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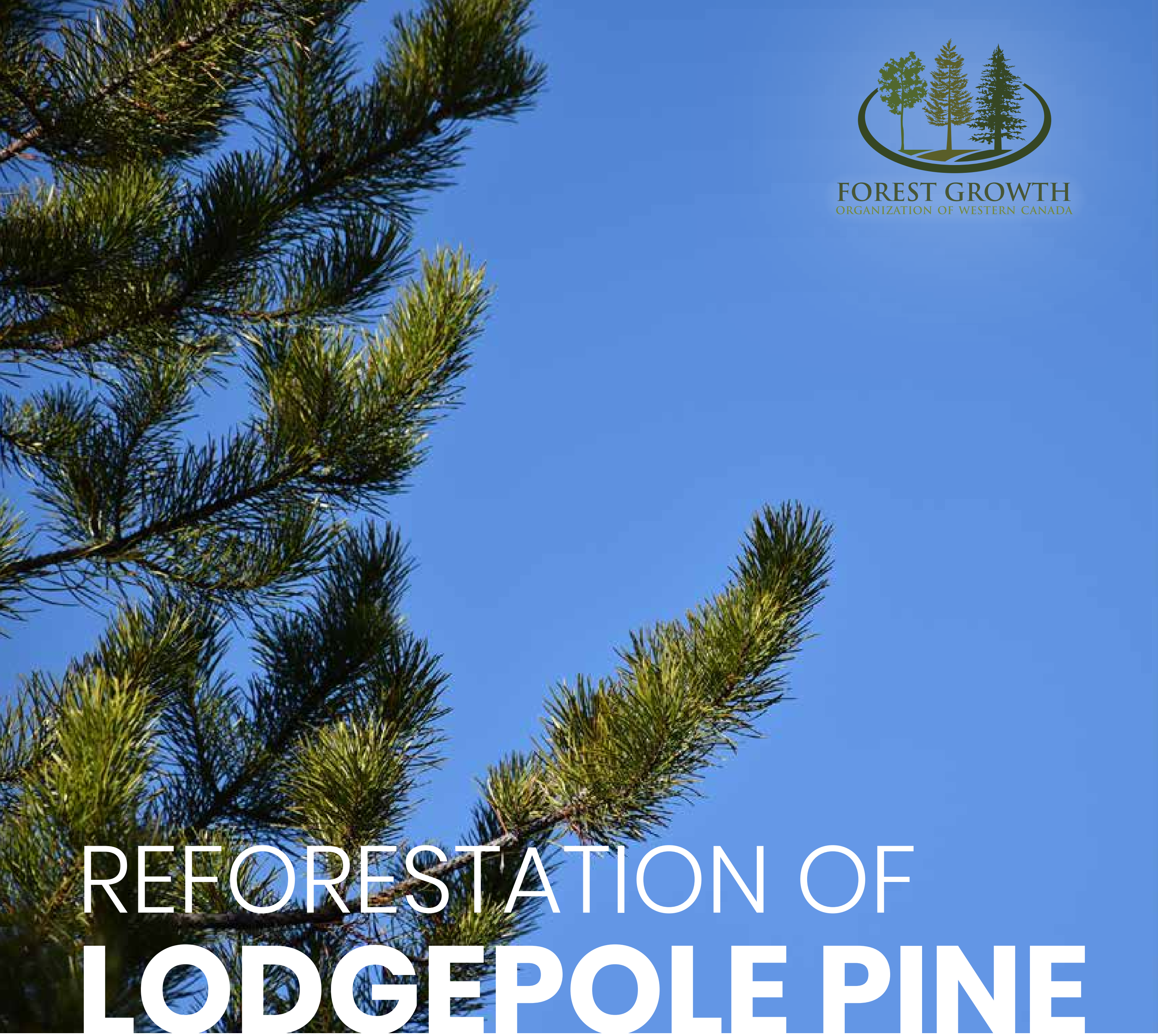


REFORESTATION OF LODGEPOLE PINE IN THE ALBERTA FOOTHILLS

Reforestation of **Lodgepole Pine** in the Alberta Foothills

Abstract

The Regenerated Lodgepole Pine Trial and related studies conducted over the last 20 years have provided information on how the development of lodgepole pine regeneration after harvesting is influenced by reforestation treatments and environmental factors. Results are summarized to describe demonstrated effects of harvesting and site preparation methods, planting density, herbicide application, and pre-commercial thinning.

Harvesting practices which imitate some of the conditions naturally following fire favour the regeneration of lodgepole pine. Mechanical site preparation improves seedling survival, root health and growing conditions, and can be used to encourage natural regeneration. Planting is not always necessary to re-establish lodgepole pine; but is essential for restocking of some sites; and may be used elsewhere to increase timber production. Herbicide application, following planting or natural seeding, facilitates regeneration of pine where it would otherwise be difficult or impossible on sites having excessive herbaceous or hardwood competition. Pre-commercial thinning can accelerate growth in individual trees and shorten rotations in dense stands; but thinning too heavily results in gaps and loss of growth potential.

The need for particular types and combinations of treatments varies greatly depending on climatic, soil and other site factors. A decision-support tool was developed to assist forest managers in selecting practices that best meet management objectives under specified site conditions.

Contents

Abstract ... 2
Introduction ... 5
The Foothills Pine Project ... 6
- The Regenerated Lodgepole Pine (RLP) Trial ... 7
- The Sundance Site Preparation Trial ... 7
- Permanent sample plots in stands attacked by mountain pine beetle ... 8
- Operational regeneration surveys ... 8
- Consolidation of results ... 9

Harvesting ... 10
Mechanical site preparation ... 12
Planting ... 14
Herbicide application ... 16
Pre-commercial thinning ... 18
More information ... 22
- Details of the Regenerated Lodgepole Pine (RLP) Trial ... 22
- Foothills Reforestation Interactive Planning System (FRIPSY) ... 23
- Further reading ... 24
- Contributors ... 24


Doug MacNearney


Bob Udell


Stephen Hanus

Introduction

The Alberta Foothills forest region is an ecosystem of major provincial, national and international importance. It stores carbon, supplies water to three Canadian provinces and the Northwest Territories, and supports timber production, a rich wildlife, and a variety of recreational opportunities. The dominant and characteristic tree species is lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.). Regeneration of pine after fire, logging and other disturbances is essential in order to sustain the ecosystem and all it provides. Understanding the regeneration process, and how it responds to reforestation practices, is therefore key to managing the forest on a sustainable basis, which is required by law on public lands in Alberta.

Lodgepole pine has been naturally regenerating after forest fires in Alberta for millennia, and the process by which it does so is generally well understood. But less information was available until recently on how stands develop following logging. Recognizing that more and better information was required, in the year 2000 a consortium of 10 forest management agreement holders, with participation and advice from the Alberta government, formed the Foothills Growth and Yield Association(Anon. 2011), which subsequently became the Foothills Pine Project of the Forest Growth Organization of Western Canada (FGrOW). Since commencement of the Project, unprecedented large-scale infestation by mountain pine beetle raised questions about how stands could be restored following attack, which led to additional research being undertaken.

The Foothills forest ecosystem, and the multiple benefits that it provides, are dependent on the regeneration of lodgepole pine.

The following pages describe the Project methodology, and what we have learned about how lodgepole pine responds to the reforestation practices of harvesting, site preparation, planting, herbicide application, and pre-commercial thinning.

Understanding the regeneration process is key to managing the forest on a sustainable basis.

