



DISCUSSION PAPER

Application of Lodgepole Pine Regeneration Research to Best Management Practices

Based on Proceedings of
Best Management Workshop, Edmonton
March 27, 2013

ABSTRACT

A group of 28 knowledgeable Alberta forest managers, silvicultural practitioners and forestry specialists met in 2013 to discuss results of a major field trial and related studies of lodgepole pine regeneration, and their implications for reforestation practice in the Alberta Foothills region. Seven areas of practice were discussed: site preparation, planting, vegetation management, pest management, tree improvement, assessment of regeneration establishment, and forecasting of growth and yield. The following paper summarizes for each area relevant trends demonstrated by the research, discussions of their implications for management practice, and recommendations for best practices to address the observed trends, as recorded at the workshop. The initial draft of the paper has been updated to incorporate additions, corrections and amendments requested by workshop participants. Conclusions and recommendations represent the consensus of the group, and provide a timely assessment of considerations and options for reforestation management in a changing environment.

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1 Introduction

Since the year 2000, the Foothills Growth and Yield Association (FGYA) has studied regeneration of lodgepole pine following harvesting in the Foothills natural region of Alberta (Foothills Growth and Yield Association, 2011). Research included establishment and annual measurements of a major regenerated lodgepole pine (RLP) trial to assess the effects of various environmental and treatment factors on stand development (Dempster, 2012), and analysis of data from earlier studies of older regeneration (Ives & Rentz, 1993) and managed-stand silvicultural trials (Stewart, Jones, & Noble, 2006).

The FGYA Steering Committee requested a discussion paper on the application of the work to best management practices. “Best management practices” in this context are recommended practices for forest resource managers to follow in pursuing responsible forest stewardship. A workshop was held on March 27, 2013 to review the latest RLP trial results, including measurements taken in 2012, and their implications for silvicultural operations (site preparation, planting and vegetation management), investment and risk management (tree improvement and pest management), assessment of regeneration establishment, and prediction of growth and yield. The 28 participants were knowledgeable forest managers, researchers and silvicultural practitioners. The following paper summarizes the trends demonstrated by the research, discussions of their implications for management practice, and recommendations for best practices to address the observed trends. Conclusions and recommendations are based on group consensus. The paper has been revised to incorporate suggestions and requests made during 2013 by workshop participants following review of an earlier draft version. Citations have been added where the discussion drew on knowledge from sources external to the FGYA, or from FGYA information already published.

Figure 1 shows the ecological site classification system adopted for analysis and discussion. Lower and Upper Foothills sites were grouped into nutrient and moisture classes based on systems developed for west-central Alberta (Beckingham, Corns, & Archibald, 1996) and southwestern Alberta (Archibald, Klappstein, & Corns, 1996). Applicable ecosites (ecological units developed under similar environmental influences) are indicated by lower case letters for each combination of moisture and nutrient regime. (Ecosites for southwestern Alberta are denoted in parentheses).

Figure 1. Ecological site classification

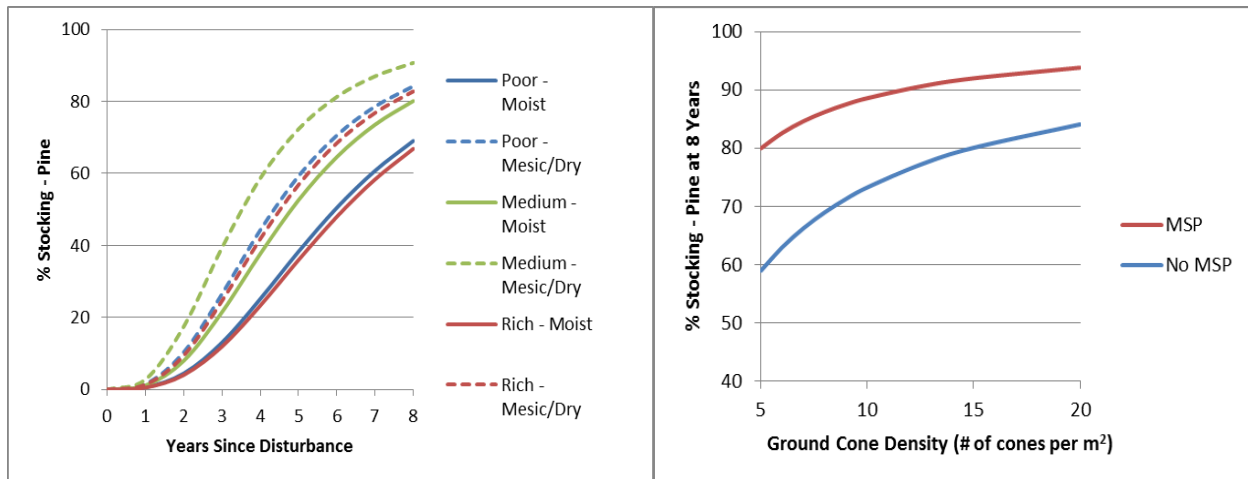
Moisture		Nutrient		
Class	Regime	Poor B	Medium C	Rich D
Dry / Mesic	Subxeric 3	(no data)	a/c (a/b)	(no data)
	Submesic 4	b/d (b)	c (b)	(no data)
	Mesic 5	d (c)	e (c/d)	f (e)
Moist	Subhygric 6	d/h (f)	e/i (d)	f/j (e)
	Hygric 7	h (f)	i/j (g)	(no data)

