**Forest Resource Improvement Association of Alberta**
**Forest Resource Improvement Program**

**Project OF-02-16**
**Enhanced Management of Lodgepole Pine**

# Annual Report (2004), Work Plan (2005-2008) and Detailed Project Design

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# 1. Introduction

In December 2003, the Forest Resource Improvement Association of Alberta (FRIAA) selected the project *"Enhanced Management of Lodgepole Pine"*, proposed by the Foothills Growth and Yield Association (FGYA), for support under FRIAA's Open Funds initiative. The five-year Project is focused on filling information gaps in nutrition and density management of fire-origin and post-harvest stands. It is complementary to the five projects already initiated by the Foothills Growth and Yield Association (FGYA) to improve the assessment of lodgepole pine growth and yield in managed stands.

The project objectives are to:

1. Develop techniques and yield tables to predict the growth response of stands to density and nutrition management practices with potential for enhancing timber volume, economic value, and / or forest health.
2. Produce stand assessment guidelines and interpretative criteria for selecting nutrition and density management treatments.
3. Establish a network of sample plots for demonstrating and monitoring actual versus predicted growth responses.
4. Assess impacts of enhanced forest management practices on stand composition, structure, biodiversity, susceptibility to fire and insect damage, and wood quality.

An annual work plan for 2004-05, including a preliminary work and cost schedule for the entire project, was submitted in March 2004. Work commenced in April 2004, and will be funded by FRIAA until June 2009.

Section 2 below describes work done in 2004-05, relative to the approved work plan. Section 3 is a work plan for 2005-06 with schedules and deliverables projected to 2008-09. Section 4 provides further details of the project design.

# 2. Annual Report (2004-05)

## *2.1. Income and Expenditures*

Table 1 shows income and expenditures for the period April 1, 2004 – March 31, 2005. Actual expenditures are substantially less than the budgeted amounts. The budgeted amounts shown are as per the annual work plan for 2004-05.

**Table 1. Income and Expenditures**

| Income / Expense | Budget | Actual (Feb 28) |
|---|---|---|
| **Income** | | |
| FRIAA funding (Project OF-02-16) | 126,200 | 126,200 |
| **Expense** | | |
| Stand reconnaissance and selection | 34,200 | 31,200 |
| Baseline measurements and foliar analysis | 78,000 | 13,534 |
| Design and analysis | 14,000 | 16,197 |
| Total expense | 126,200 | 60,931 |
| **Ending Balance** | 0 | 65,269 |

Revised schedules were subsequently developed for the project, and are included in Section 3 below.

The baseline measurements and foliar analysis work is currently proceeding under contract. It will not be completed until May 31, 2005, but at less cost than originally budgeted. The unspent budget has been re-distributed according to a revised project schedule (see text below and Table 5).

## *2.2. Achievements and Shortfalls*

Achievements, shortfalls and problems encountered with this project are summarized in Table 2.

**Table 2. Achievements and Shortfalls**

| Deliverable | Achievements / Shortfalls / Problems |
|---|---|
| Stand reconnaissance and selection (see Appendix 1) | - All member companies provided lists of stands expected to meet project experimental criteria<br>- Candidate stand list large (44,000 stands), variable and stand classification was in some cases unreliable<br>- High incidence of poorly stocked stands with aspen or brush competition<br>- Selection criteria did not include pine-aspen stands (now proposed for inclusion in sub-project 2)<br>- Stand database developed and filtered<br>- Ground measurements made on 66 stands with potential for further experimentation |
| Detailed project design (see Section 4) | - Design options reviewed by Technical Committee and outside experts; action plan developed<br>- Detailed design drafted (but final version not yet reviewed and endorsed by Technical Committee) |
| Baseline measurements and foliar analysis (see Appendix 2) | - Work delayed; re-scheduled and contracted for completion by May 31, 2005 |
| Annual work plan (2005) | - See Section 3 below |

During 2004 the development of the detailed project design was preceded by identification and reconnaissance of candidate stands, review of other projects and results in Alberta and B.C., and consultation with researchers in both provinces. Based on the reconnaissance, review and consultations options were identified for the final design and for resolving design questions.

The options were reviewed by the FGYA Technical Committee, and an action plan was developed involving:

- Dividing the project into 2 sub-projects: (1) lodgepole pine nutrition and (2) pine-aspen density management;
- Further consultations with specialists to resolve design questions;
- Initiating baseline measurement and foliar analysis work for the first sub-project, through a contract sole-sourced to MCH Forestry Ltd.;
- Finalizing the detailed project design.

The action plan was incorporated into the FGYA Business and Work Plan which was approved by the Steering Committee on March 16, 2005.

# 3. Work Plan

## *3.1. Methods, Activities and Deliverables*

During 2004 the development of a detailed project design was preceded by identification and reconnaissance of candidate stands, review of other projects and results in Alberta and B.C., and consultation with researchers in both provinces. Based on considerations described below in Section 4, the Project has been divided into 2 sub-projects aimed at addressing the main information gaps limiting achievement of the objectives. The 2 sub-projects are: (1) lodgepole pine nutrition and (2) pine-aspen density management. Separate experimental designs have been developed for each sub-project.

### 3.1.1. Methodology for Sub-project 1: Lodgepole Pine Nutrition

This study will focus on providing members the ability to determine:

1. Which stands on their forest management areas are most likely to respond best to fertilization;
2. What yield increases can be expected from the stands most likely to respond.