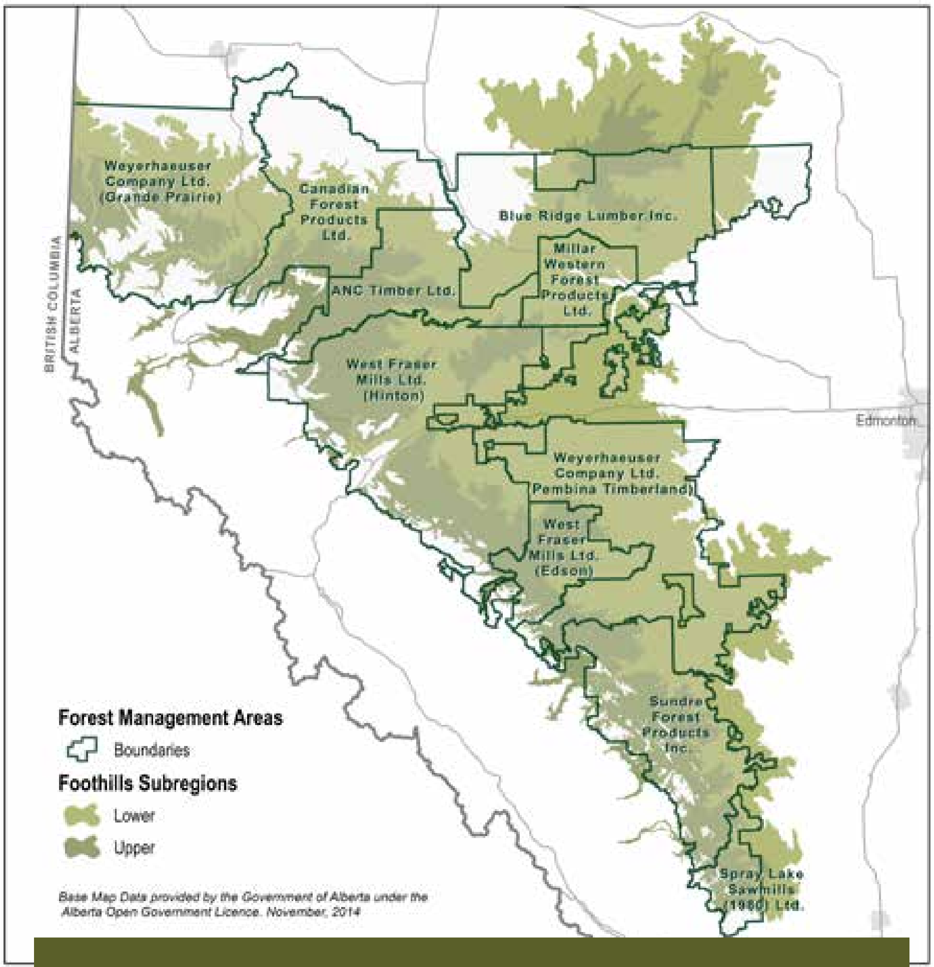
THE FOOTHILLS **PINE PROJECT**

A large part of the Project's mandate is to monitor and quantify how lodgepole pine regeneration is influenced by reforestation treatments and environmental factors. The main activity over the last 20 years was the establishment and measurement of the Regenerated Lodgepole Pine (RLP) Trial to monitor, over a wide range of environmental conditions and under experimentally controlled conditions, the effects of planting, weeding, and pre-commercial thinning on the development of pine stands following harvesting. Although the RLP trial has been the mainstay of the Project, we gained further insights by analyses of data from several additional sources, including the Sundance Site Preparation Trial, permanent sample plots in stands attacked by mountain pine beetle, and operational regeneration surveys. The scope of the Project is not limited to the study of regeneration, and includes ongoing re-measurements of historic research trials. *(The latter, being confined to already regenerated stands of fire-origin, are not described here; but interested readers are referred to Stewart et al. 2006).*

A large part of the Project's mandate has been to quantify how lodgepole pine regeneration is influenced by reforestation treatments and environmental factors.

The Regenerated **Lodgepole Pine** (RLP) Trial

The RLP trial consists of 102 installations planted with pine at a range of target densities (trees per ha). The installations are distributed across 10 forest management agreement areas, in the Upper and Lower Foothills natural sub-regions of Alberta. Each installation contains 4 treatment plots: control (“C”), weed (“W”), thin (“T”), and weed-plus-thin (“WT”). The weeding treatment involved herbicide application where required for control of competing vegetation during the first 8 years after harvest. The thinning treatment involved favouring the best crop trees, and removing natural regeneration that was in excess of target densities. The trial was established in the year 2000, and the last measurements analysed to date were made in 2020.



To learn more about the trial's installations, layout, treatments and measurements, see details of the RLP trial in the More Information section of this document.

The Sundance Site
Preparation Trial

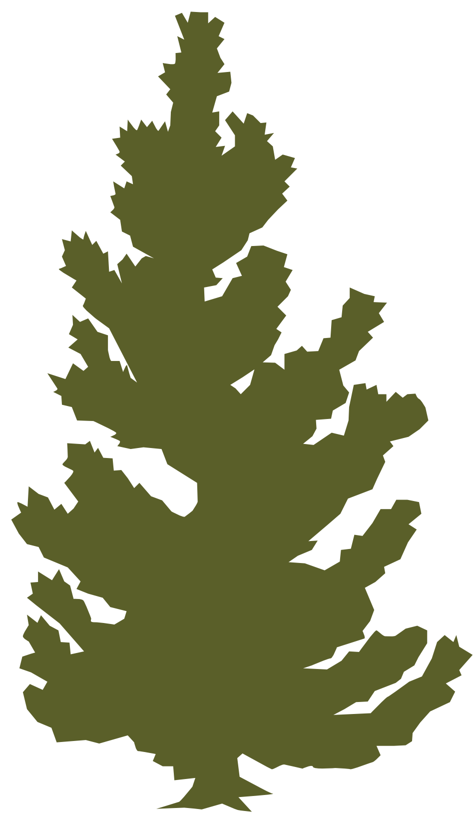
The trial was established in 2001 by Sundance Forest Industries in cooperation with the University of Alberta to evaluate the effects of alternative harvesting and site preparation methods on lodgepole pine stand development in the Upper Foothills (Landhäusser 2009). This was fortuitous for our Project, because harvesting and site preparation methods were not experimentally controlled in the RLP trial. Following harvesting, slash was removed from half the sample plots, to emulate full-tree extraction, and retained on the rest to represent conditions after stump-side cut-to-length operations. Two site preparation treatments (drag scarification and mounding) plus a control treatment (no site preparation) were applied, followed by planting with pine. We re-measured the trial in 2017.

Permanent sample plots
in stands attacked by mountain pine beetle

Over the decade following the initial provincial outbreak of mountain pine beetle in 2006, we monitored and re-measured permanent sample plots, originally installed by the provincial government in natural (fire-origin) stands, that subsequently were attacked by the beetle. This enabled us to assess the effects of the disturbance on tree mortality, growth and regeneration, in stands that were not subject to salvage or other management interventions.

Operational
regeneration surveys

Data from the FGrOW Empirical Post–harvest (EPH) project facilitated comparison of regeneration on experimental sample plots with that achieved under normal operational conditions.