2 Site Preparation

2.1 Trends

Site preparation, ground cone density and soil nutrient and moisture all have a significant effect on the natural regeneration of lodgepole pine (see Figure 2).

Figure 2. Factors affecting natural regeneration of lodgepole pine: site and years since disturbance (left), mechanical site preparation (MSP) and ground cone density (right)



Current harvesting and mechanical site preparation practices are generally effective for achieving satisfactory or higher stocking providing that sufficient cones are left on or near the ground following disturbance. Densities of about 10 cones per m² generally result in good natural regeneration, and densities below 5 result in low or unpredictable stocking.

2.2 Discussion

The amount of viable seed from slash-borne cones that becomes available for natural regeneration is influenced by site strata, the age and density of stands at the time of harvest, and harvesting and site preparation. Amounts can be controlled by manipulation of:

- Harvesting systems, especially stump-side versus road-side processing;
- Season of operation;
- Distribution of slash as influenced by the type and orientation of site preparation;
- Mineral soil exposure.

There are a numerous barriers constraining reliance on natural regeneration and the selection of the best site preparation practices for this purpose. They include:

- Availability of contractors and equipment;
- Slope and aspect;
- Cost;
- Removal of access before mechanical site preparation is possible;
- Harvesting system - road-siding is easier and better for product optimization and utilization than alternative systems that facilitate natural regeneration;
- Slash loadings in relation to fire risk;
- Complexity of openings in terms of ecological site types and reforestation strata;

- Soil disturbance guidelines and priorities limiting the amount and type of soil disturbance (Alberta Environment and Sustainable Resource Development, 2012);
- Risk aversion leading to early and aggressive silvicultural interventions aimed at avoiding reforestation uncertainty or failure (reforestation standards in the past have necessitated such interventions);
- Social considerations and public perceptions that favor early planting;
- Missed opportunities for genetic gain through planting of improved stock or assisted migration through seed zone transfers;
- Limitations in silvicultural knowledge and experience.

These constraints need to be weighed carefully against the potential benefits of adopting site preparation practices favoring natural regeneration. Benefits of site preparation practices focused on promoting good natural regeneration include:

- Reduced regeneration delay;
- Better distribution of natural regeneration;
- Maintenance of genetic diversity;
- Increased age diversity (which may reduce risks of crop failure resulting from surges in disease and insect activity that occur irregularly or early in the regeneration phase);
- High stand densities reducing the impacts of biotic and climatic injury (e.g. hail);
- Winter desiccation of seedlings reduced by slash return;
- Reduced initial costs;
- Fewer subsequent operational site returns (e.g. planting, seeding) to achieve regeneration;
- Less reliance on the availability of suitable planted stock;
- Reduced slash piling;
- Improved safety resulting from fewer planters on the ground and less hazardous slash alignment.

2.3 Conclusions and Recommendations – Site Preparation

The benefits of adopting site preparation practices focused on promoting good natural regeneration need to be assessed site-specifically and weighed carefully against operational constraints. The benefits depend in large part on the viability of alternative reforestation systems, such as planting. Planting may be the best practice on sites with limited natural regeneration potential, adequate soil conditions, good potential for tree improvement or assisted migration, and low health risks (see Section 3). But on other sites partial or total dependence on natural regeneration is likely to remain the most effective strategy for successful reforestation of lodgepole pine

The choice of harvest system and timing of the cut should take into account and be matched to reforestation strategies. The best harvesting practices on sites where reforestation depends on natural regeneration are stump-side de-limbing (including skidder blading to break limbs) or, where roadside processing is unavoidable, winter extraction.