The sub-project involves sampling and selective treatment of 30 stands reconnoitered in 2004, of which 15 are young (10 – 30 years of age) post-harvest, and 15 mid-late (30-80 years) fire-origin. Detailed baseline assessments are in progress and scheduled for completion May 31, 2005. Available models and diagnostic techniques will be used to rank the stands by probable response. Subject to results of the baseline assessment and requests for financial proposals to undertake the fieldwork, fixed-area treatment plots will be established in some or all of the stands ranked. Treatments will include thinning to 2500 stems per ha (post-harvest stands only) and fertilization (300 kg per ha N plus blend), plus controls. Tree, stand and foliar variables will be measured prior and after treatment, and at 3, 6, and 9 years following treatment. (Only measurements up to year 3 are included in the current funded project).

### 3.1.2. Methodology for Sub-project 2: Pine-aspen Density Management

The study will assess, on pine sites subject to hardwood competition, what density management alternatives are expected to provide the best total and coniferous timber productivity.

The sub-project will involve selection[1] of up to 30 post-harvest pine-aspen stands between 10 and 40 years of age, partitioning the stands into areas of high, medium and low aspen density, and measuring 6 or more plots in each stand. Plots will be tree-mapped and measured in detail. A sub-sample of plots in about 5 of the stands will be destructively sampled to obtain retroactive data on height and diameter increment for both pine and aspen. The remaining plots will be maintained for re-measurement.

The subsequent analysis will involve assessment of competition indices and responses useful for developing or validating whole-stand, individual-tree, and/or distance-dependent growth models. The resulting models will be used to provide the required forecasts within the project term, while

[1] The selection criteria for stands assessed during the 2004 reconnaissance excluded stands classified in FGYA members' inventories as less than 80% pine composition. Although the identified stands included many that meet the density and composition criteria of pine-aspen sub-project, FGYA members will be asked to identify additional candidate stands.

the maintained plots will allow for longer-term monitoring of actual versus forecast growth and yield.

### 3.1.3. Tasks and Deliverables

Table 3 shows tasks for scheduled by month for the 2005-06 fiscal year (April 1, 2005 – March 31, 2006). Thinning treatments under Sub-project 1 will be completed in the third quarter of the 2005-06 fiscal year, but fertilization will not be applied until the first quarter of the 2006-07 fiscal year. The sampling under Sub-project 2 is expected to be spread over 2 field seasons, with approximately 50% of the work completed during 2005.

**Table 3. Work Program by Month for 2005-06 Fiscal Year**

| Task | 2005 | | | | | | | | | 2006 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | M | J | J | A | S | O | N | D | J | F | M |
| Sub-project 1 - baseline assessment | X | X | | | | | | | | | | |
| Sub-project 1 – field installation | | | | | | | X | X | X | | | |
| Sub-project 1 - thinning | | | | | | | | | | X | X | X |
| Sub-project 2 – stand selection | X | X | X | X | | | | | | | | |
| Sub-project 2 – field sampling | | | | | X | X | X | X | | | | |
| Analysis and reporting | | | X | X | X | | | | X | X | X | X |

Table 4 shows the schedule of activities and deliverables by fiscal year (April 1 – March 31).

In 2005-06 a technical progress report will be produced describing the results of the baseline assessment (including response forecasts) and the field installation, thinning, stand selection, and field sampling work undertaken. An annual report will be submitted including financial statements.

**Table 4. Work Program by Fiscal Year**

| Activity | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|
| ***Sub-project 1: lodgepole pine nutrition*** | | | | |
| Baseline assessment[2] | x | | | |
| Installation and pre-treatment measurement of plot clusters | x | | | |
| Thinning, fertilization and post-treatment measurements | x | x | | |
| 1-year post-fertilization foliage analysis | | x | | |
| 3-year growth response measurements | | | | x |
| 3-year post-fertilization foliage analysis | | | | x |
| Analysis | x | x | x | x |
| ***Sub-project 2: pine-aspen density management*** | x | | | |
| Stand selection | x | | | |
| Field sampling | x | x | | |
| Analysis | | x | x | |
| ***Analysis, synthesis of results and reporting*** | | | | |
| Annual reports and work plans | x | x | x | x |
| Scientific paper (pine-aspen results) | | | x | |
| Technical and information reports | x | x | | x |

[2] Field and laboratory work contracted for completion by May 31, 2005.

During the subsequent 3 years:

- At least 2 information reports, one including managed stand yield tables, and one including stand assessment guidelines and interpretative criteria for thinning and fertilization, will be prepared and published.
- At least one scientific paper will be prepared for peer review and publication in a recognized scientific journal.
- A final technical reports will be submitted to FRIAA and the FGYA membership at the end of the fifth year, including (or referencing as reported elsewhere) details of trial establishment, techniques applied, responses measured, responses forecast, predictive models developed, and conclusions regarding factors influencing responses.
- Annual and final financial reports will be submitted.

## *3.2. Budget and Payment Schedules*

The project (FRIAA # OF-02-16) will be supported with FRIP funding to a maximum of $442,800, provided under FRIAA's *Open Funds* initiative. Table 5 shows the proposed cost schedule by year. Note that this schedule applies to the total project term, which is from April 1, 2004 to June 30, 2009, and includes the past year actual expenditures as well as those projected for 2005-06 onwards.