Consolidation of results

The RLP trial is ongoing, but with measurements having been made over the 20 years since harvest, it has already provided data for the entire regeneration phase[1] of stand development. Making the Project results available and useful for forest managers presented a challenge. Responses to treatments varied greatly depending on climatic, soil and other site conditions. A reforestation treatment may be essential on some sites, but unnecessary or even counter-productive on others. For example, harvesting alone may be all that is required to stimulate satisfactory pine regeneration on some sites, whereas on others a combination of mechanical soil preparation, planting, and herbicide application may be needed..

In order to address the challenge, we consolidated Project results into a quantitative regeneration model linked to the Alberta government's growth and yield projection system. The resulting decision-support tool "FRIPSY" allows users to examine what combination of treatments (mechanical site preparation, planting, herbicide application, and pre-commercial thinning) are most likely to meet management objectives under specified site conditions. It includes projections of the structure and timber production of forest stands at maturity.

Results have been consolidated into a decision-support tool for assisting selection of treatments that best meet management objectives under specified site conditions.

See Foothills Reforestation Interactive Planning System (FRIPSY) in the More Information section of this document.

Harvesting

The Foothills region is a fire-prone ecosystem, with average fire cycles estimated to have been in the order 80 to 100 years historically (Andison 1998). Fire is unlikely to ever be completely eliminated from the ecosystem, and its frequency will tend to increase with climate change. Nevertheless, harvesting is undertaken on public lands, in combination with protection of the forest from fire, with the intent of producing timber on a sustainable basis, and replacing fire as the agent of stand renewal.

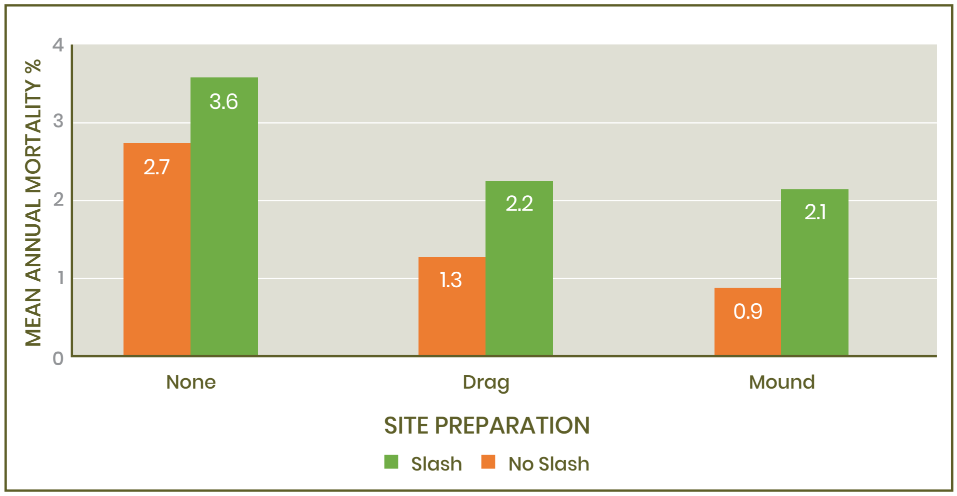
Cut-to-length harvesting in cut-block

Harvesting of timber partially replaces fire as the agent of stand renewal in the Foothills forest region.

Lodgepole pine typically regenerates naturally and prolifically following fire. This is made possible by its production of serotinous cones, which do not open until subjected to high temperatures. Wildfires cause cones to open and release seeds, and produce a suitable substrate for seed to germinate. Cones on or near the ground will also open without fire, albeit more slowly, given high enough soil surface temperatures during the summer. This latter characteristic is key to successful natural regeneration following harvest.

Harvesting usually involves either cutting trees into required lengths at the stump, and leaving branches and tops in the cut-block, or extracting full trees to the roadside. Stump-side processing leaves significantly more slash in the stand than does full-tree extraction or fire. The retained slash can improve the abundance and distribution of cones, and hence seed; but it can also reduce soil temperatures, and reduce the effectiveness of subsequent site preparation techniques aimed at improving soil conditions. The temperature effect is particularly important in the Upper Foothills, where cold soils are a limiting factor for seedling establishment, root development, and growth.

Regeneration of lodgepole pine is helped by harvesting practices which create conditions similar to those occurring naturally following fire.



Lodgepole pine mortality rates averaged by harvesting and site preparation treatment over the first 15 years following planting of the Sundance trial. Mortality is significantly reduced by slash removal during harvesting, and by site preparation (drag scarification or mounding).

Harvested area with retained patches of old timber emulating natural fire disturbance

In the absence of fire or harvesting, stands severely attacked by mountain pine beetle are unlikely to regenerate to lodgepole pine.

Our information on how the two harvesting methods compare in their effects on juvenile stand development relies primarily on the Sundance Site Preparation Trial. Although slash retention increased the number of seed-bearing cones left on the site, by 17 years after harvesting we found no significant effect of slash removal or retention on the abundance of pine natural regeneration. However, slash retention resulted in poorer root health and higher mortality of planted trees. Slash removal, which occurs both in full-tree harvesting and wildfire, improved conditions for seedling survival and growth.

Reforestation treatments like slash removal during harvesting, and mechanical soil preparation following harvesting (see page 12), create some of the conditions favourable for regeneration, that result from forest fires. Emulating forest fires at the landscape level during forest harvesting can also be beneficial. For example, judiciously retaining patches of the old stand, to imitate areas skipped by wildfires, increases habitat diversity and creates valuable hiding and thermal cover for wildlife.

The combination of fire protection, allowing accumulation of older forest age classes, and climate change has recently resulted in other natural disturbances, notably by mountain pine beetle, becoming more widespread. Strategies for ameliorating the effects of such disturbances include the prompt salvage and reforestation of attacked stands, and longer term management planning aimed at reducing areas of susceptible age classes.

Insights into the effects of harvesting or, more specifically, the effects of not harvesting, were provided by our examination of regeneration in permanent sample plots attacked by mountain pine beetle. In this study, no harvesting was allowed in the attacked plots, allowing us to track what happened in its absence. Results 10 years after the outbreak suggested that, in the absence of salvage and reforestation treatments, severely attacked stands in the Lower Foothills will seldom naturally regenerate to pine, at least within timescales consistent with timber management objectives. Instead, a slower succession of other species will follow. The rate at which forest cover and timber volume is restored naturally in such stands will depend on site conditions, and particularly on the amount and composition of non-pine species like trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white birch (*Betula papyrifera*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), and black spruce (*Picea mariana*) present at the time of disturbance. Regeneration of lodgepole pine will usually require either fire (natural or controlled), or management interventions like removal of standing timber, mechanical preparation of a suitable seed bed, and / or planting.

Mechanical site preparation

Drag scarification is the most effective site preparation method for stimulating natural regeneration; but on some sites the resulting high stand densities are likely to reduce growth unless thinning is undertaken.

Drag scarification

Mounding

One of the reasons why lodgepole pine is able to regenerate after forest fires is that burning not only removes slash, but also ground vegetation and undecomposed organic matter. This creates a suitable substrate for germinating seed released from cones by the fire. If fire is replaced by harvesting, other means may be necessary to facilitate natural regeneration or create suitable micro-sites for planting. Site preparation methods fall into two general categories: drag scarification to expose mineral soil and encourage natural regeneration from dispersed cones; and mounding or ploughing to create suitable microsites for planting. Mechanical site preparation may not be necessary at all where post-harvest soil conditions are considered adequate without further treatment.

Drag scarification is the most effective means of stimulating natural regeneration. At 17 years after harvesting and 15 years after planting in the Sundance trial, average numbers of lodgepole pine per ha were four times as high on scarified plots as on those where no site preparation took place.