Drag scarification producing good mineral soil exposure is generally the most effective method for achieving satisfactory stocking on sites with mesic to dry soil moisture and medium to poor nutrient regimes. Mounders may be effective if fitted with chains. Cone assessments are recommended on sites where cone dispersal is uncertain. On sites where good ground cone densities (preferably 10 or more cones per m²) are not achieved and conditions are not suitable for planting, slash return operations are recommended. Options include Cat-mounted brush rakes for slash distribution and skidders for returning tops from roadside processing locations. Aerial seeding in the first growing season after site preparation has sometimes proven effective as an alternative or supplement to natural seed from slash, and may be

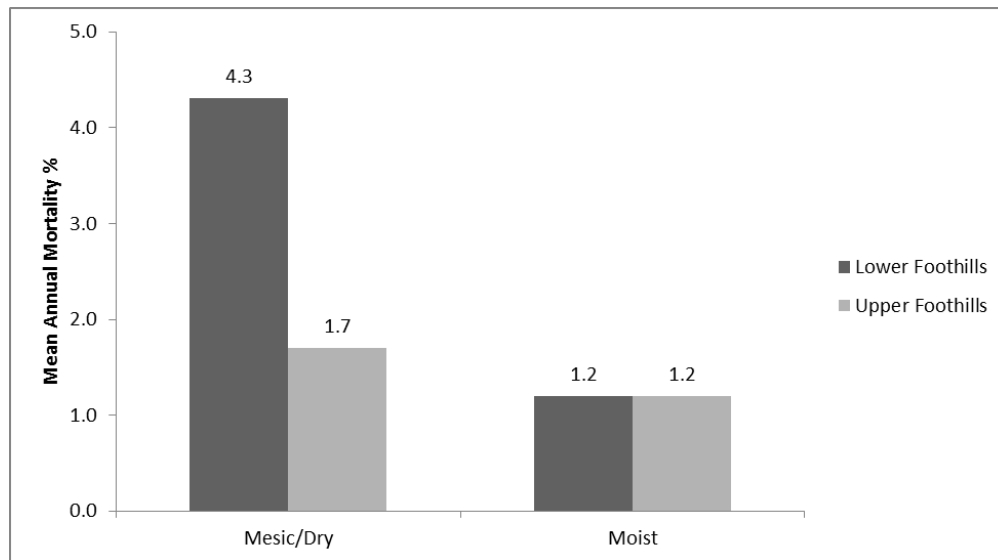
required if viability of slash-borne cones is poor. Disc trenching, if used for site preparation, may need to be combined with seeding.

3 Planting

3.1 Trends

On some sites high levels of mortality of planted stock occur (see Figure 3) and continue into the second decade after planting.

Figure 3. Effects of natural sub-region and soil moisture on mortality of planted stock



Under natural fire-origin conditions high densities of lodgepole pine regeneration offset early mortality; and on many harvested sites high levels of natural regeneration also occur, particularly if suitable site preparation methods are used (see Section 2). In this respect FGYA results closely mirror those from earlier studies by the Canadian Forest Service (Johnstone, 1976).

3.2 Discussion

Decisions about if, when and where to plant have to take into account a large number of considerations including:

- Forest management objectives such as yield and strata-balancing targets (Alberta Sustainable Resource Development, 2006);
- The Alberta Reforestation Standard (Alberta Environment and Sustainable Resource Development, 2013);
- Site characteristics and limitations (e.g. elevation, slope, aspect, organic or cold soils, local climate, vegetative competition);
- Influence of harvesting system on conditions for regeneration;
- Amount and timing of access for site preparation and planting;
- Seed rules and availability;
- Cost and availability of various stock types;
- Risk or incidence of high mortality resulting in failure to meet target densities;
- Presence of advance natural regeneration and probability of ingress.

Although there is a lot of uncertainty about climate change, it appears likely to exacerbate the types of juvenile mortality currently observed on lowland and dry sites. It is increasingly a consideration in planting decisions, as demonstrated by:

- Efforts to ensure improved seed is adapted;
- Need for up-slope and northerly assisted migration recognized in seed rules;
- Planting densities adjusted to allow for increased insect and disease attack;
- Planting of alternative or mixed species, and mixture of planting and natural regeneration to spread risks.

3.3 Conclusions and Recommendations - Planting

Lodgepole pine should not be planted to reforest pine stands where:

- High levels of natural ingress make planting unnecessary;
- Costs are prohibitive;
- Extreme disease and insect risks are likely to result in regeneration failure (this requires an assessment of risk based on ecosite characteristics and knowledge of pre-harvest and adjacent stand conditions);
- Natural regeneration of pine is poor and the site is more suitable for planting spruce (this situation is most prevalent in reforestation of coniferous-deciduous (CD) pine-aspen stand types, but may apply to other ecosites where black or white spruce is the natural climax species);
- Approved management planning objectives (e.g. strata balancing targets) dictate otherwise.

Under these conditions, and depending on which conditions apply, one or more of the following alternatives to planting pine should be applied:

- Encouragement of natural lodgepole pine regeneration through appropriate harvesting and site preparation practices (see Section 2.3 above);
- Artificial seeding;
- Planting of black or white spruce (depending on ecosite and natural climax species) or other species suited to the site;
- Acceptance of natural mixed-wood regeneration.

There is a need for continued monitoring of climate change impacts to help in making future planting decisions.

