Interim Report:

Monitoring Growth and Yield of Treated Stands

Prepared for
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Executive Summary

This paper reviews current protocols and discusses our ideas for monitoring estimates of growth and yield after treatment and treatment response. The purpose of this monitoring is to ensure accurate information is used in forest- and stand-level planning.

A literature review and Internet search produced no relevant information on monitoring estimates of treatment responses.

We conclude that the Intensive Forestry Program, Silviculturally Treated Program, NIVMA TRENDS, EXPLORE, and PROBE are not suitable for monitoring estimates of treatment response, and that only NIVMA TRENDS is suitable for monitoring estimates of growth and yield after treatment.

We recommend that the monitoring design described in J.S. Thrower & Assoc. (1999a) be used to monitor estimates of growth and yield after treatment for timber supply analysis purposes (forest level-planning). For stand-level silviculture decision making, estimates of net growth and yield after treatment should be monitored with modified silviculture surveys designed to enumerate stand conditions over time, thus tracking yield after treatment.

We recommend that treatment response not be monitored at the stand or forest level. The costs and logistics of obtaining a representative estimate of operational treatment response across any population is not warranted. The more efficient choice is to monitor growth and yield after treatment. We recommend that treatment response estimates are obtained from statistically designed trials outside of the growth and yield monitoring program. These will provide new information for silviculture decision-making and model development and also help answer "why?" when monitoring of growth and yield estimates after treatment indicates discrepancies.

Acknowledgements

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1. INTRODUCTION

1.1 TERMS OF REFERENCE

The Ministry of Forests (MOF) Growth and Yield Monitoring Task Force (GYMTF) made recommendations on developing protocols, which have been accepted for implementation by the Forest Productivity Council (FPC). The MOF contracted us to further develop the GYMTF recommendations in six areas: (1) Volume and Decay; (2) Stand Growth; (3) Treatment Response; (4) Stand Yield; (5) Early Stand Development; and (6) Provincial-level Monitoring (Appendix I). This paper addresses recommendations for monitoring treatment response.

This paper was prepared under contract to the MOF Resources Inventory Branch by J.S. Thrower & Associates Ltd. Our team included Ian Cameron, *MF, RPF,* Eleanor McWilliams, *MSc, RPF,* A.Y. Omule, *PhD, RPF*, Guillaume Thérien, *PhD,* and Jim Thrower, *PhD, RPF.*

1.2 PHASE OBJECTIVES

The objectives of this phase (3) of the project are to:

1. *Review the Intensive Forest Management (IFM), Silviculturally-Treated (ST), and other programs for use in monitoring treatment response (Section 2 and Appendix I);*
2. *Review GYMTF recommendations on monitoring treatment response to silviculture activities considering feasibility, utility, practicality, and efficiency (Section 3);*
3. *Identify users of treatment response information (Section 4 and 5);*
4. *Recommend protocols for monitoring treatment response that consider feasibility, utility, practicality, efficiency, and acceptance in the forestry community, including clear statements for the intended use of information (Section 4 and 5).*

1.3 DOCUMENT OBJECTIVE

This paper presents ideas for *monitoring growth and yield of treated stands* for review by Jon Vivian, *RPF* (MOF Resources Inventory Branch). This includes growth after treatment and treatment response. A revised version of this report will be sent to the Expert Review Panel (ERP) in the second year of the contract. We will consider the ERP comments and prepare a final report for review by Jon Vivian.

1.4 DEFINITIONS

To help focus discussion, we define the following terms:

Growth after Treatment is the growth[1] of a stand or group of stands after the application of a treatment.

Yield After Treatment is the yield of a stand or group of stands at some point in time after application of a treatment.

Treatment Response is the incremental growth or yield in a stand or group of stands resulting from the treatment. Treatment response is the difference between growth or yield after treatment, and what would have occurred without the treatment.

2. OTHER PROGRAMS

The IFM, ST, NIVMA TRENDS, EXPLORE, and PROBE protocols were evaluated for their potential to monitor growth after treatment and treatment response. None were suitable for monitoring treatment response and only the NIVMA TRENDS protocol was suitable for monitoring growth after treatment (Appendix I). A literature search and Internet mailing list request for information produced no useful information on other protocols to monitor treatment response (Appendix II).