However, projections of future growth suggest that the high stand densities, resulting from drag scarification without subsequent thinning, might reduce merchantable timber yields, relative to those on mounded plots. This is most likely to happen on soils of medium fertility, with a shallow organic layer and a plentiful supply of dropped pine cones. On some such sites, mounding may be a better option, or mechanical site preparation may be unnecessary. The yield reduction expected to result from high regeneration densities is currently uncertain, because the role of mortality factors such as western gall rust in reducing stand densities is only partially understood.

Dense pine regeneration in scarified stand

Mounding produces suitable micro-sites for establishing planted trees.

On sites where planting is likely to be necessary (see Planting on page 14), mounding or other methods creating suitable micro-sites for the planted trees is applicable.

In the Sundance trial, both drag scarification and mounding decreased mortality of planted stock, and reduced the proportion of trees attacked by root collar weevil, a common and serious cause of juvenile mortality in lodgepole pine.

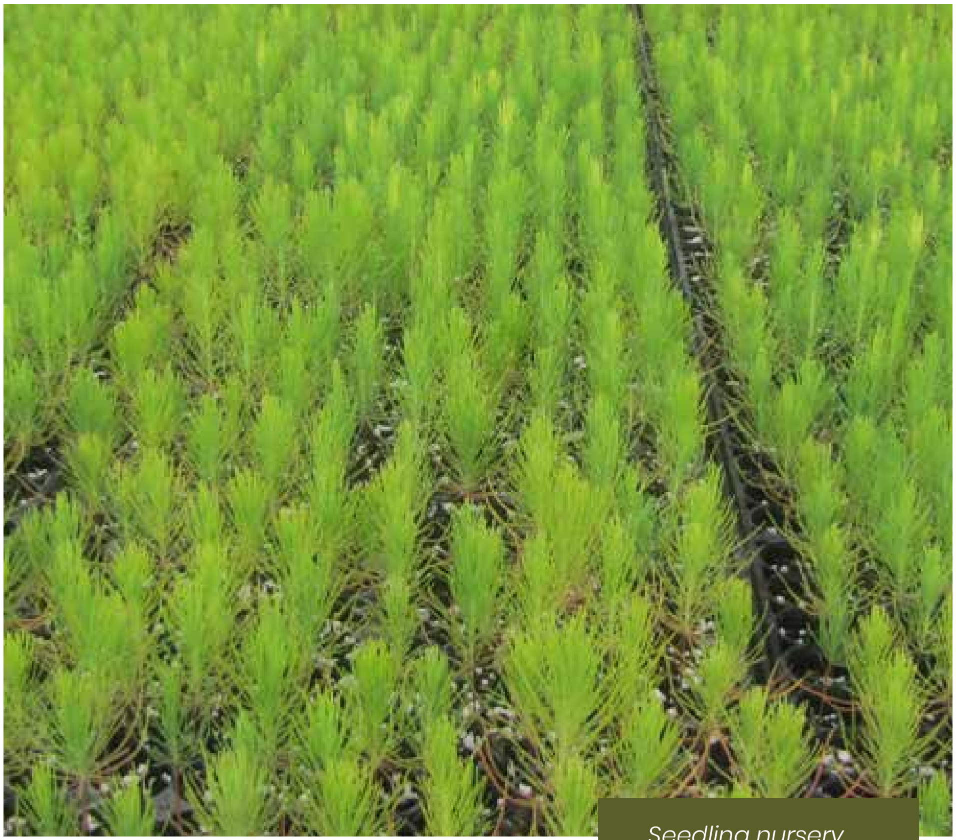
The beneficial effect of mechanical site preparation on seedling survival and root health was also apparent in the RLP trial. We analyzed data on tree mortality and health, acquired from the RLP trial and an earlier study by the Canadian Forest Service (Ives and Rentz 1993). Results suggested that physiological stress related to evapotranspiration is the most prevalent cause of overall juvenile mortality and susceptibility to *Armillaria* root disease in planted pine. Mortality and disease not only increase at higher rates of drying during the growing season, but also in response to low spring temperatures. Mechanical site preparation appears to improve soil conditions and ameliorate these effects.

Juvenile mortality of lodgepole pine

Mechanical site preparation improves seedling survival, root health and growing conditions, and ameliorates adverse climatic effects on regeneration.

Root collar weevil larva (Hylobius warreni)

Planting



Seedling nursery

Planting is not always necessary to re-establish lodgepole pine, and planted trees are often outnumbered by natural regeneration.

Results of the RLP trial, based on measurements taken at the end of the regeneration phase (about 18 years since harvest and 17 years since planting), are consistent with much of what reforestation practitioners already know and apply.

On the most commonly occurring lodgepole pine site types, densities from natural regeneration often exceed those achievable by planting, and planting may not be necessary in order to restore pine. Such sites occur most frequently in the southern Foothills on mineral soils of medium fertility, with a shallow organic layer and a plentiful supply of dropped pine cones.

However, natural regeneration is highly variable, and planting at medium to low densities is often undertaken as a precaution reducing the risk of reforestation failure. Planting and other interventions may be essential to re-stock pine on nutrient-rich soils in the Lower Foothills (where competition from other plant species can severely impede natural regeneration), and on poor soils in the Upper Foothills.

Planting reduces the risk of regeneration failure, and is essential to re-stock pine on some sites.

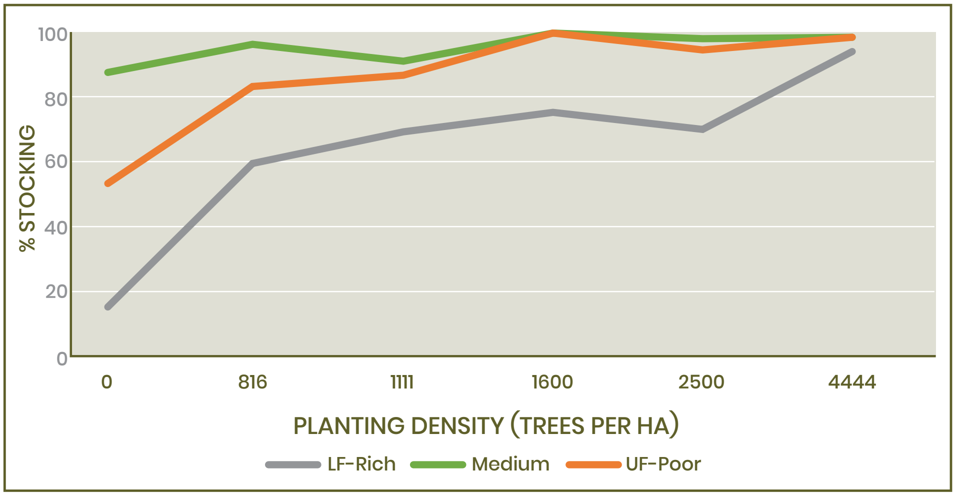
PLANTING WHERE NATURAL REGENERATION IS SPARSE

Without fire or planting, lodgepole pine is difficult to regenerate naturally on Upper Foothills sites having cold moist soils of low fertility, such as that shown in this aerial view 20 years after harvesting. The problem is exacerbated where a thick organic litter layer insulates the mineral soil underneath. Here, a combination of mechanical site preparation, planting and vegetation control was necessary to re-establish pine. Note the sparse tree cover on the unplanted "0" installation, and compare it to the almost complete tree cover on the "4444" installation (planted with 4,444 tree per ha). Note also that on the "816" installation (planted with 816 trees per ha), the trees tend to have bigger crowns than those planted at the higher density, but the proportion of the ground covered by trees is less.