4 Vegetation Management

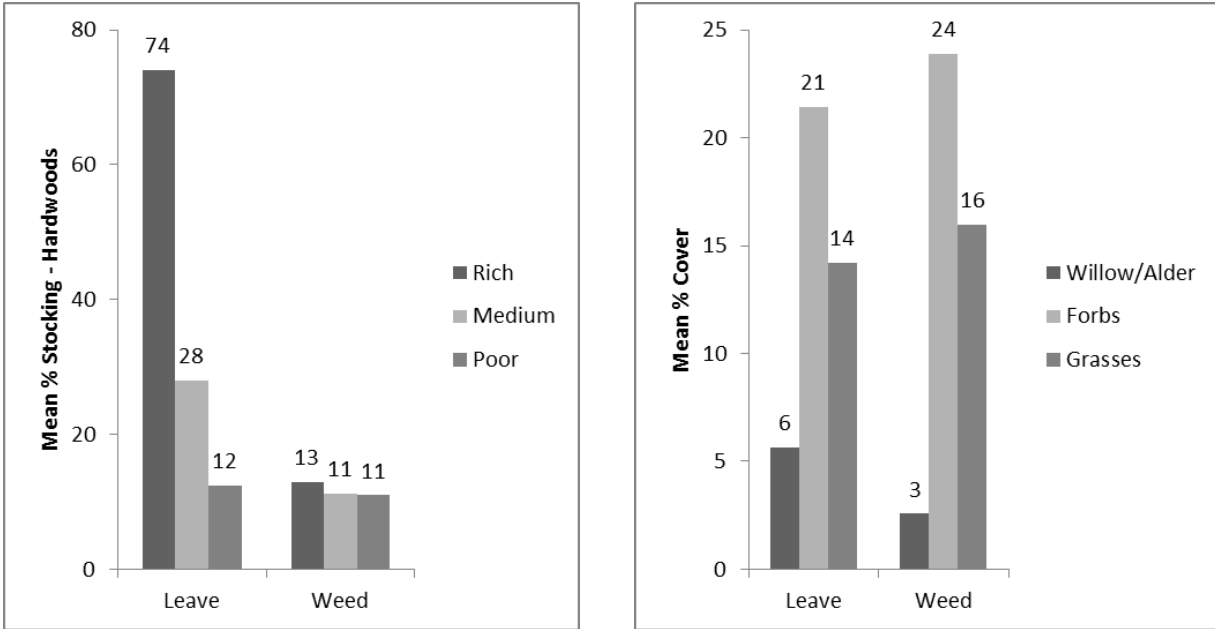
4.1 Trends

Although the RLP trial measurements to 12 years have not yet shown pine mortality or total¹ ingress rates being significantly affected by weeding treatments, weeding has proven effective for reducing hardwood stocking (see Figure 4), and very substantial reductions in diameter growth have been linked to high levels of hardwood competition. The results suggest that it is only a matter of time before pine stands subject to high levels of hardwood competition will incur increased mortality. Monitoring will be continued to confirm this. The implications of trial results for herbaceous vegetation control are unclear,

¹ “Total” ingress rates include all naturally regenerated pine trees 10cm+ in height. Ingress to 30cm and 1.3m show decreases with vegetative competition because of reduced growth rates.

because the weeding treatments did not generally reduce herbaceous cover (see Figure 4). On some sites the control of hardwoods appears to be increasing grass and forb cover.

Figure 4. Effect of weeding on percent stocking of hardwoods (left) and percent cover of herbs and shrubs (right)



4.2 Discussion

Management of competition from herbaceous vegetation, particularly grasses, is a concern to silviculturists on Lower Foothills and some Upper Foothills sites in central and northern Alberta. It is usually addressed by artificial reforestation practices being applied promptly after harvest, including site preparation, planting and herbicide application, guided by the limiting factors of the site. Less attention has been paid to limiting the effects of herbaceous vegetation on natural ingress occurring over a protracted ingress period.

4.3 Conclusions and Recommendations – Vegetation Management

Control of hardwood competition, using post-emergent chemical herbicides such as glyphosate or triclopyr, is necessary and effective on most rich sites and on some medium sites in order to achieve good regeneration performance of lodgepole pine. On such sites, although pine seedlings may survive high levels of hardwood competition during the first decade, their crown development and diameter growth is likely to be too compromised for longer-term growth and survival.

Where grass or other herbaceous competition is anticipated to be a problem and where planting is not precluded by other considerations (see Section 3.3), glyphosate can be efficacious providing interception by a hardwood canopy is avoidable. The best reforestation strategy will usually be a selective combination of:

- Mechanical site preparation resulting in high mineral soil exposure;
- Mechanical site preparation creating elevated microsites;
- Application of herbicide during site preparation;
- Prompt planting of large vigorous stock;

- Appropriate pre- or post-emergent herbicide selection;
- Careful timing of aerial application to reach ground vegetation before the hardwood canopy is too advanced;
- Minimal brushing of hardwoods to avoid release of grasses and forbs.