Program	Summary and Recommendations
IFM	The IFM installations are not suitable for monitoring estimates of growth and yield after treatment or treatment response because they were subjectively located, and the control and treated areas within each installation were also subjectively located.
ST	The ST plots are not suitable for monitoring estimates of growth and yield after treatment or treatment response because they were subjectively located and do not represent the population of treated stands.
TRENDS	The NIVMA TRENDS protocol is suitable for monitoring estimates of growth and yield after treatment as sites are randomly chosen, but not for monitoring treatment response as treatments are not randomly applied.
EXPLORE	The EXPLORE installations are not suitable for monitoring estimates of growth and yield after treatment or treatment responses, as they are subjectively located.
PROBE	The PROBE installations are not suitable for monitoring estimates of growth and yield after treatment or treatment responses, as they are subjectively located.

[1] Net growth is the difference in yield between time 1 and time 2. Net growth is equal to survivor growth plus ingrowth minus mortality.

3. GYMTF RECOMMENDATION

The Silviculture Working Group (SWG) of the GYMTF recommended piloting the establishment of legacy areas (areas to be left untreated) as a methodology for monitoring treatment responses (Appendix III). This recommendation was endorsed at the GYMTF Mesachie Lake Workshop.

4. SUMMARY OF NEW RECOMMENDATIONS

As discussed below (Section 5 and 6), we have considered the GYMTF recommendation and no longer endorse it. Alternatively, we recommend that:

1. *Growth (net) and yield of treated stands be monitored at the forest-level using the VRI approach to forest-level monitoring.*
2. *Stand-level yield and net growth after treatment be monitored using modified silviculture surveys designed to enumerate stand conditions and estimate stand yield.*
3. *Treatment response not be monitored at the forest or stand level.*
4. *Estimates of treatment response be obtained from statistically designed trials outside the growth and yield monitoring program.*

Monitoring growth and yield after treatment will provide the data to check that accurate projections are being used for timber supply planning and silviculture decision making. When discrepancies are noted, the results from statistically designed trials can be used to help answer why the discrepancies are occurring.

5. MONITORING GROWTH AND YIELD AFTER TREATMENT

5.1 OBJECTIVES

The objective of monitoring *growth or yield after treatment* is to:

> *Periodically measure a representative sample from a treated stand or group of treated stands to compare actual with predicted growth or yield.*

5.2 BASIC REQUIREMENTS

The basic requirements for monitoring growth or yield after treatment of a stand or a group of stands are the same as for monitoring the growth and yield in any forest population and include:

1. Taking samples periodically from the targeted stand or group of stands to compare actual and predicted values for the attributes of interest.

2. Ensuring each sample is representative of the stand or group of stands.
3. Ensuring each sample contains enough independent observations from the stand or group of stands to compute a sampling error that is sufficient to detect significant difference in the attributes of interest.

5.3 USE OF GROWTH AND YIELD AFTER TREATMENT INFORMATION

5.3.1 Forest Level

Treated stands are part of the inventory and their growth and yield must be predicted as for all other stands. Thus, the need to monitor the growth and yield of treated stands is the same as for any other stand types in the inventory. At the forest level, information describing growth and yield after treatment is primarily used in timber supply analysis. Consequently, the primary users are the same as for other growth and yield curves, i.e., MOF Timber Supply Branch, forest licensees, and consultants that use yield curves in forest-level planning. Ultimately, information on the growth and yield of stands after treatment is considered by the Chief Forester and assimilated into AAC determinations through timber supply analysis

5.3.2 Stand Level

Stand-level growth and yield estimates of treated stands are primarily used by silviculturists. The number and distribution of forest-level growth and yield monitoring plots will likely not provide enough information to answer silviculturists questions about growth after treatment of specific stand types. Silviculturists would like more feedback on the performance of treated stands to aid decision-making regarding the future application of treatments. Growth and yield monitoring at the stand level can be used to check projections of treated stand growth and yield from models used for silviculture decision-making.