Ground-level views comparing the interiors of the 816 (top) and 4444 (bottom) plots

Planting improves site occupancy (i.e. it fills gaps that would otherwise occur in natural regeneration). In order to maximize timber production, planting at higher densities may be beneficial even on sites where natural regeneration is expected. Pine percent stocking[2] and basal area[3] per ha, measured at age 18 years in the RLP trial, and merchantable volume yields predicted at rotation[4], increase with the number of trees planted per ha.

Planting may be used to increase timber production, even on sites where natural regeneration is expected.



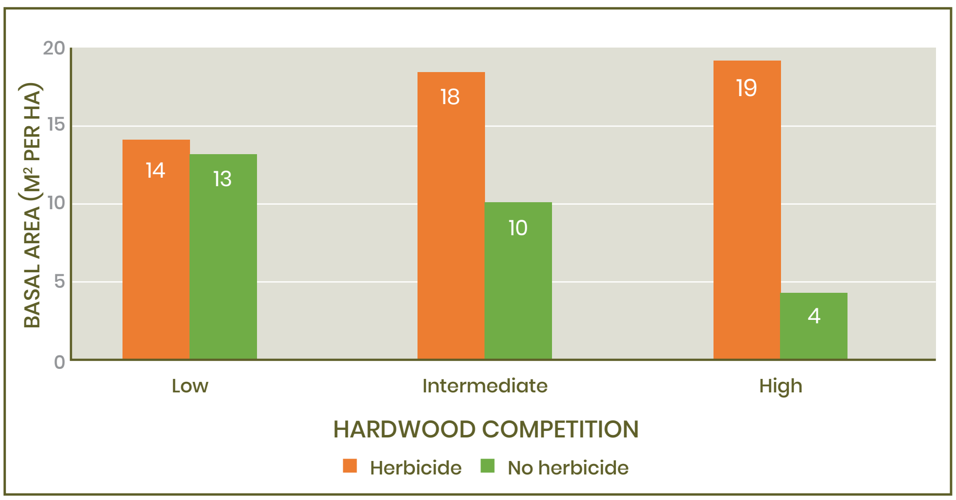
Percent stocking of unthinned lodgepole pine in the RLP trial 17 growing seasons after planting, averaged by target planting density. Stocking values include both planted stock and natural regeneration. Significantly different trends of stocking with target planting density are compared between sites with rich soils in the Lower Foothills (LF-Rich), poor soils in the Upper Foothills (UF-Poor), and medium soils throughout both sub-regions.

Herbicide application

Herbicide application during reforestation of pine usually involves spraying of glyphosate, either aerially or from the ground. It is used to control herbaceous vegetation limiting the establishment of pine, or hardwoods reducing the establishment and longer-term survival and growth of pine.

Naturally occurring hardwood regeneration severely constrains the regeneration of pine on some Foothills sites. In the RLP trial, hardwoods (mainly trembling aspen and to a lesser extent balsam poplar), regenerating at less than about 1000 stems per ha had little effect on pine stocking and growth; but as hardwood densities increased, pine stocking was reduced until, at very high densities, no pine survived by the end of the regeneration

Herbicide application improves the stocking and growth of lodgepole pine where there is competing vegetation. It facilitates restoration of pine, which would otherwise be difficult, on sites where herbaceous or hardwood competition is severe.



Basal area of unthinned lodgepole pine in the RLP trial 17 growing seasons after planting. Average values are shown comparing control (untreated) plots with plots where herbicide was applied, for installations with high, intermediate and low levels of hardwood competition. (Competition was considered "low" in installations with less than 1000 hardwood (aspen plus balsam poplar) trees per ha in the control plot; and "high" where there were more than 5,000 hardwood trees per ha in the control plot.)

phase. The density of hardwood competition was in turn greatly influenced by site factors. It was highest in the Lower Foothills, increased with soil nutrient richness, and decreased steeply with elevation. Herbaceous competition was less predictable. Some species, like *Calamagrostis* grasses, which can invade a wide range of sites, are serious impediments to the establishment of both planted and naturally regenerated pine. Glyphosate, applied by manual back-pack spraying once or more during the first 8 years following harvest, was effective in controlling both herbaceous and hardwood competitors. On sites prone to competition, application increased the stocking, density, basal area and growth of pine, and reduced the time taken for pine to naturally regenerate in unplanted plots.

HERBICIDE APPLICATION WHERE HARDWOOD COMPETITION IS EXCESSIVE

In the above aerial view, pine in the treated plot (W) can be distinguished, by its different shade of green, from the aspen occupying the control (C) plot.

Although the original stand was dominated by lodgepole pine, aspen suckering was extremely vigorous on this rich Lower Foothills site. In the non-weeded control plot, 17 years after 2,500 pine trees had been planted per ha, 90% of the planted trees were dead, there was no natural pine regeneration, and there were over 18,000 aspen trees per ha. Conversely, the plot where herbicide was applied had no aspen, and was almost fully stocked with planted and naturally regenerated pine.

Ground-level views comparing the interiors of the control plot "C" (top) and treated plot "W" (bottom)

Under most site conditions, herbicide application to control hardwoods is not predicted to increase the combined timber yield of softwood and hardwood tree species.

The high levels of hardwood control observed in experimental trials may not be consistently achievable under operational conditions.

The RLP trial involved application of herbicide under experimental control. It indicates high effectiveness of herbicide in controlling hardwood competition. Empirical data from regeneration performance surveys suggest that aerial spraying under normal operating conditions might be less effective. We were unable to determine whether this observation was the result of (a) experimental ground applications really being more effective than operational treatments, or (b) lack of experimental control in the operational data. The extent to which responses to herbicide observed in trials are operationally achievable is therefore uncertain. Validation requires controlled monitoring following operational treatments. In the meantime, forecasts based on the experimental data should be interpreted as indicating potential, but not necessarily achievable, treatment responses.

Herbicide application is not expected to increase total combined production of pine and hardwoods under site conditions where the competition with pine is mostly from other tree species. However, where young tree regeneration is subjected to excessive competition from herbaceous species like *Calamagrostis*, establishment of any tree cover may be delayed or precluded.

Cutting of hardwoods does not appear to be a reliable alternative to herbicide application. This will be further discussed under Pre-commercial thinning.

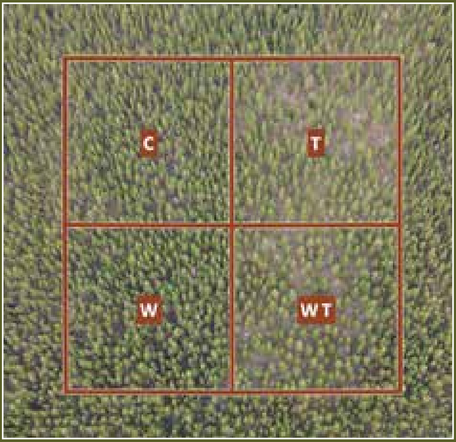
Pre-commercial **thinning**

Pre-commercial thinning, as conducted in the RLP trial, usually favours retention of the larger, well-spaced, and healthy trees of the preferred species. Smaller less vigorous trees, and those with disease, damage, poor form, or belonging to undesired species, are cut down. This results in an immediate increase of average tree size, but of course reduces number of trees and amount of basal area per ha. The key consideration when planning thinning is to what extent, and how quickly, can the reduction in basal area be compensated by the increased growth of retained trees, made possible by giving their crowns more space to expand.