Additional attention to the selection of herbicides and timing of their application will likely be needed on sites where grass completion is anticipated or encountered, planting is precluded by other considerations, and reliance is being placed on natural regeneration. Repeated aerial application may be necessary, especially if the initial application is intercepted by a hardwood canopy.

On-going monitoring and investigation are required to confirm, clarify and explain responses to weeding observed in the RLP trial, particularly the lack of early survival differences and herbaceous effects.

5 Pest Management

5.1 Trends

Mean annual mortality of planted lodgepole pine (see Figure 3) during the first decade since planting, mainly attributable to *Armillaria* root disease and *Hylobius* root collar weevil (see Figure 5), has averaged over 4% per year in RLP plots located on mesic to dry Lower Foothills sites. Unlike mortality from direct climate injury, mortality from disease and insects does not appear to be declining with sapling age. Data from an earlier study by the Canadian Forestry Service of naturally regenerated stands up to 30 years old (Ives & Rentz, 1993) showed changes in the levels of various mortality factors over time, but no overall trend between mortality rates and age. Observed trends of pest damage and of mortality with temperature (see Figures 5 and 6) appear consistent with observations from elsewhere that lodgepole pine pests are becoming more widespread, and host susceptibility and mortality are increasing, with climate warming (Mather, Simard, Heineman, & Sachs, 2010).

5.2 Discussion

There is currently limited concern among Alberta silviculturists about *Armillaria* and *Hylobius* (the 2 most prevalent mortality factors observed in the RLP trial). Concerns about biotic mortality agents have tended to focus on mountain pine beetle (because of the outbreak in Alberta) and on western gall rust (the only tree disease specifically addressed in the Alberta Reforestation Standard). Fire of course is a well-recognized and ever-present threat. The highest level of operational concern during the early stages of reforestation is with direct climate injury to planted seedlings.

Research results may at first glance appear difficult to reconcile with these views. In the RLP trial direct climate injury was implicated in some mortality occurring shortly after planting, but has not been identified as a prevalent cause of mortality throughout the first decade. Continuation of the 4% average level of periodic mean annual mortality on Lower Foothills mesic and dry sites, attributed mainly to biological agents, would result in less than 25% survival by age 30, well before rotation, and possibly even before crown closure and the onset of normal intra-specific competition mortality. Without supplementary natural regeneration, it is probable that such levels of survival would drastically reduce both the regional long-term sustained yield and, ironically, the long-term threat from mountain pine beetle.

There are several reasons for pest management concerns not having received more attention in reforestation practice.

- The observed dangerously high levels of mortality have not been previously quantified and are mostly confined to lower-elevation warmer and drier sites. Throughout much of the Upper Foothills, and on moist Lower Foothills sites, average mortality levels currently remain low (see Figure 3).
- Mortality itself is not usually monitored in regeneration surveys and losses to dispersed damage agents like root disease, weevils and rusts tend to be less noticeable than the more spectacular localized events like hail and red belt.
- Mortality is often offset by ingress of natural regeneration. Both ingress and mortality occur progressively over a period of at least a decade.
- Insect and disease dynamics may well have changed as a result of observed climate trends, resulting in more mortality now than in the past.
- There has been (and still is) uncertainty about the exact nature, seriousness and implications of the observed trends. For example: it is not yet clear whether planted stock is more vulnerable to damage agents than is natural regeneration; neither is it clear the extent to which climate is influencing susceptibility of pine to opportunistic pests like *Armillaria* and *Hylobius*, versus directly influencing pest dynamics.
- Opportunities for controlling pests and other mortality factors are perceived as limited.

However, there are also justifications for increasing attention on juvenile stand health.

- Mortality appears linked to temperature (see Figure 5), and may increase and become more widespread as a result of projected climate trends (see Figure 6).

Figure 5. Percentage of total mortality by cause in the RLP trial (left) and trend of mortality with mean annual temperature in the RLP and CFS trials (right)