5.4 MONITORING GROWTH AND YIELD AFTER TREATMENT – FOREST-LEVEL

We recommend that:

> *Growth (net) and yield of treated stands be monitored at the forest-level using the VRI approach to forest-level monitoring (J.S. Thrower & Assoc. 1999a).*

A special program to monitor growth and yield of treated stands is not warranted as these stands will be represented at the forest-level in the proportion at which they occur in the management unit. For example, 20% of a TFL may consist of post-harvest regenerated (PHR) stands, of which 10% have been juvenile spaced. Establishing 50 monitoring plots in PHR stands would provide about five plots in spaced stands. Special studies may require more samples in these treated stands; however, at the forest level, these stands account for 10% of the PHR stand area and should be represented accordingly.

Growth and yield monitoring data collected from treated and untreated stands should not be used to make inferences about treatment responses. Operationally, treatments are not randomly applied, and thus treatment effects are confounded with site and initial stand conditions.

Monitoring growth and yield after treatment does not require pre-treatment measurements; however, pre-treatment measurements would greatly increase the value of the information for checking estimates of growth and yield. Provincial or Regional coordination would be required to obtain this information, as openings to be treated would need to be screened to identify those that contain growth and yield monitoring plots.

5.5 MONITORING GROWTH AND YIELD AFTER TREATMENT – STAND-LEVEL

We recommend that:

> *Stand-level yield and net growth after treatment be monitored using modified silviculture surveys designed to enumerate stand conditions and estimate stand yield (J.S. Thrower & Assoc. 1999b).*[2]

These surveys should either be carried out in all treated stands or a randomly chosen subset of stands. In the latter case, the population from which the stands are chosen should be well documented and defined on the landscape so that inferences can be made back to this population.

This process also requires a representative sample from each stand with a large enough sample size to detect meaningful differences between the predicted growth and yield estimates (Section 5.2). Data from repeated[3] surveys (where the primary objective is enumerating stand conditions) will provide a series of stand-yield estimates over time, the differences being net growth. If such data were available for all stands, it could be post-stratified and summarized to show trends in treated stand yields for specific stand types. Pre- and post-stand tending surveys should provide estimates of stand yield that can be used as the starting point for subsequent estimates.

As with forest level monitoring, inferences about treatment response should not be made by comparing growth or yield in treated and untreated stands. Treatments are not randomly applied operationally, and thus treatment effects are confounded with site and initial stand conditions.

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[2] The report J.S. Thrower & Assoc. (1999b) refers specifically to early stand development. However, the proposed modifications to silviculture surveys are equally applicable to surveys carried out after free-growing.

[3] Stands should be surveyed post-treatment at a frequency dictated by information requirements. "Repeated" is not meant to imply re-measured plots.

6. MONITORING TREATMENT RESPONSE

6.1 OBJECTIVES

The objective of monitoring treatment response is to:

> *Periodically measure treatment response from a representative sample of treated and untreated stands (or portions of stands) to compare with the predicted response.*

6.2 BASIC REQUIREMENTS

The basic requirements to estimate treatment response using statistical inference include:

a) Random allocation of treatments (including controls).
b) Replication of treatments (including controls).

Randomization and replication are the two basic requirements needed to use statistical inference to estimate the response of a treatment, and develop some level of confidence about that estimate. Chance events and uncontrollable sources of variation are "averaged-out" by repeatedly randomly applying treatments.

Statistical theory is not the only method of inference. For example, the magnitude of a treatment response can be estimated using gut feeling, personal experience, anecdotal evidence, or back-yard experiments. However, these estimates are difficult to defend to outside agencies and may be very biased. The theory of statistics and experimental design methods were developed over the last century specifically to deal with these difficulties.

The basic requirements to monitor treatment response estimates using statistical inference include:

a) Random selection of sites on which to estimate treatment response.
b) Estimation of treatment response using randomization and replication of treatment application.

Random selection of sites eliminates selection bias. The list from which the sites are selected defines the sample population to which inferences can be made. Therefore, the randomization process defines the scope of inference. An example will illustrate this point. If the objective is to monitor treatment response for a group of stands, then:

a) Stands must be randomly chosen from that group.
b) Areas must be randomly chosen from within each chosen stand.
c) Treatments, including controls, must be randomly assigned to the chosen areas.

Step (a) ensures that the stands are representative of the population of interest. Step (b) ensures that the estimated treatment response is representative of the stand response. Step (c) allows treatment response to be estimated in an unbiased statistically defensible manner.

