ST program should continue with clarification of program objectives and potential use of the data.*

2a. Data from the ST program are suitable for some forms of model development and calibration, but do not provide a representative sample of the population of all treated stands. The program objectives should be re-written to clearly state this and emphasize this is not a monitoring program (under our proposed definition).

2b. Future installation of plots should include pre-treatment measurements. This will greatly increase the usefulness of the data for growth and yield modeling.

2c. The future of the ST program should be addressed in a Provincial strategy for obtaining model development data.

Rationale

These plots are subjectively located and therefore do not represent the average of the population of all treated stands. However, subjectively located plots are suitable for some forms of model development and calibration. The efficiency of subjectively located plots increases when installed using a response surface approach that ensures that condition extremes are included in the sample.

Implementation Strategy

i. Clearly define the objectives of the program, the intended use of the data, and the scope of inference of the program. This should be followed by a statement of where the data cannot be used to avoid future confusion and misguided expectations.

ii. Involve current and future potential users of the data in discussions of a Provincial model development data strategy.

6.3. Future Development of a Growth and Yield Monitoring System

3. *We recommend that a new Growth and Yield Monitoring program be designed, tested, and implemented as soon as possible. This program should provide data representative of the areas and at the resolution which the growth and yield estimates are used in forest management and planning.*

Rationale

Predicted growth and yield is an important component of planning - it is imperative that estimates are periodically checked to ensure they are within a reasonable margin of error of what is achieved in the operational forest.

Implementation Strategy

i. A small group of technical experts in growth and yield and forest-level planning should be chosen to lead the development of a new Growth and Yield Monitoring program. These persons should be able to devote a significant portion of their time to this initiative. The purpose would be to plan, coordinate, and develop a new program in conjunction with an advisory committee of information users.

ii. The committee to advise the development team should be composed of other technical experts and representatives from potential user groups. This committee would act as a think tank and sounding-board for ideas. Advisory team members should not be expected to undertake major time consuming tasks.

iii. The first objective should be to clearly define the objectives of a new monitoring program. This should detail exactly what is expected of the program - and what it is not expected. These objectives should be thoroughly discussed and agreed to by all potential user groups.

iv. A new Growth and Yield Monitoring program should consider factors including:

- Coordination with the new forest inventory and the forest inventory audit procedures.
- The many potential sources of error in growth and yield estimates.
- Identifying significant differences between actual and expected growth and yield. A strategy should also be developed to deal with differences should they occur.
- The use of TSPs, PSPs, or both.

6.4. Related Initiatives

This review identified or reiterated five related growth and yield initiatives that should be addressed in conjunction with the development of a new Growth and Yield Monitoring program.

4. We recommend that a program be developed to estimate Operational Adjustment Factors (OAFs) to ensure predicted growth and yield reflects that achieved in the operational forest. This should be done at the level and resolution for which the predictions are used in forest management and planning. This could be fully integrated with a monitoring program, however, the objectives of each should not be compromised in efforts to combine the programs.

5. *We recommend that the issue of observing response to operational treatments be addressed by a committee of silviculturalists and researchers.*

5a. Discussion should focus on the pros and cons of observing treatment response in operational stand versus relating research results through operational adjustment factors.

6. *We recommend that standards be developed to define the quantity and quality of data for model development and that a program is implemented to ensure the collection of these data.*

6a. This could be achieved through a committee of technical experts and data users under the direction of the Forest Productivity Council or similar administrative group.

6b. This is virtually an impossible task as the needs for growth and yield data continually change. However, it is important to have a plan to achieve stated objectives even though they will change over time.

7. *We recommend that a program be developed to estimate the severity of pest impacts on growth and yield and how they interact with silvicultural treatments. This should be done in conjunction with existing programs at Forestry Canada.*

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