In the RLP trial, by the end of the regeneration phase (on average 5 years after thinning), tree diameters were growing significantly faster, and fewer trees were dying, in the thinned plots than in the non-thinned plots.

THINNING WHERE NATURAL REGENERATION OF PINE IS EXCESSIVE

On moderately drained or dry soils of medium fertility, natural regeneration of lodgepole pine may be very profuse, especially where harvesting is followed by drag scarification, providing there is little competition from other plant species and an adequate supply of seed-bearing cones on the ground.

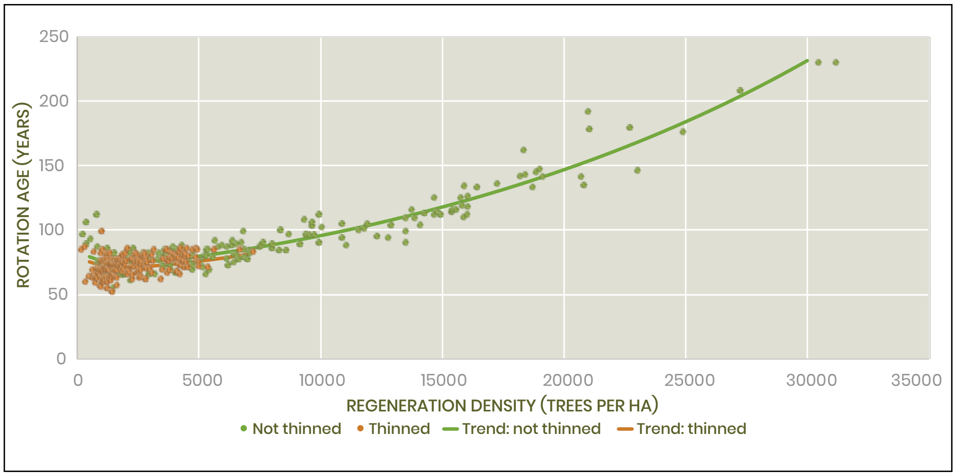


The non-thinned portion of the RLP installation shown here (plots "C" and "W") illustrate these conditions. The installation was planted at 1,111 trees per ha (3 m spacing), but the planted trees suffered high levels of *Armillaria* root disease and mortality. In the control plot "C", 18 years after harvest, the surviving 520 planted trees per ha were greatly outnumbered by over 17,000 naturally regenerated trees per ha. Thinning in the "T" plot reduced this to about 1,400 trees per ha. It remains to be seen whether the thinning will be beneficial or detrimental.

Ground-level views comparing the interiors of the un-thinned control plot "C" (top) and the thinned plot "T" (bottom)

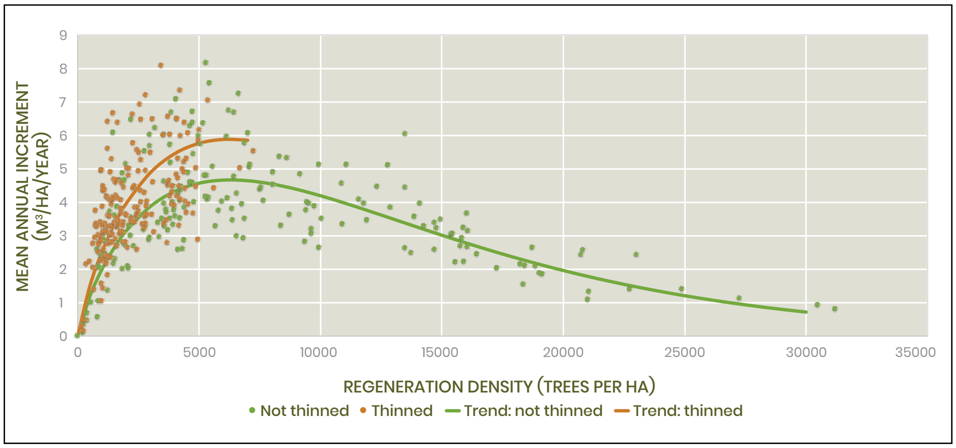
However, basal area increment on a per hectare basis remained lower in the thinned versus non-thinned plots, indicating that the increase in diameter growth was not yet offsetting the treatment's reduction of basal area.

We estimated the longer-term outcome of thinning by projecting stand conditions observed at the end of the regeneration phase to rotation age, using GYPSY, the Alberta government growth and yield model.



Predicted relationship between rotation age of lodgepole pine, and regeneration density as observed in the RLP trial 17 growing seasons after planting. Rotation here is defined as the age at which mean annual increment of merchantable timber volume culminates. The displayed data include all treatments and sites, but distinguish only between thinned and unthinned plots.

Pre-commercial thinning can shorten rotations in dense stands, especially where excessive natural regeneration has occurred.



Predicted relationship between growth of lodgepole pine, and regeneration density as observed in the RLP trial 17 growing seasons after planting. Growth is defined here as the mean annual increment of merchantable timber volume (cubic metres per ha per year), projected to rotation age. The large variation in predicted growth reflects the wide range of sites and treatments included in the trial.

The resulting projections indicated that pre-commercial thinning has potential for substantially reducing lodgepole pine rotations. This is the result of the increased diameter growth, as already observed 5 years after thinning. The possibility of reducing rotations is an important consideration in the long-term planning of sustainable timber supplies from Foothills forests, because mountain pine beetle has depleted reserve stocks of mature timber. The projections also suggested that thinning is likely to increase the yields of merchantable timber at rotation age in stands where pine densities otherwise exceed between 6,000 and 7,000 trees per ha at the end of the regeneration phase. Densities higher than this commonly result from natural regeneration on soils of medium fertility, especially following drag scarification.

MANAGING FOR OPTIMUM DENSITY

In the installation shown, the combination of planting and thinning in the T and WT plots has resulted in an average of 4,500 trees per ha, evenly spaced and fully occupying the site (100% stocking). Targeting lower densities may produce bigger trees faster, but at the risk of reduced site occupancy, lower volume growth per ha, and knottier timber. Targeting higher densities may reduce these risks, but would tend to produce smaller trees on possibly longer rotations.

Ground-level view showing interior of plot WT.

If the management objective is to maximize long-term timber production, stands with more than 6-7,000 trees per ha may require thinning, typically down to 4-5,000 well-spaced trees per ha.

The highest lodgepole pine timber yields in the RLP trial are forecast for plots on moderately drained or moist soils, of medium to rich fertility, with less than 500 hardwood trees per ha, and pine stocking approaching 100% at the end of the regeneration phase. Optimum densities to be targeted at the end of the regeneration phase will vary with site conditions and management objectives. They will likely be in the range of 4-5,000 trees per ha, possibly less (3-4,000 trees per ha) in planted and thinned evenly-spaced stands on good quality sites.

Caution is required to avoid thinning too heavily, which results in loss of productivity if crowns cannot respond enough to occupy the available growing space. Young lodgepole pine is susceptible to climatic damage (e.g. from frost, drought, desiccating winds, hail), and a large number of pathogens. By the end of the regeneration phase some of the latter have declined, but others continue to damage and kill trees. We do not currently know enough about these impacts, and how they will be affected by climate change, to predict future tree mortality with confidence.