6.3 USE OF TREATMENT RESPONSE INFORMATION

6.3.1 Forest Level

Treatment response information is primarily used for broad-based strategic planning at the forest level. Information on the magnitude of responses can be used to prioritize treatments. In cases where there are no models to project the growth and yield of treated stands for timber supply analysis, treatment response information can be used to modify projections of untreated stand growth. For example, prior to the availability of fertilizer response models, yields for fertilized stands were projected by incrementing the untreated stand yield curves by a fixed percentage.

6.3.2 Stand Level

At the stand level, silviculturists use treatment response information to prioritize stands for treatment. The incremental gain in stand value is what is being purchased with silviculture investments. Silviculturists also want feedback on the response to operationally applied treatments versus treatment responses observed in experiments.

6.4 MONITORING TREATMENT RESPONSE – FOREST-LEVEL

We recommend that:

> *Treatment response not be monitored at the forest level. Checks on projections of treated stand growth and yield should be done by monitoring growth and yield after treatment.*

Estimating operational treatment responses will be difficult or impossible in many situations. Unless site, stand age, density, and structure are relatively uniform, their variability can mask treatment responses.

The growth and yield monitoring protocols developed for checking estimates of growth and yield are based on probability theory, and thus provide a statistical basis for inference and a highly defensible methodology. Monitoring estimates of treatment response at the forest level in a similar fashion, while theoretically possible, is likely not practically feasible. The elaborate logistics and costs of:

- randomly choosing a relatively large number[4] of stands from a population of stands to be treated;
- randomly choosing areas within those stands to treat and not to treat; and
- carrying out the operational application of treatments;

[4] A large sample size would likely be required due to the high amount of within and between stand variation.

are likely not worth the benefit of having a statistically defensible estimate of treatment response for a given population of stands. This is particularly true when estimates of growth after treatment that provide the information necessary to check projections of treated stands are much simpler to obtain.

We recognize that there has been considerable discussion and debate on this topic, and that the GYMTF recommended pilot testing of legacy areas for monitoring treatment response (Appendix III). Consequently, although we do not support the GYMTF recommendation, a proposed methodology for monitoring treatment response at the forest level is outlined in Appendix IV.

6.5 MONITORING TREATMENT RESPONSE – STAND-LEVEL

We recommend that:

> *Treatment response not be monitored at the stand level. Checks on projections of treated stand growth and yield should be done by monitoring growth and yield after treatment.*

As with monitoring treatment response at the forest level, the logistics and expense of obtaining a statistically defensible estimate of treatment response for an individual stand are likely not worth the costs. Monitoring growth and yield after treatment is a much more efficient choice.

There has also been considerable discussion and debate on this topic and the GYMTF recommendation to establish legacy areas could be interpreted as applying to the stand level. Consequently, although we do not support the GYMTF recommendation, a proposed methodology for monitoring treatment response at the stand level is outlined in Appendix V.

6.6 ESTIMATING TREATMENT RESPONSE – STAND-LEVEL

We recommend that:

> *Estimates of treatment response be obtained from statistically designed trials outside the growth and yield monitoring program.*

As silviculture practices are continually changing, new information on the response of stands to new and varied treatments is always required. The growth and yield monitoring program should not be viewed as a vehicle for obtaining new treatment response information. Rather, information on treatment responses should come from statistically designed trials. These trials may be established in many forms, but, to be efficient, they should meet the basic requirements of randomization and replication specified in Section 6.2.

Trials may have a research focus (i.e. be designed to determine causal relationships) or they may have an operational focus (i.e., providing a mechanism to determine the response to an operationally

applied treatment on a specific site). The measurements taken in these trials can be complex (detailed tree and stand attributes, typical in research trials) or simple (basic tree attributes to estimate yields).

The key difference between trials designed to estimate treatment response, and trials designed to monitor treatment response at the stand level, is the level of randomization and thus the scope of inference. In a trial, plots (experimental units) are typically subjectively chosen to minimize site and stand variability between plots,[5] thus making treatment responses easier to detect. Treatments are then randomly assigned to the plots. Based on statistical inference, the estimated treatment response is representative only of those plots. Assumptions must then be made, and a certain amount of risk taken to extrapolate the results to other areas. In contrast, monitoring treatment response at the stand level requires that plot locations are randomly chosen within the stand and then treatments are randomly applied. The estimated treatment response can then be assumed representative of the response for the entire stand. The problem with this approach is that the requirement for randomly located plots will in many cases introduce enough variation to mask treatment response.