**Table 5. Cost Schedule by Fiscal Year**

| Activity | 2004-5 | 2005-6 | 2006-7 | 2007-8 | 2008-9 | Total |
|---|---|---|---|---|---|---|
| ***Reconnaissance and design*** | | | | | | |
| Field reconnaissance | 31,200 | | | | | 31,200 |
| Compilation and design | 16,197 | | | | | 16,197 |
| Subtotal | 47,397 | | | | | 47,397 |
| ***Sub-project 1: lodgepole pine nutrition*** | | | | | | |
| Baseline assessment | 13,534 | 39,469 | | | | 53,003 |
| Installation of experimental plots[3] | | 30,000 | | | | 30,000 |
| Experimental treatments[4] | | 25,000 | 25,000 | | | 50,000 |
| 1-year foliage analysis | | | 10,600 | | | 10,600 |
| 3-year growth measurements | | | | | 18,900 | 18,900 |
| 3-year foliage analysis | | | | | 10,600 | 10,600 |
| Subtotal | 13,534 | 94,469 | 35,600 | | 29,500 | 173,103 |
| ***Sub-project 2: pine-aspen density management*** | | 83,700 | 83,700 | | | 167,400 |
| ***Analysis and synthesis of results*** | | 14,000 | 14,000 | 6,300 | 20,600 | 54,900 |
| **Total project** | 60,931 | 192,169 | 133,300 | 6,300 | 50,100 | 442,800 |

[3] Includes pre-treatment measurements
[4] Includes post-thinning measurements

# 4. Details of Project Design

## *4.1. Preliminary Design Concept*

The following concept was conceived and outlined in the original project proposal[5].

1. An initial list of candidate stands were to be assembled by the FGYA Technical Committee based on the 9 members' forest inventory data.
2. The stands were to be reconnoitered and filtered, as required to make a selection of approximately 60 stands, distributed across the range of nutrient regimes and stand development stages (see Appendix 1).
3. Tree, stand, foliar (including nutrient), and soil / site variables implicated in response to thinning and fertilization would be measured on the final selection of stands.
4. Available models and diagnostic techniques would be used to rank the stands into 3 categories (i.e. with about one-third of the stands in each category). Categories are: (A) high probability for treatment response and suitable for fixed-area experimental treatments, (B) uncertain response potential and suitable for continued diagnosis and (C) little probability of response and not meriting further assessment.
5. Clusters of fixed-area treatment plots would be established in the category "A" stands. (20 such clusters were assumed, in a maximum of about 5 strata.) The basic design for a cluster was envisioned as a 2-factor split plot e.g. with control, thinning, fertilization, and thinning-plus-fertilization treatment combinations. Tree and stand variables would be measured prior to treatment, and at 1, 3, 6, and 9 years following treatment.
6. Additional stands with uncertain response potential (category "B") would continue to be screened during the project period. This will involve micro-plot application of fertilizer, and re-analysis of needle weights and nutrient concentrations after 1 and 3 years.

The FGYA committed to preparing a detailed project design following reconnaissance and initial assessment of candidate stands in 2004.

## *4.2. General Design Considerations*

During 2004 the reconnaissance identified in the original proposal was conducted (see Appendix 1), other research trials and results in Alberta and B.C. were reviewed, and experts in both provinces were consulted as part of the design process. The considerable inputs of Rob Brockley of the B.C. Ministry of Forests and Vic Lieffers and Phil Comeau of the University of Alberta are gratefully acknowledged.

Comprehensive assessment of fertilization and density management treatments across a wide range of stand and site conditions is desirable in order to meet the project objectives. However, this consideration has to be weighed against the following observations and conclusions drawn from the 2004 reconnaissance and reviews.

- The project required prioritization and partitioning of design components in order to limit excessive proliferation of experimental treatments, measurements and costs.

[5] Foothills Growth and Yield Association. 2003. *Enhanced management of lodgepole pine.* Proposal submitted to Forest Resource Improvement Association of Alberta, FRIP Open Funds Program.

- Thinning and fertilization trials already established in Alberta in fire-origin stands (and being monitored and analyzed by individual members and collectively by the FGYA in collaboration with the Canadian Forest Service) can be utilized effectively to complement and avoid duplication with new work.
- Sub-optimal stocking, particularly that resulting from aspen and brush competition, is severely limiting the opportunities for enhancing productivity in managed stands through thinning and fertilization.
- Treatment and competition effects on productivity of pine sites prone to aspen competition are not being adequately addressed by other projects, and should be given high priority.
- The highest priority for nutritional management research remains to identify what site and stand conditions have the best potential for response to fertilization.

Based on the above considerations, the Project was divided into 2 sub-projects aimed at addressing the main information gaps limiting achievement of the objectives. The 2 sub-projects are *Lodgepole Pine Nutrition* and *Pine-aspen Density Management.*

## *4.3. Lodgepole Pine Nutrition*

The first (*"Lodgepole Pine Nutrition"* sub-project) will investigate the best fertilization opportunities across the range of pine types and age classes available to FGYA members, by (a) expanding and consolidating research already conducted in fire-origin stands and (b) investigating the potential for optimizing fertilization response in combination with density management in stands regenerated following harvesting.

### 4.3.1. Objectives

The experimental objectives will be to provide foresters managing lodgepole pine stands in Alberta the ability to determine:

1. Which stands and stand conditions are most likely to respond best to fertilization;
2. What yield increases can be expected from the stands most likely to respond.

### 4.3.2. Design Considerations

The following issues were addressed, and conclusions drawn, during the design phase.

1. *Utility of baseline foliar and stand assessments versus one-year foliar responses and / or vector analysis for answering Question 1*. Work by Brockley in B.C. has suggested that nutrient assessment using pre-fertilization foliar levels of nitrogen and sulphur may have greater utility than 1$^{st}$-year increases in fascicle mass (from fertilizer screening trials) for assessing fertilization response potential. This is consistent with results obtained by Hinton Forest Products in Alberta. The extra information gained from assessing one-year foliar responses are not considered therefore to merit delaying selection of stands for installing fixed-area trials. Given the concomitant time savings, we will rely on baseline assessments to select stands likely to respond to fertilization, followed by installation of fixed-area plots to quantitatively assess yield increases
2. *Use of a large number of dispersed "mini" plots versus smaller number of fixed-area trial plots.* Small or individual-tree plots are useful for identifying potentially responsive stands, but ineffective in ranking stands in order of yield response. Fixed-area trials require replicated plots each with buffered inner assessment areas large enough to contain 50 trees tagged for re-measurement. Experimental clusters (replicates) should be compact and small

enough to facilitate placement within areas of uniform site and stand conditions. We will establish area-based treatment plots with inner assessment areas sufficiently large to contain a minimum of 50 tagged trees (densities projected to last scheduled measurement at year 9), with a 10m treated (fertilized) buffer to the treatment plot edge (i.e. creating 20m between assessment plot edges).