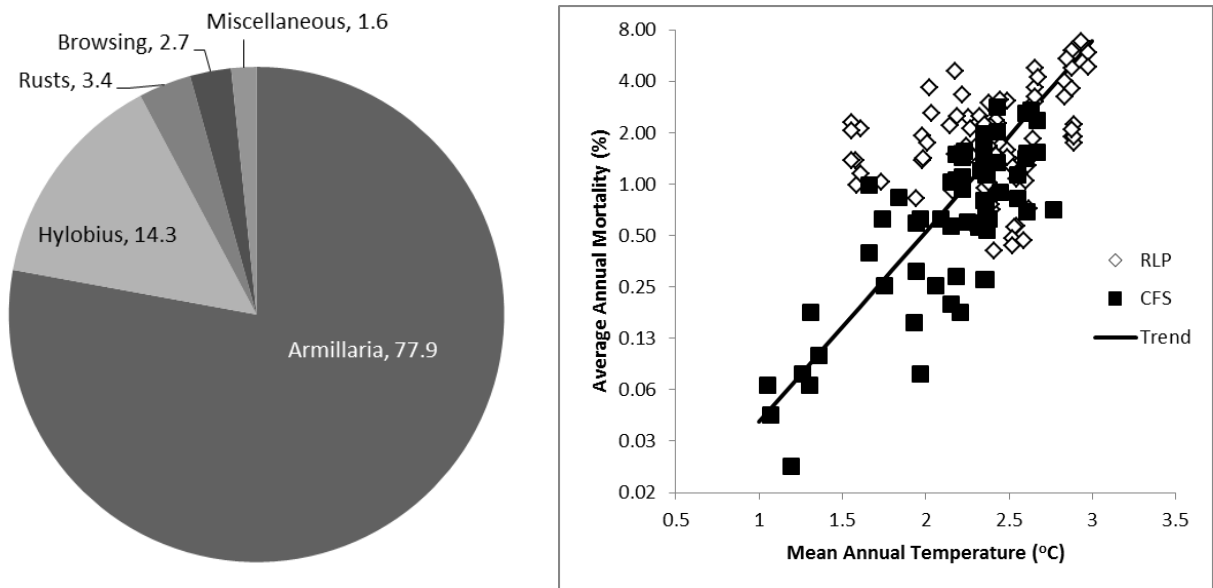
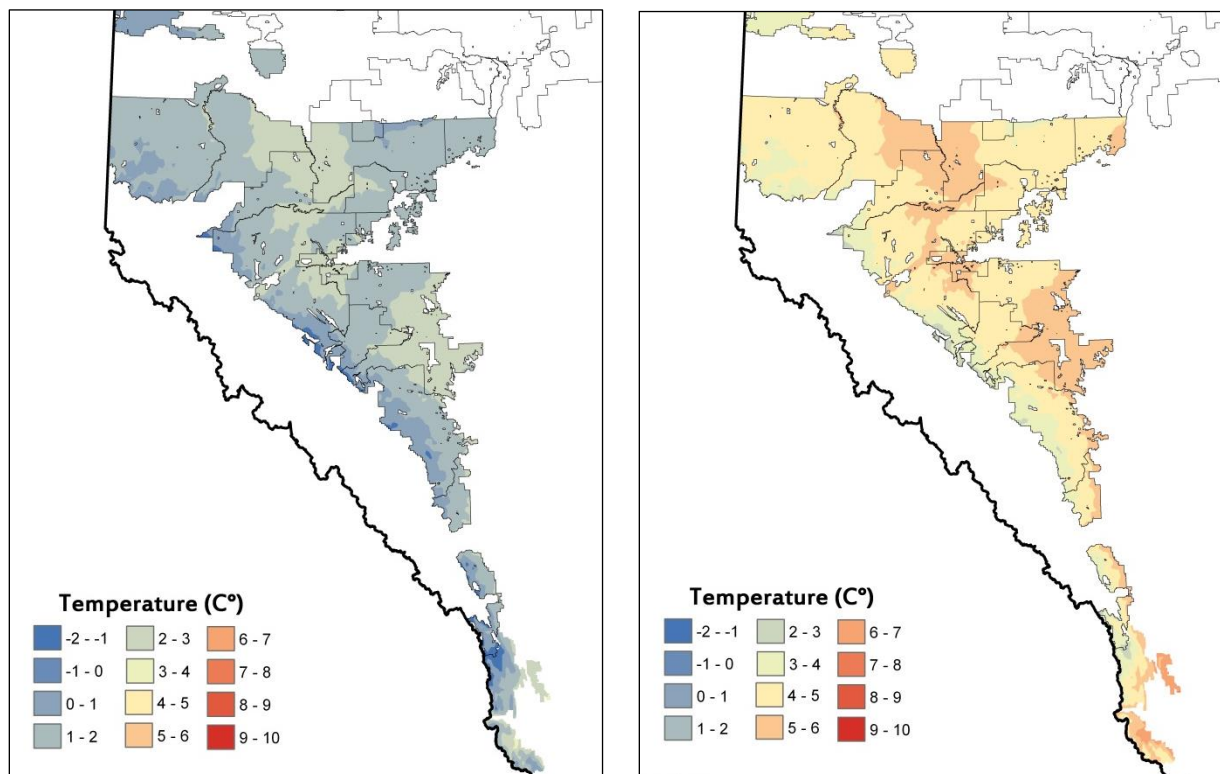


Figure 6. Map of Foothills forest management areas showing mean annual temperatures for the period 1961 - 1990 (left) compared to those predicted for the 2050s (right)²



- Current reforestation practices may be exacerbating the impacts of pests relative to natural fire disturbance by changing environmental characteristics e.g. surface warming as a result of site preparation on some sites, un-burned duff accumulation on others, early planting, creation of relatively low-density evenly spaced stands, changes in stand-edge frequency and characteristics (all these factors can favor common pests).
- While ameliorating direct climate effects is difficult or impossible, there may be opportunities to reduce the impacts of common pests through modifications to reforestation practice based on practices developed locally or in other parts of the world.