There is an often-expressed desire to establish trials with operationally applied treatments to quantify the responses obtained in the "real world" as opposed to research trials. While trials with operationally applied treatments will provide information on the treatment response for the specific site and stand conditions in question, they will not provide all the answers about why differences are observed between operational and experimental settings. Stand growth is a function of many factors (e.g., site conditions, density, spatial distribution of stems, age distribution, stand health, and species composition) in addition to treatments. In an experimental setting, an attempt is made to control as many factors as possible so that the treatment effect can be isolated. Understanding why there are differences between operational and experimental conditions requires understanding how the treatments interact with all other factors that influence stand growth. Trials specifically designed to look at these interactions are needed to completely understand why responses differ between experimental and operational settings.

The following should also be considered when trying to determine why responses differ between operational and experimental settings. First, data from the growth and yield monitoring plots established in treated stands may provide some clues or indicate trends potentially explaining why differences occur. Second, by enumerating with surveys the key factors that differentiate operations from research, experiments could be conducted that focus on the interactions between these factors

[5] Not doing this greatly reduces the chance of being able to estimate the treatment response as treatment responses are often small relative to the natural variation.

and treatments. For example, the impact of irregular spatial distributions on growth and yield could be tested experimentally. Third, survey data that enumerates and describes stand conditions may lead to better predictions of growth after treatment, resulting in fewer cases of large differences between actual and predicted growth after treatment.

7. LITERATURE CITED

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8. APPENDIX I – OTHER PROGRAMS

8.1 INTENSIVE FOREST MANAGEMENT INSTALLATIONS

The 1978 IFM Program resulted in a tremendous increase in the area treated with "incremental silviculture." An Operational Monitoring Program, also called the Intensive Forestry Management (IFM) program, was initiated in 1979 to track the growth of these treated stands. Clusters of five to ten fixed-radius plots were established in a treated portion of a subjectively chosen stand, and an equal number in an untreated portion of the stand. The intent was to compare tree growth between these two areas to estimate treatment response.

The IFM installations are not suitable for monitoring estimates of growth after treatment or treatment response because they were subjectively located, and were not representative of any population (which is a primary requirement for growth and yield monitoring). In addition, treatment response cannot be determined in many of the installations. Deficiencies include the subjective location of the control and treated areas and the lack of randomization and replication. These deficiencies introduce unknown effects confounding with the treatment effect, thus making it impossible to determine what component of the observed difference in growth is due to the treatment and what is due to differences in initial stand structure and site conditions.

We continue to endorse our recommendations for the IFM installations reported September 1994 (J.S. Thrower & Assoc. Ltd. 1994). These recommendations were also endorsed by the GYMTF.

8.2 SILVICULTURALLY TREATED PROGRAM

The Silviculturally Treated (ST) program was initiated in 1985 to provide information about the growth and yield of silviculturally-treated stands. Stands were subjectively chosen by District Silviculture and Inventory staff to represent current treatments.

The ST plots are not suitable for monitoring estimates of growth after treatment or treatment response because they were subjectively located and do not represent the population of treated stands. We continue to endorse our recommendations for the ST program reported September 1994 (J.S. Thrower & Assoc. Ltd. 1994). These recommendations were also endorsed by the GYMTF.

8.3 NIVMA TRENDS

The Northern Interior Vegetation Management Association (NIVMA) is an industry cooperative that has been assessing vegetation management effects on plantation performance since 1989. Members use a common monitoring protocol and database. Their original protocol was the Unified System of Silvicultural Monitoring (USSM). The current protocol is called TRENDS (Treatment Regime Evaluation - Numerical Decision Support). The overall goal of TRENDS 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).

The NIVMA TRENDS protocol is suitable for monitoring estimates of growth after treatment, but not for monitoring treatment response.

The population monitored using TRENDS includes land in northern BC and Alberta that members are required to reforest. Installation sites are randomly selected from the population and members establish a specified number of installations each year proportional to their AAC. Each member randomly selects (with replacement and probability proportional to size) the specified number of blocks from those they plan to harvest the following year. Installations are established in chosen blocks by randomly choosing the center point. Data collected from installations in treated blocks can be used to monitor estimates of growth after treatment.