3. *Importance and feasibility of conducting experimental thinning treatments versus selecting existing stands for fertilization across a range of densities.* Fertilization response will be confounded by differences in site and stand conditions, particularly in fire-origin stands. We will test fertilization under both thinned and non-thinned conditions at as many locations as can be accomplished within the project budget, using a single thinning regime (2500 stems per ha). Several trials combining thinning and fertilization are already installed in fire-origin stands in Alberta. We will therefore focus combined thinning and fertilization in managed stands of post-harvest origin.

4. *Timing of fertilization relative to thinning.* Serious problems (primarily animal, snow, and wind damage) have been observed in B.C. when fertilization and thinning are undertaken at the same time. However, work in B.C. and Alberta indicates that higher responses may be expected when the treatments are not separated over time. Furthermore, delaying fertilization would severely curtail results achievable within the limited funded term of this project. High-density fire-origin stands with large height-diameter ratios (e.g. > 90) are most susceptible to damage. We will attempt to minimize or avoid the associated risks by conducting experimental thinning and fertilization at the same time, but limiting thinning treatments to post-harvest managed stands with low-risk height-diameter ratios.

5. *Assessment of appropriate fertilizer composition and rate*. Nitrogen is the nutrient most limiting the growth of lodgepole pine forests in Alberta. Secondary or induced nutrient deficiencies of sulphur and boron, similar to those reported in the B.C. interior, are indicated as likely for Alberta. The operational use of blended fertilizer with sulphur and boron added may be prohibitively expensive. Application rates of 200kg N are commonplace in B.C., but there is some indication that these may be sub-optimal for Alberta, particularly if blended to offset induced deficiencies. Studies are ongoing in B.C. on the efficacy of urea versus other N formulations. Initial results suggest that the low relative price of urea is likely to offset marginally and inconsistently higher responses observed in ammonium nitrate. We will employ 3 basic fertilization treatments: (1) control, (2) 300kg N (urea), and (3) 300kg N (urea) + S (or complete blend). The decision whether to add boron and / or other blended elements will be deferred pending assessment of the baseline foliar analyses.

6. *Relative importance of sampling across the range of site index, age and stand origin.* B.C. experience suggests focusing on (a) commonly occurring good to medium mesic sites, (b) younger stands (15-30 years), (c) stands of post-harvest origin. In Alberta, there are currently large areas of mid-late stage fire-origin stands that are ostensible candidates for short-term stand-level investments. However, work in B.C. and elsewhere suggests that the largest absolute productivity responses are obtained at earlier ages. Furthermore, no comprehensive studies have been conducted on fertilization in the rapidly expanding area of managed post-harvest stands. We will conduct baseline assessments in 30-80 year fire-origin stands as well as 10-30 year old stands of post-harvest origin. Subject to results of the baseline analysis, we will undertake fixed-area fertilization in the fire-origin stands, and both thinning and fertilization in the post-harvest stands. Stands selected for baseline assessment will be those already identified by the 2004, with some further elimination of fire-origin stands based on age, health, access and squirrel damage.

### 4.3.3. Methods

The methods applied will be as included in the original proposal (and summarized in Section 4.1 above), with the following variations and / or clarifications.

- The sub-project will be involve sampling and selective treatment of 30 stands reconnoitered in 2004, of which 15 will be young (10 – 30 years of age) post-harvest, and 15 mid-late (30-80 years) fire-origin. All stands were pre-selected as having good stocking and health. The pre-selection was also aimed at stands identified by experts as having potential for enhanced forest management.[6]
- Detailed baseline assessments are being conducted as described in Appendix 2.
- Available models and diagnostic techniques will be used to estimate expected responses.
- Depending on bid costs and baseline assessment results, fixed-area treatment plots will be established in all 30 assessed stands. The number of stands treated and sampled may be less depending on actual or bid costs per stand relative to that assumed in Table 5. In order to maximize the power of the between-stand covariance analysis, there will be no within-stand replication. Tree and stand variables will be measured prior and after treatment, and at 3, 6, and 9 years following treatment. (Only measurements up to year 3 are funded under the current project) Foliar nutrient concentrations and needle mass will be measured 1 and 3 growing seasons after treatment.

In the post-harvest stands selected for fixed-area thinning and fertilization treatments (minimum post-treatment densities of 2500 stems per ha) the experimental split-plot design will involve:

- Thinned and non-thinned whole-plots (i.e. 2 whole-plots per stand). The placement and minimum buffer between and surrounding whole-plots will be designed to provide a minimum of 20m between assessment plot boundaries, and from assessment plot boundaries to stand edge.
- Each whole-plot will be split into 3 square fertilizer sub-plots (control, N, and N+S/blend), each with an inner assessment area of 200$m^2$ (50 trees at 2500 stems per ha), and a 10m treatment buffer (i.e. treated sub-plot size approximately 1,225$m^2$).