During thinning treatments in the RLP trial, hardwoods were cut down. However, within five years of thinning, aspen densities were observed to be increasing in some thinned plots, most notably in those which had not been previously treated with herbicide. The observed density increases suggest that thinning, without herbicide application, can extend the regeneration phase of aspen by stimulating suckering, and may not be advisable on competitive sites.

Thinning too heavily will result in gaps and growth losses.

Severe hail damage

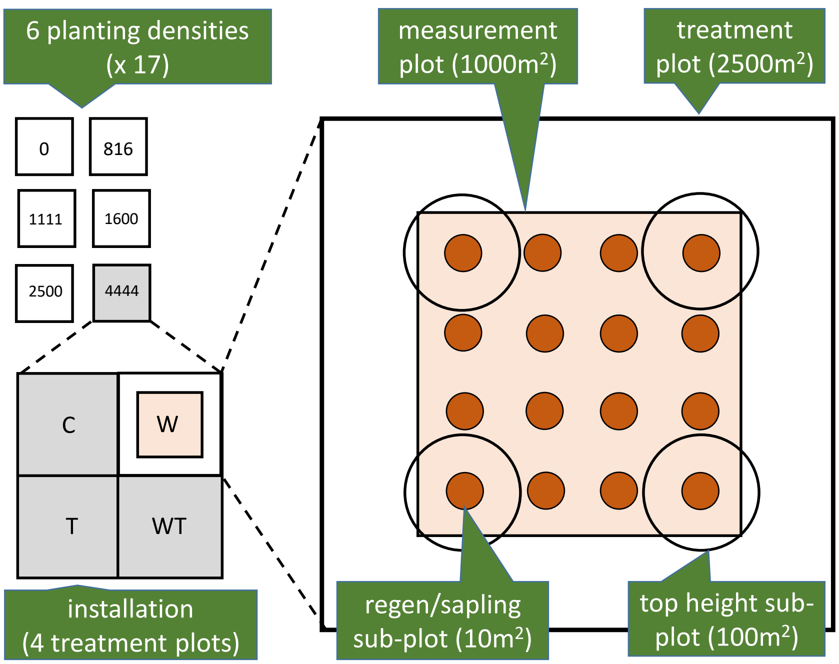
Western gall rust (Endocronartium harknessii)

Cutting of hardwoods, without chemical treatment, can stimulate re-suckering of aspen, and is less effective than herbicide application in controlling hardwood competition.

More **information**

Details of the **Regenerated Lodgepole Pine** (RLP) Trial

The 102 installations were planted with regular lodgepole pine nursery stock at six different target densities: 0, 816 (3.5 m), 1111 (3.0 m), 1600 (2.5 m), 2500 (2.0 m) and 4444 (1.5 m) trees per ha. (Equivalent spacing distances are shown in brackets.) Each installation was split two ways to create 4 treatment plots: control (C), weed (W), thin (T), and weed-plus-thin (WT). Sixteen regeneration / sapling sub-plots, and 4 sub-plots for assessing top height[5], were placed in each treatment plot.



Design and layout of the RLP trial

The W and WT plots were weeded during the first 8 years after cut, as required to control non-tree vegetation and keep hardwood densities below 1000 trees per ha. Weeding usually involved chemical spraying at normal operational rates of glyphosate per ha on plots subject to hardwood competition; but was not required where competition was below threshold levels. Some plots, usually those with marginally competitive hardwood densities, were weeded manually.

The T and WT plots were thinned at stand ages between 11 and 15 years (average 13 years), when crowns were approaching closure and the average height of pine was 3 to 5 m. Where ingress of natural regeneration resulted in the target density being exceeded, planted installations were thinned to their target planting densities. In non-planted installations the target post-thinning density was set at 4444 stems per ha. Hardwoods and shrubs were also cut down. Retained trees were, to the extent possible, well-spaced, healthy, co-dominant or dominant pine with good form and vigour, and no serious disease or damage.

Measurements were made at two-year intervals throughout the first 18 years after cut. All planted trees throughout each 1000 m^2 measurement plot were checked for vigour, health and mortality, and natural regeneration was counted by species on the 16 sub-plots. During the first 14 years, detailed tree measurements were restricted to sub-samples of planted trees, except on non-planted installations where naturally regenerated pine was sampled. In 2015 an expanded protocol was introduced, involving detailed measurement of all live trees > 1.3 m in height occurring on the 16 sub-plots, as well as continued tracking of all planted trees throughout the measurement plot. The last complete set of measurements for all installations was acquired during 2017 and 2018, 17 growing seasons following planting and (on average) 18 years after harvest. Measurements for a further two years were acquired from a sub-set of plots, with emphasis on those occurring in stands with persistently high levels of aspen competition.

For information about the location, treatment history and site conditions of individual RLP field installations, refer to the online version of this document (at: https://bit.ly/3qYeST7), which includes an interactive map allowing you to select and inspect installations by forest management area.

Foothills

Reforestation Interactive

Planning System (FRIPSY)

FRIPSY is a quantitative planning tool to assist management of Alberta's lodgepole pine forests. It is designed to:

- Encourage and facilitate application of research undertaken by the FGrOW Foothills Pine Project;
- Assist silviculturists in selecting what combination of treatments (mechanical site preparation, planting, herbicide application, and pre-commercial thinning) best meet objectives for reforestation following harvesting;
- Support timber supply planning by linking regeneration performance to predictions of long-term growth and yield.

The application comes with a comprehensive user guide, including easy-to-follow instructions, plus more detailed background information on design and structure of the system.

FRIPSY is run in Microsoft Excel, using either of two interactive processing modes: single-stand or batch. An example of the summary report worksheet, output in single-stand mode, is shown here, for a stand that will be drag scarified, planted and thinned. The regeneration forecast predicts stand metrics at the time of thinning, performance assessment, and end of the regeneration phase. It is followed by a projection of metrics at stand maturity.

Stand, Site and Establishment Factors							
Natural sub-region:	UF	**Elevation (m):**	1200		**Latitude (deg.):**	53.5500	
Soil moisture class:	mesic	**Soil nutrient class:**	medium		**Depth LFH (cm):**	7.50	
Cone density (per m^2):	unknown	**Slope %:**	4.0				
Secondary species % stocking		AW:	15	SB:	unknown	SW:	unknown

Selected Projection Options	
No adjustment for Western Gall Rust	PL ingress included in all projections

Events	**Year**	**Details**	
Cut (timber year of cut)	2000		
Site preparation	2001	Drag scarification	
Plant	2001	Density:	1600 trees per ha
Weed (last chemical)	Never		
Thin (manual)	2012	Target density:	2000 trees per ha at handover
Performance assessment	2014		
Handover	2018		

Regeneration Forecast (PL ingress included)

Event	Years since cut	Species	Age (years)	Top ht (m)	% * stocked	Trees * per ha	DBH (cm)	Basal area (m^2/ha)
Thin	12	AW	10.3	2.89	19.1	479		
(before)		PL	12.0	4.10	96.6	15535		
Thin	12	AW	2.9	1.17	0.6	12		
(after)		PL	12.0	4.10	92.1	2477		
Performance	14	AW	4.6	1.43	1.7	32		
		PL	14.0	5.02	91.9	2458		
Handover	18	AW	7.9	2.17	11.4	209	0.43	0.00
		PL	18.0	6.86	92.0	2000	8.66	11.78
		SB						
		SW						

Yield Projection to age of PL MAI culmination at 72 years after cut

Species	Site index (m @ 50 yrs)	MAI (m^3/ha/yr)	Volume (m^3/ha)	Age (years)	Top ht (m)	Trees (per ha)	DBH (cm)	Basal area (m^2/ha)
AW	14.8	0.20	14.3	61.9	16.1	188	16.5	4.0
PL	19.8	3.91	281.4	72.0	22.7	883	21.4	31.7
SB								
SW								
Con		3.91	281.4			883	21.4	31.7

** Based on minimum tree height 0.3m for conifers at thinning and performance, and 1.3m for AW (always) and conifers at handover.*

The program file and user guide can be downloaded at:

https://fgrow.friresearch.ca/resource/foothills-reforestation-interactive-planning-system

1 "Regeneration phase" refers to the crucial period following harvesting when new trees become established on the site. Typically, during this period the number of seedlings and saplings per ha is increasing, owing to the combined effects of natural regeneration and planting. Tree crowns have not yet fully closed, and any mortality is most likely caused by climatic factors, insects, disease, or competition with other plant species, rather than by trees of the desired species competing with each other.