Treatment response cannot be determined or monitored because treated and untreated "control" areas are not randomly assigned, and the distribution of treatments is a function of management decisions. The following quotes from Banerjee (1996) illustrate this point.

"… *Sites that were brushed actually took longer to reach free growing status than sites that had no weed control treatment." "Are we looking at a case where (a) brushing treatments actually reduced the growth rate of seedlings or (b) brushing treatments were only done on sites where vegetation competition had already severely impacted growth rates? Similar questions can be asked concerning differences between site preparation treatments and the 'interaction' between site preparation and brushing and weeding treatments*."

8.4 EXPLORE

The experimental design protocol for long-term operational response evaluations (EXPLORE) was developed to provide a standard methodology for establishing operational experiments in silviculturally-treated areas (Biring, et al. 1998). This protocol allows for evaluation of silviculture treatments effects (particularly site preparation, and vegetation, broadleaf, and mixed wood management) on stand performance and plant community structure. The protocol also is designed to address growth and yield and vegetation management issues associated with alternative silviculture systems.

In its current application, EXPLORE cannot be used for monitoring estimates of growth after treatment or treatment response. These installations are subjectively located and therefore do not representative a particular population other than the area where the plots area located. The

installation design *would allow* for both monitoring growth after treatment and treatment response if installation locations were randomly chosen from the population of interest.

We do not recommended the EXPLORE protocol be adopted for monitoring estimates of growth after treatment or treatment response because the focus of the monitoring is to understand *why* the observed treatment response occurs. The EXPLORE research installations focus on operationally applied treatments. In addition, they are too expensive (10-14 crew days to establish), and collect more information than required to be used efficiently as growth and yield monitoring plots.

8.5 PROBE

The protocol for operational brushing evaluation (PROBE) (Simard 1993) has been used in the Kamloops and Nelson Forest Regions since 1991. This protocol provides information on crop tree, target non-crop vegetation, and plant community responses to operational brushing treatments. PROBE cannot be used to monitor estimates of growth after treatment or treatment response. Installations are not randomly established and area-based growth and yield estimates are not obtained.

9. APPENDIX II – LITERATURE REVIEW

A literature review of treated stand monitoring protocols used by other national and international agencies was conducted. No relevant material was found. Most identified information focused on large experimental trials replicated over the landscape [e.g., the Competition Omission Monitoring Project (Miller et al. 1995)]. The first part of the search used Internet "meta-search" engines (e.g., *dogpile* and *google*). Search terms included combinations of treatment, response, monitoring, protocol, operational, and silviculture. Search terms were also truncated (e.g., monit*, silvic*) to attempt to increase the number of hits. The second part of the literature search used the CD-ROM databases at the University of BC. TREECD, AGRICOLA, FSTA, and TROPAG+RURAL were all searched using the same search terms shown above. Results were reviewed by year from the mid-1970s.

A request for information was also posted to the FOREST mailing list, which has over 900 participants. This mailing list is for anyone interested in forest research. One interesting response was received from France, which is currently being pursued.

10. APPENDIX III – GYMTF RECOMMENDATIONS

The following is from Section 4.2.2, page 16 of the Silviculture Working Group report (Silviculture Working Group 1997).

"For monitoring operational growth response to spacing, the SWG recommends that legacy areas be created among the blocks to be spaced. A sub-sample of these spaced and legacy areas would be sampled at any time using re-measured TSPs. Operational response would then be estimated by comparing the treated and the untreated growth statistics. These areas would be similar to the Stand Management Cooperative (SMC) Type III installations. The only difference is that the legacy areas (areas not to be treated) would be selected at random (e.g., 5%) from all candidate areas that are due for spacing in (say) a forest region in a given year. The spaced blocks to be sampled for comparison purposes would also be selected at random from the population of treated blocks in a given year.

Taking pre- and post-treatment measurements and using split blocks may increase precision of estimates of operational growth response. However, this will also increase sampling costs and lead to an operationally less manageable program. The ability to install these legacy areas should be tested."