In the fire-origin stands selected for fixed-area fertilization treatments, the design will involve:

- Non-thinned whole-plots (1 whole-plot per stand). The placement and minimum buffer between and surrounding whole-plots will be designed to provide a minimum of 20m between assessment plot boundaries, and from assessment plot boundaries to stand edge.
- Each whole plot will be split into 3 square fertilizer sub-plots (control, N, and N+S), each with an inner assessment area of 400$m^2$ (50 trees at 1250 stems per ha), plus a 10m treatment buffer (i.e. treated sub-plot size 1,600$m^2$).

The sub-project essentially involves 3 experiments:

1. Baseline assessment, currently in process, aimed at enumerating site, stand and foliar variables with potential for forecasting response to thinning and fertilization, and assessing for these variables any significant differences between stands;

[6] The following criteria were used to indicate potential for nutrition or density management:

- In the 0 - 30 age class: average height over 1.3m but less than 4m, with maximum stump diameter 8cm, 5000+ healthy stems per ha, low gall rust and canker incidence, stocking 80%+;
- In the 31-70 age class: good stocking (80%+, min. 2500 spha), good crowns (min 40% LCR), low disease incidence.

Difficulty was encountered in locating such stands, and as a result not all conditions could be consistently met.

2. Assessment of growth response to thinning and fertilization in managed stands regenerated following harvesting;

3. Assessment of growth response to fertilization in non-thinned fire-origin and post-harvest stands.

In experiments 2 and 3 the questions addressed will be:

- What effect do fertilization and (for experiment 2 only) thinning treatments have on growth response?
- To what extent can variation in responses between stands be explained by operationally-measurable covariates?

The analyses will involve application of a general linear model with continuous dependent variables, controlled factors (thinning and fertilization), and continuous covariates (e.g. site index, age, stand density index, average bole and crown dimensions, fascicular mass, foliar nutrient concentrations).

## *4.4. Pine-aspen Density Management*

The *Pine-aspen Density Management* sub-project will focus exclusively on density and species management in pine-aspen mixtures regenerated following harvesting.

### 4.4.1. Objectives

The information gathered in the field will contribute to development of models describing effects of aspen competition on growth of lodgepole pine in post-harvest stands between 10 and 40 years of age in the Lower and Upper Foothills ecological sub-regions of western Alberta. It will enable direct estimation and modeling of growth at both the tree and stand (per ha) level, and support both spatial and non-spatial models and competition indices.

The information will be used to assess, on pine sites subject to hardwood competition, what density management alternatives are expected to provide the best total and coniferous timber productivity.

### 4.4.2. Design Considerations

Three design options were considered.

1. Establish a long-term replicated regeneration trial immediately following harvests in pine-aspen cover types or pine types prone to competition by aspen and/or other tree/shrub species. Experimental treatments would include 2 or more initial densities of lodgepole pine, and a range of permitted inter-specific competition levels.

2. As above, but instead of initiating at harvest and incurring a very long delay before obtaining results, the trial would be established in 10 -15 year old stands in which both pine and aspen are already established, over a range of densities. Plot locations would be selected, and both species thinned as necessary, to obtain a range of density combinations.

3. A combination of destructive sampling and ongoing re-measurement to assess the relationship between competition and growth in existing 10 – 40 year old pine-aspen stands. The project would be designed to provide in both the short and medium term data and relationships that would be used to enhance the prediction capability of growth and yield models (MGM, GYPSY, TASS).

Options 1 and 2 have potential for long-term monitoring. However, they were rejected in favor of option 3, because the latter has the potential for quickly providing useful and urgently needed

information on growth response to competition. This information is expected to produce sufficient improvements in forecasting capability to allow the experimental objective to be met within the term of the Project (i.e. before March 31, 2009). The existing FGYA lodgepole pine regeneration trial will go part way meet the first design option, since many of the experimental installations are incurring aspen invasion, and all installations involve split-plots with and without brush control.

### 4.4.3. Methods

The methodology is based on a proposal by Dr. P. Comeau of the University of Alberta to provide individual-tree competition measurements required for development and calibration of the Mixedwood Growth Model (MGM). The approach has been adapted to provide unbiased estimates of growth for direct estimation and modeling of growth at both the tree and stand (per ha) level, and to support both spatial and non-spatial models and competition indices.

It will involve selection of up to 30 pine-aspen stands[7], partitioning the stands into areas of high, medium and low aspen density, and locating 6 plots in each stand (2 or more in each area).

Data will be obtained from stands ranging from 10 to 40 years of age. Within each 10 year age class, up to 5 stands in the Lower and Upper Foothills ecological sub-regions will be selected from sites characterized as having circum-mesic (submesic-mesic) soil moisture regimes.

Selected stands will be at least 5 ha in size and be reasonably homogeneous in terms of soil moisture regime and ecosite. They will contain both pine and aspen (see below). Selected stands will be characterized in terms of ecosite, soil moisture and soil nutrient regime, and soil drainage to provide descriptive site information and as a basis for possible additional stratification of the data. A soil pit will be excavated and described at each site.

The selection criteria for stands assessed during the 2004 reconnaissance excluded stands classified in FGYA members' inventories as less than 80% pine composition. Although screened stands included some that met the required density and composition, FGYA members will be asked to identify additional candidate stands, using the following criteria:

- Age 10 – 40 (years after harvest).
- Mesic soil moisture regimes (inclusions of drier or wetter areas are acceptable, provided that there is sufficient area that is mesic to allow sampling of only the mesic portions of the block).
- Minimum area of 5 ha reasonably homogeneous in soil moisture regime and ecosite.
- Stand is healthy and showing no evidence of serious gall rust infection, root disease, or damage by insects or other agents.
- Pine density averages over about 1000 stems per ha.
- Component of aspen present, but stand should have areas with no (or low densities) of aspen as well as areas exceeding minimum targets (see below). Since we want to capture the widest possible range of aspen densities, it is desirable to find stands with high densities of aspen in portions of the blocks while also having portions with little or no aspen.
- Stands should contain areas with minimum aspen densities exceeding the following stems per ha, depending on age:
    - 10-20 years: minimum 2000 stems per ha;
    - 20-30 years: minimum 1000 stems per ha;

[7] The number of stands sampled may be less depending on actual or bid costs per stand relative to that assumed in Section 6.