5.3 Conclusions and Recommendations – Pest Management

A number of reforestation strategies and practices have the potential to reduce the impact of the 2 most prevalent mortality agents observed in the RLP trial: *Armillaria* and *Hylobius*.

- **Improved awareness, recognition and understanding.** Highest losses are forecast in the Lower Foothills. Local knowledge of pre-harvest and adjacent stand conditions, ecosite guides (Beckingham, Corns, & Archibald, 1996), risk maps based on mean annual temperature (Dempster & Wiens, 2011) may be used as indicators to improve these forecasts. Field guides produced by the Alberta government and other agencies are available for diagnosis (Alberta Sustainable Resource Development, 2009).

² Map developed using the ClimateAB model (Wang, Hamann, Spittlehouse, & Aitken, 2006).

- **Aggressive site preparation.** Stumping, although effective for dealing with *Armillaria*, is not considered generally feasible. Trenching during site preparation has been locally observed to reduce *Armillaria* spread. Aggressive site preparation to remove duff, and avoidance of planting in moist duff, are techniques widely used throughout North America for reducing losses to *Hylobius* (McCulloch, Aukema, White, & Klingenberg, 2009). Control burning is potentially very effective, but may not be prudent or feasible given the associated risks.
- **Delayed planting.** Fallow periods following clear-cutting and other risk-reduction strategies based on careful site assessment are practiced elsewhere in plantations subject to *Hylobius* (Heritage & Moore, 2001). Delayed planting may also reduce exposure to *Armillaria* when the disease is most active (Cleary, van der Kamp, & Morrison, 2008). However, it is not clear whether this practice would be effective in Alberta, where regeneration is likely to be exposed to irregular and recurrent attacks from multiple agents.
- **High stand densities and variation in seedling age.** This combination should be encouraged by appropriate harvesting and site preparation practices (see Section 2.3) wherever mortality risks from either (or both) *Armillaria* or *Hylobius* are high and conditions are suitable for natural regeneration. It is the usual result of natural regeneration occurring where there is good mineral soil exposure and adequate cone dispersal. Achievement by planting is unlikely to be economic. Under natural conditions lodgepole pine appears to have adapted to *Armillaria*, *Hylobius* and other juvenile mortality factors by prolific regeneration (frequently 10,000-20,000+ trees per ha) dispersed over time (1 to 2 decades), thus avoiding dependence on smaller numbers of trees originating at any one time and being exposed to mortality agents when all at the same age or size.
- **Selection of alternative species.** Black or white spruce (depending on ecosite) should be considered as alternatives to planting pine in openings or portions of openings (e.g. around edges) where the incidence or risk of *Hylobius* is high. On sites where the risk of mortality from *Armillaria* is high and natural coniferous regeneration is not feasible, retention of any aspen regeneration may be the best way to maintain forest cover.
- **Increased species diversity.** Given uncertainty about future site conditions, health threats and their impacts, a good risk management strategy is to establish or encourage species mixtures (e.g. spruce, pine, fir and native hardwoods) wherever site conditions and land-use objectives allow.
- **Modification of clear-cut system.** Although there has been much interest and effort in Alberta to emulate natural disturbance patterns when harvesting, little attention has been paid to the effect of differences between natural and artificial disturbances on common pests in young stands. More investigation of these differences is required to determine whether modifications to the system, such as reduction of edge areas and / or extension of the pass interval, are justified.

6 Tree Improvement

6.1 Trends

On many pine sites, very high densities of natural regeneration occur, with the potential of outnumbering planted stock in the final crop. On some sites mortality of planted pine is likely to be high (see Figure 3). Climate warming trends (see Figure 6) suggest that stock may not remain well adapted to conditions in seed zones of origin.

6.2 Discussion

Not all lodgepole pine sites are suitable for planting genetically improved stock, such as those with high mortality risks or high rates of natural ingress. Others barriers that are constraining successful deployment of improved stock include:

- Availability of suitable seed and stock;
- Currently limited information and knowledge about site-specific gains and benefits (though data are becoming increasingly available);
- Poor understanding and negative perceptions of tree improvement;
- Market and investment risks e.g. declining timber values, possibility of policy changes regarding stumpage incentives;
- Conflicting land management objectives (e.g. rotation extensions for caribou management, land-base balancing);
- Seed transfer rules and guidelines limiting movement of genetic material (though some important provisions have been introduced in genetic resource management and conservation standards to accommodate adaptation to climate change (Alberta Sustainable Resource Development, 2009));
- Complacent reliance on past practice and reluctance to change the *status quo*.