2 Stocking of regeneration in Alberta is usually measured as the percentage of circular sample plots, each 10m^2 in area, containing at least one live acceptable seedling. The plots are laid out systematically within the opening being reforested.

3 Basal area is the summed cross-sectional area of tree stems, usually expressed on a per hectare basis, measured at 1.3 m ("breast-height") above the ground.

4 "Rotation" refers to the number of years between successive harvests. It is often set at the age when mean annual increment of timber volume culminates. This maximizes the long-term supply of timber sustainable over successive rotations.

5 "Top height" is the average height of the 100 largest-diameter trees per ha. It is frequently used, indexed to age, as a measure of site quality.

Further reading

The references listed below provide more background information on what is presented above. Links to these, and updated versions or new information, are available at: https://bit.ly/3qYeST7,

Andison, D.W. (1998). Patterns of age-class distributions on foothills landscapes in Alberta. Ecography 21: 543-550.

Anon. (2011). Progress and achievements of the Foothills Growth and Yield Association: the first decade April 2000 - March 2010.

Dempster, W.R., Meredith, S. (2014). A discussion of best management practices for reforestation following harvesting of lodgepole pine in the Alberta foothills. Forestry Chronicle, 90:6, 763-770.

Dempster, W.R. (2017). Impact of climate on juvenile mortality and *Armillaria* root disease in lodgepole pine. Forestry Chronicle, 93:12, 148-160.

Dempster W.R., Landhäusser, S.M., Ramsfield, T., Meredith, S. (2020). Effects of harvesting and site preparation methods on juvenile stand development of lodgepole pine: final technical report for the Sundance site preparation trial. Prepared for Edson and Hinton Woodlands, a division of West Fraser Mills Ltd.

Dempster, W.R. (2021). Linking silviculture to growth and yield in Alberta: a new version of the Foothills Reforestation Interactive Planning system (FRIPSY). FGrOW Spring 2021 webinar series, March 26.

Dempster, W.R. (2021). Regenerated lodgepole pine trial: final regeneration phase report.

Dempster, W.R., Gulyas, G. (2021). Foothills reforestation interactive planning system: user guide (version 210908).

Dempster, W.R., Meredith, S. (2021). Growth and yield of lodgepole pine stands disturbed by mountain pine beetle in the Lower Foothills of Alberta. The Forestry Chronicle. 97(01): 65-77.

Huang, S., Meng, S., Yang, Y. (2009). A growth and yield projection system (GYPSY) for natural and post-harvest stands. Alberta Sustainable Resource Development Tech. Report Pub. No. T/216, Edmonton, Alberta.

Ives, W.G., Rentz, C.L. (1993). Factors affecting the survival of immature lodgepole pine in the foothills of west-central Alberta. Forestry Canada Information Report NOR-X-330. Northern Forestry Centre, Edmonton, Alberta.

Landhäusser, S.M. (2009). Impact of slash removal, drag scarification and mounding on lodgepole pine cone distribution and seedling regeneration after cut-to-length harvesting on high elevation sites. Forest Ecol. Manag. 258: 43–49.

Stewart, J.D., Jones, T.N., Noble, R.C. (2006). Long-term lodgepole pine silviculture trials in Alberta: history and current results. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB.

Contributors

Design: Penny Snell, BubbleUP Marketing

Cartography: Julie Duval, fRI Research.

Narrative: Dick Dempster, Forest Growth Organization of Western Canada (FGrOW).

Ortho-photography: Greenlink Forestry, Canadian Forest Products (Grande Prairie), West Fraser Mills (Hinton), Weyerhaeuser Company (Grande Prairie).

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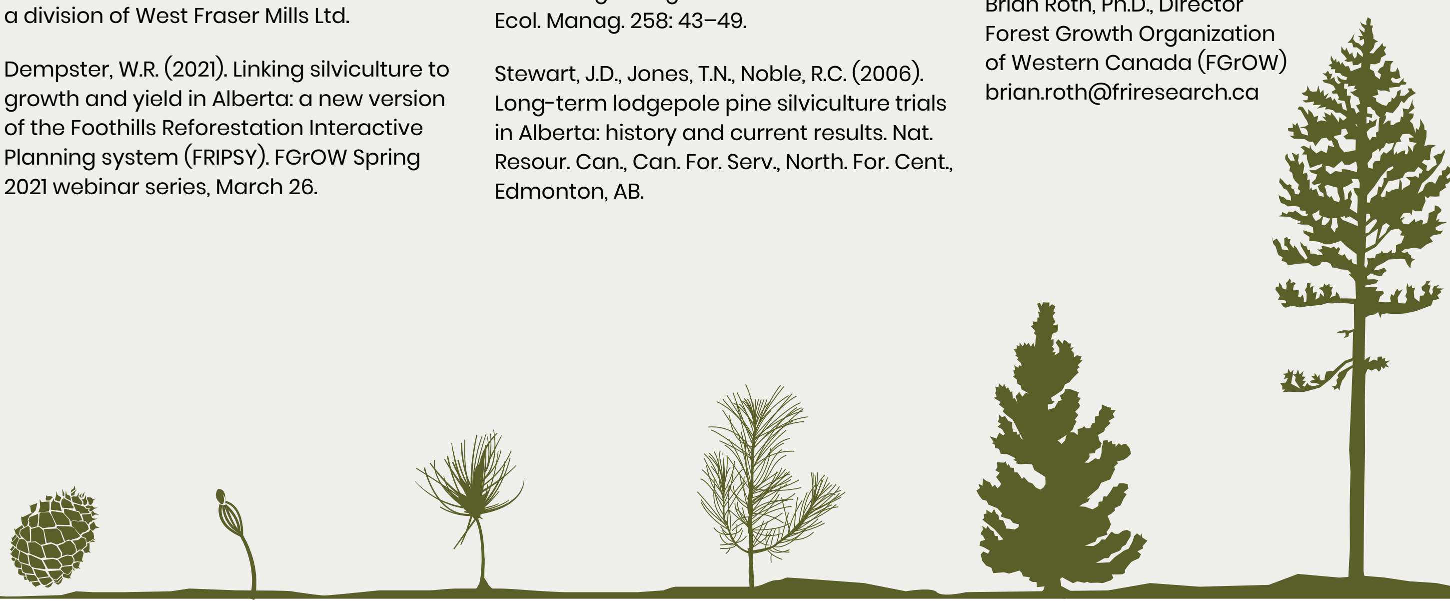
Contact

Brian Roth, Ph.D., Director
Forest Growth Organization
of Western Canada (FGrOW)
brian.roth@friresearch.ca



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