    - 30-40 years: minimum 500 stems per ha.
- Brushed blocks should generally be avoided. However, brushed-blocks with non-brushed portions of blocks exist adjacent to brushed portions may be used if the areas are sufficiently large and provided that brushing was done at least 5 years ago (prior to 2000).

The plot size will be 300$m^2$ and circular. It will usually be large enough to include 12 lodgepole pine subject trees (assuming minimum densities at any point in the stand of about 400 stems per ha). Plots will be measured using laser hypsometer technology facilitating automated digital mapping and spatial analysis. All trees > 1.3m in height will be measured for height and diameter. The 3 largest-diameter aspen and lodgepole pine trees will also be measured for breast-height age and hence site index. Additional measurements will be made on subject trees. Additional neighborhood competitor trees external to the mapped plot will be measured where necessary to complete "competition measurement plots" centered on each subject tree.

Three plots in 5 of the stands will be sampled (or sub-sampled) destructively to obtain or confirm retroactive assessments of height and diameter increment for both pine and aspen. The remaining plots will be maintained for re-measurement; with limited plot demarcation (staked and geographically positioned plot centers and tagged subject trees).

The analysis will involve:

- Spatial compilation of tree data and locations to create plot maps, virtual stocking and competition measurement sub-plots, and hence computation of a variety of spatial and non-spatial competition indices.
- Compilation of tree and stand-level increments, comparison of competition indices, and assessment of responses useful for developing or validating whole-stand, individual-tree, and/or distance-dependent growth models.
- Application of resulting models and relationships to investigate alternative density management options.

Subsequent re-measurement of the maintained plots (not included in the project budget) will allow for expansion of this data set and for long-term monitoring of actual versus forecast growth and yield.

# Appendix 1. Identification and Reconnaissance of Candidate Stands

FGYA member FMA-holders were requested to provide lists and locations for candidate stands meeting the following criteria:

- pine leading (minimum 80% lodgepole pine composition);
- adjacent to road;
- not scheduled for harvesting within 9 years;
- containing an undisturbed and relatively homogenous area of at least 5 ha;
- no watercourse or water body within 30m;
- be classified into stand origin, age, and site classes.

Records for 44,000 stands were provided. These were pre-screened to 12,423. Further selections were made based on access, logistics, and representation across the range of origin, age and site, to produce a candidate long list for reconnaissance containing 769 stands. Reconnaissance was conducted in 3 steps: air-photo inspection, ground viewing, and ground measurement. Approximately 50% of the long list were subsequently rejected as incorrect classifications, or as experimentally unusable for one or more of the following reasons:

- poor access;
- fragmented by linear disturbance;
- insufficient area;
- laid out for harvest or already harvested;
- anomalous terrain or non-modal wet site;
- presence of over-storey;
- containing existing trial or PSP;
- wrong location.

This left a short list of 379 stands, distributed as indicated in Table 1.

**Table 1. Distribution of short-listed candidate stands by development stage and site class**

| Origin type | Age class | Soil nutrient regime | | | Total |
|---|---|---|---|---|---|
| | | poor | medium | rich | |
| Fire | 0-30 | 1 | 1 | | 2 |
| | 31-70 | 6 | 45 | 17 | 68 |
| | 71+ | 9 | 68 | 25 | 102 |
| | sub-total | 16 | 114 | 42 | 172 |
| Managed | 0-30 | 13 | 82 | 54 | 149 |
| | 31-70 | 3 | 25 | 30 | 58 |
| | sub-total | 16 | 107 | 84 | 207 |
| Total | | 32 | 221 | 126 | 379 |

In addition to the selection criteria mentioned above, following a field inspection with experts from the University of Alberta, an attempt was made to target stands with the following conditions indicating potential for nutrition or density management:

- In the 0 - 30 age class: average height over 1.3m but less than 4m, with maximum stump diameter 8cm, 5000+ healthy stems per ha, low gall rust and canker incidence, stocking 80%+;
- In the 31-70 age class: good stocking (80%+, min. 2500 spha), good crowns (min 40% LCR), low disease incidence.

These were applied as additional selection criteria in the first half of the reconnaissance (Alberta Newsprint, Sundance and Weldwood FM areas). However, difficulty was encountered in consistently locating such stands, and the conditions were dropped as selection criteria for the second half of the reconnaissance.

Of 379 stands, 171 were well-stocked, 208 (55%) were under-stocked (less than 80% pine stocking). In more than half of the latter the under-stocking was aspen or brush related. Table 2 shows a breakdown of the 171 candidate stands retained as adequately stocked.

Ground measurements were acquired for a total of 66 of the retained stands. The distribution of these plots is shown in Table 3, and averages for a number of stand variables are summarized in Table 4. Although averages are differentiated by site class, the reliability and utility of the breakdown is questionable, given the inconsistencies, small sample size, and lack of differentiation in site index.

The number of candidate stands targeted in the Project 2004-5 Annual Work Plan was 240, with a minimum of 15 stands in each site and age class (except the 31-70 year managed, which was not included). The intent was to narrow the candidate stands down to between 48 and 64, with a minimum of 3 per site and age class combination. Note that insufficient candidate stands were found, from the long list of 769 stands, within young fire-origin stands, on poor sites in managed stands, and on rich sites in fire-origin stands. (The original pre-screened database of 12,423 stands contains a minimum of 25 stands in each stratum combination.)