11. APPENDIX IV – PROPOSED METHODOLOGY FOR MONITORING TREATMENT RESPONSE AT THE FOREST LEVEL

The following proposed methodology for establishing legacy areas can theoretically be used to monitor treatment responses at the forest level. Legacy areas should not be viewed as a replacement for research trials designed to quantify treatment responses. The information obtained will be of relatively low precision and at best will ensure that treatment responses are as expected, on average and across several areas of application. Establishment of legacy areas likely will not result in detectable treatment responses, unless the responses are large relative to the natural variation in the stand.

Proposed methodology:

1. Group silviculture openings scheduled for treatment in a specified period. This defines the population to which inferences can be made. For example, all lodgepole pine stands in the 100 Mile House Forest District slated for spacing in the 1999. The treatments targeted should be restricted to those applied on a large scale.
2. Randomly chose openings with probability proportional to size in which to establish "legacy" (untreated) areas.
3. Randomly chose areas in the chosen openings (Step 2) to set aside as "legacy" areas. It is critical that these legacy areas are representative of the area to be treated.
4. Once legacy areas are established they should be well documented so that no further treatments are applied.
5. The basic options for monitoring treatment response once legacy areas are established are:
    a) Randomly establish plots in the legacy areas and in areas scheduled for treatment in the chosen openings. The five point VRI plot cluster should be used as the sampling unit to allow integration with other growth and yield monitoring plots. The first measurement should be completed before the treatment is applied. Re-measure after treatment, and on a defined re-measurement schedule thereafter. The difference between the observed growth in the treated areas and the legacy areas will be the treatment response. Estimates of response will be determined for each chosen opening.
    b) Some time after treatment, randomly sample both treated and legacy areas in the chosen blocks to get an estimate of average yield. The difference between the two yields will be the estimate of treatment response. Estimates of response will be determined for each chosen opening. This option is essentially an audit. The key component is to have legacy areas previously established.

Comparing yields (option b) will require a greater number of plots than comparing growth (option a) to obtain comparable levels of precision. When comparing yields, the assumption must be made that the treated and untreated areas had similar yields prior to treatment.

Taking measurements prior to treatment under option (a) will greatly aid future ability to detect treatment responses. Pre-treatment information can be used to adjustment treatment response estimates to reflect pre-treatment differences between control and treated areas (using covariance or regression techniques). No pre-treatment information requires assuming there were no pre-treatment differences. This is not a safe assumption as analyzing data from silviculture trials has shown that pre-treatment differences almost always exist, even under experimental conditions where an effort is made to minimize stand variability.

The following outstanding issues are central to our concerns regarding the feasibility of using legacy areas. Both could be addressed with the pilot study, and the first also may be addressed with a simulation study.

1. Sample sizes required to detect different magnitudes of treatment response over different levels of natural variation.
2. The operational logistics of defining a population of treated stands and establishing and documenting randomly selected legacy areas.

12. APPENDIX V – PROPOSED METHODOLOGY FOR MONITORING TREATMENT RESPONSE AT THE STAND LEVEL

Estimates of treatment response (and associated statements of their reliability) can be determined in each chosen stand, as long as a minimum of two untreated and two treated areas are randomly assigned. The purposed approach below intentionally does not specify plot types or measurements to be taken, as these should vary to meet specific objectives and interests.

Purposed approach:

1. Choose an individual stand or stands. This may be done to represent a range of site and stand conditions of interest, or for a demonstration area.
2. Divide each chosen stand into a minimum of four areas, or randomly choose a minimum of four areas within the stand. These areas must be large enough to accept the operational application of the treatment.
3. Randomly choose half of the areas (minimum of two) as areas to be treated. This will meet the basic requirements for randomization and replication.
4. The basic options for monitoring treatment response within each stand are then:
   a) Randomly establish plots in both treated and untreated areas and measure prior to treatment. Re-measure after treatment and on a defined re-measurement schedule thereafter. The difference between the observed growth in the treated areas and untreated areas will be the estimated treatment response.
   b) Some time after treatment, randomly sample both treated and untreated areas to get estimates of average yield in each area. The average difference between the yields of the treated and untreated areas will be the estimate of treatment response. This option is essentially an audit. The key component is to have randomly established treated and untreated areas within the stand.
5. The treatment response estimates obtained will only be representative of the stands in which they were determined. There is no statistical basis for inference to a larger population of stands.