**Table 2. Distribution of adequately-stocked stands**

| Origin type | Age class | Soil nutrient regime | | | Total |
|---|---|---|---|---|---|
| | | poor | medium | rich | |
| Fire | 0-30 | 1 | 1 | | 2 |
| | 31-70 | 5 | 24 | 6 | 35 |
| | 71+ | 9 | 38 | 12 | 59 |
| | sub-total | 15 | 63 | 18 | 96 |
| Managed | 0-30 | 3 | 23 | 10 | 36 |
| | 31-70 | 3 | 15 | 21 | 39 |
| | sub-total | 6 | 38 | 31 | 75 |
| Total | | 21 | 101 | 49 | 171 |

**Table 3. Distribution of ground-measured stands**

| Origin type | Age class | Soil nutrient regime | | | Total |
|---|---|---|---|---|---|
| | | poor | medium | rich | |
| Fire | 0-30 | 1 | 1 | | 2 |
| | 31-70 | 3 | 15 | 2 | 20 |
| | 71+ | 5 | 11 | 1 | 17 |
| | sub-total | 9 | 27 | 3 | 39 |
| Managed | 0-30 | 1 | 13 | 2 | 16 |
| | 31-70 | 1 | 6 | 4 | 11 |
| | sub-total | 2 | 19 | 6 | 27 |
| Total | | 11 | 46 | 9 | 66 |

## Table 4. Averages of measured stands

| Variable | Origin type | Age class | Soil nutrient regime | | | Total |
|---|---|---|---|---|---|---|
| | | | Poor | Medium | Rich | |
| Site index (m) | Fire | 0-30 | 16.8 | 17.4 | | 17.1 |
| | | 31-70 | 19.0 | 17.7 | 16.2 | 17.7 |
| | | 71+ | 13.9 | 17.2 | (24.1) | 16.6 |
| | | sub-total | 15.9 | 17.5 | 18.8 | 17.2 |
| | Managed | 0-30 | (19.2) | 20.5 | 22.0 | 20.6 |
| | | 31-70 | (16.3) | 17.5 | 19.7 | 18.2 |
| | | sub-total | 17.7 | 19.6 | 20.5 | 19.6 |
| | Total | | 16.3 | 18.3 | 19.9 | 18.2 |
| Density (stems/ha) | Fire | 0-30 | 5500 | 26000 | | 15750 |
| | | 31-70 | 1733 | 3263 | 2550 | 2963 |
| | | 71+ | 2024 | 955 | 1100 | 1278 |
| | | sub-total | 2313 | 3165 | 2067 | 2884 |
| | Managed | 0-30 | (6000) | 6877 | 8000 | 6963 |
| | | 31-70 | (11800) | 6000 | 3090 | 5469 |
| | | sub-total | 8900 | 6600 | 4727 | 6354 |
| | Total | | 3511 | 4584 | 3840 | 4303 |
| BH age (years) | Fire | 0-30 | 19 | 24 | | 22 |
| | | 31-70 | 39 | 43 | 38 | 42 |
| | | 71+ | 97 | 96 | 81 | 95 |
| | | sub-total | 69 | 64 | 52 | 64 |
| | Managed | 0-30 | 12 | 14 | 17 | 14 |
| | | 31-70 | 20 | 27 | 26 | 26 |
| | | sub-total | 16 | 18 | 23 | 19 |
| | Total | | 59 | 45 | 33 | 46 |
| Top height (m) | Fire | 0-30 | 8.1 | 10.2 | | 9.2 |
| | | 31-70 | 15.5 | 15.5 | 13.3 | 15.2 |
| | | 71+ | 19.6 | 23.5 | 29.6 | 22.7 |
| | | sub-total | 16.9 | 18.5 | 18.7 | 18.2 |
| | Managed | 0-30 | 6.4 | 7.5 | 10.4 | 7.8 |
| | | 31-70 | 8.1 | 11.4 | 12.2 | 11.4 |
| | | sub-total | 7.3 | 8.7 | 11.6 | 9.2 |
| | Total | | 15.2 | 14.5 | 13.9 | 14.5 |
| Stocking (%) | Fire | 0-30 | 60 | 80 | | 70 |
| | | 31-70 | 67 | 66 | 73 | 67 |
| | | 71+ | 63 | 65 | 65 | 64 |
| | | sub-total | 64 | 66 | 70 | 66 |
| | Managed | 0-30 | 50 | 59 | 70 | 60 |
| | | 31-70 | | 65 | 65 | 65 |
| | | sub-total | 50 | 62 | 66 | 62 |
| | Total | | 63 | 64 | 68 | 65 |
| Live crown (%) | Fire | 0-30 | 21 | 50 | | 36 |
| | | 31-70 | 40 | 32 | 33 | 34 |
| | | 71+ | 30 | 34 | 18 | 32 |
| | | sub-total | 33 | 34 | 28 | 33 |
| | Managed | 0-30 | 83 | 66 | 37 | 63 |
| | | 31-70 | 47 | 48 | 44 | 46 |
| | | sub-total | 65 | 60 | 41 | 56 |
| | Total | | 39 | 45 | 37 | 43 |

# Appendix 2. Lodgepole Pine Nutrition Sub-project: Terms of Reference for Baseline Nutrition and Mensurational Assessment

## *Stand selection*

Stands for this phase of the NDM project will be drawn from stands identified in the phase 1 reconnaissance completed in 2004. There are a total of 40 candidates available; 15 managed stands in the 0-30 age class and 25 fie origin stands (19 in the 31-70 age class, and 6 in the 71-80 age class) from which 15 fire origin and 15 managed stands will be selected for sample plot establishment and measurement. Criteria on selection of the fire-origin stands will be developed in consultation with, and subject to the approval of, the FGYA Director.

## *Sample plot measurement*

Tree, stand, foliar, and soil / site variables implicated in response to thinning and fertilization will be measured, as a basis for initial forecasting of growth and treatment potential, and for screening of the sample locations for treatment and further evaluation. For this purpose 5 circular sample plots, each $300m^2$, will be located in each stand. Plot centre locations will be recorded by GPS, and permanently staked. Site and soil conditions will be classified according to published guidelines for forest ecosystems of west-central and south-west Alberta. Tree and stand variables measured will include site index, density, height, diameter, crown radius, percent live crown, and canopy position. Pith-bark profiles of annual ring widths will be measured from increment cores taken at breast-height from one site tree in each plot (i.e. 5 trees per stand).

The following sections detail the methodologies to be employed in meeting the above requirements.

### Pre-work and mapping

Once the 30 candidates have been identified, 1:5000 scale ortho photo based maps of each candidate stand will be produced in order to facilitate accurate plot establishment and more detailed stratification where required. MCH Forestry will work with Christian Weik from the Foothills Model Forest to complete this phase using data submitted by member companies for the initial site reconnaissance. Alternatively, maps can be requested directly from the member companies in which case MCH Forestry would liaise with the technical representative from each member company for map production.

### Plot location

Using the 1:5000 site map, the longest axis through the stand from a pre determined tie point easily accessed and located in the field will be identified and will serve as the transect along which plots will be established. The total transect length will be divided equally to provide uniform spacing between the plots along the transect. The distance from the tie point to the first plot will be one half of the calculated inter plot spacing. Depending on the size and shape of the stand, irregular transects may be required. In all cases, the minimum inter plot spacing will be 25m, and the maximum inter plot spacing will be 200m. All plots will be located in the field using compass and hip chain. (Note: the above protocols for locating plots may be adjusted to concentrate measurements into potential locations for fixed-area trials.)

Plot centers will be permanently established using ¾" galvanized steel conduit 5' in length, painted blue (or appropriate color set out by FMA). An aluminium tag affixed to each center post will indicate the project name, date, member company, company key and plot number.

A tie point will be established at the point of transect commencement. A live tree will be blazed on one side and pained blue and will have an aluminium tag indicating the project name, member company, company key and distance/bearing to the first plot on the transect.

### Measured tree variables

Tree variables to be measured will include species, dbh, height to live crown, crown radius, canopy position, damage code and severity, and breast-height age. All live trees within the plot that are >1.3m in height will be measured for all tree variables except BH_age. BH_age will be measured on the 3 largest dbh trees per 300m plot. Stand descriptors, tree damage and crown measurements may be modified subject to the direction and agreement of the FGYA Director.

The plot size will be 300m2. On all plots the 3 largest dbh trees will be measured and cored for height, dbh, and breast height age. Due to the variable densities in the candidate stands, plots may be sub-sampled for counts and measurement of other trees where the following conditions occur:

- Fire-origin stands. Providing at least 30 trees occur on the first half of the plot, only half the plot (150m2) need be sampled.
- Managed stands. Providing at least 30 trees occur in a 50m2, additional measurements need only be taken on this sub-plot. Where there are less than 30 trees in the sub-plot, it will be expanded to 100m2 or 300m2 as required to obtain a minimum of 30 trees.

Plot sizes should be the same for all plots within a stand.

Based on the reconnaissance data, this approach will result in averages of 39 and 42 trees per plot in fire-origin and managed stands respectively.

All tree measurements must be completed by April 30, 2005, and before flushing of tree terminal buds.

### Plot geo-referencing

To facilitate plot mapping for re-location and to identify the location of the sample plots within the target stand, tie point and plot center UTM co-ordinates will be determined using a global positioning system. GPS equipment used will provide the highest available accuracy (1-2m) that can produce on site UTM co-ordinates for each plot. This will eliminate the time consuming and costly process of obtaining the correct base station files from each geographic location necessary for file correction.

## *Site/soil conditions*

A preliminary assessment of site and soil conditions has been made for all candidate stands. Further assessments may be required, but cannot be conducted during the winter and therefore will not be included in this assessment.

## *Foliar sampling*

Foliar sampling will be completed concurrently with sample plot measurement. Three dominant or co-dominant trees free of major defect, insect infestation or stem disease not representative of the overall stand condition will be selected from each plot for foliage collection. From each tree

an equal number of needle fascicles will be collected from the base of the upper 1/3 of the live crown and combined into one composite sample containing at least 150 needle fascicles.

The resulting 150 samples will be kept frozen until shipping to Pacific Soil Analysis in Richmond BC for analysis. The analysis will include needle dry weights, and total concentrations of N, P, K, Ca, Mg, Cu, Mg, Zn, Fe, Mn, Al, B, S, plus active Fe and available S.
All field collection of foliage must be completed by April 15, 2005.

### *Site index and pith to bark profile*

Site index data (total height and BH age) will be collected from the largest 3 DBH trees within each 300m plot for a total of 15 trees per site. Increment cores from one tree per plot will be annotated and retained for subsequent ring-count checking and pith to bark ring width measurement. The cost for analysis in this phase is as per the original (FRIAA) project proposal, and is based on basic binocular microscope and micrometer measurements of each core.

### *Submission of data*

Data for required stand and tree variables, foliar sampling, and pith-to-bark profiles will be submitted in an electronic format acceptable to and pre-authorized by the Director of the FGYA.