6.3 Conclusions and Recommendations – Tree Improvement

Deployment of genetically improved lodgepole pine has very important roles to play in:

- Maintaining forest productivity and increasing productivity on sites selected for planting;
- Adaptation to climate change;
- Combating insect and disease problems.

Success will be dependent on:

- Breeding for appropriate characteristics (this requires continual re-evaluation of priorities e.g. breeding may need to be extended to alternative species like Douglas fir and ponderosa pine);
- Cost effectiveness;
- Selection of sites that will yield the best return on investment;
- Appropriate site preparation and diligent tending to ensure that investment in improved stock is realized;
- Reduction in current uncertainties about benefits.

In order to reduce uncertainty about the benefits, more progress is needed on:

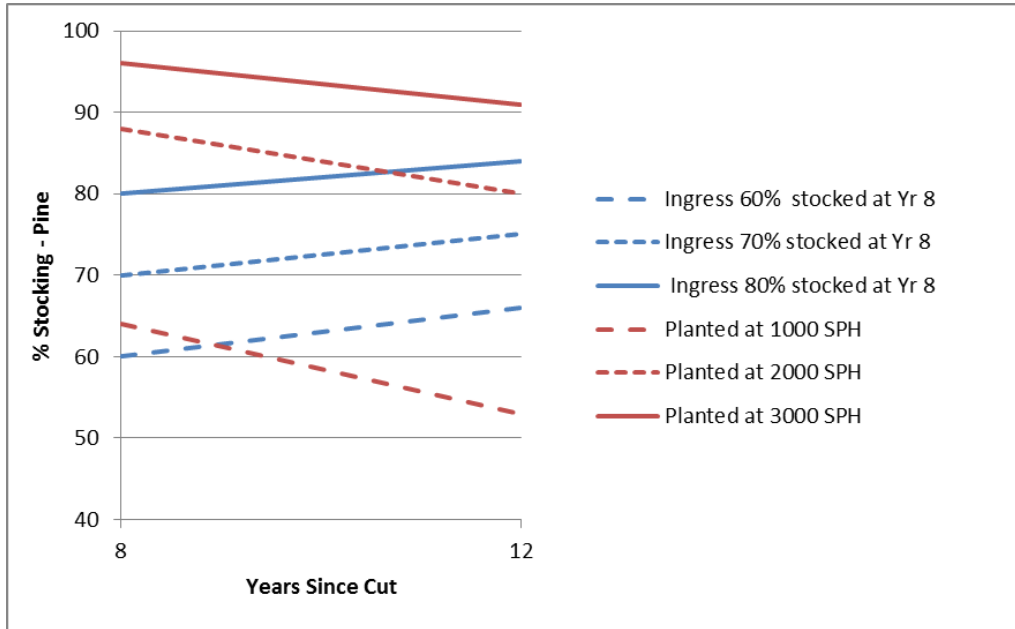
- Creation of a favorable policy environment: policy is perceived by industry as limiting investment in tree improvement and needing improved recognition of environmental change;
- Improvement of response forecasts: this requires better and more site-specific modeling to project growth responses, a better understanding of climate change and opportunities for assisted migration, and continued monitoring of performance.

7 Assessment of Regeneration Establishment

7.1 Trends

Some of the trends observed in lodgepole pine regeneration may have implications for establishment surveys and the evaluation of establishment success in young regeneration. For example, both mortality of planted stock and ingress of natural regeneration continue between establishment and performance surveys (see Figure 7), and some ingress is missed during establishment surveys because of survey minimum height thresholds and reliance on aerial surveys.

Figure 7. Examples of predicted change in stocking between 8 and 12 years



7.2 Discussion

The latest procedures for conducting establishment surveys 5 to 8 years following cut (Alberta Environment and Sustainable Resource Development, 2013) have been well received by industry and government practitioners. The combination of photo stratification, expert aerial and ground reconnaissance and selective ground surveys is perceived as a cost effective and generally adequate way of meeting regulatory requirements. At the same time it puts “eyes in every block” facilitating knowledgeable identification and prioritization of issues requiring management intervention. This is especially effective if the people making the assessment are those responsible for operational follow-up.

The system has a number of limitations. It places a great deal of reliance on the expertise and knowledge (and, in the case of aerial reconnaissance, endurance!) of the surveyor. It has limitations in the recognition of species and under-height stock, and does not differentiate planted stock from natural regeneration. To date there has been little focus on identification of forest health issues. The system assesses stocking (site occupancy) but not some productivity-related variables like height growth, mortality, ingress density and competition. As a result there is uncertainty about the implication of results relative to management objectives.

7.3 Conclusions and Recommendations – Assessment of Regeneration Establishment

The current system of assessing regeneration establishment is generally adequate, but has a number of limitations. Costs and complexity of fieldwork and availability of surveyors are significant barriers to expanding the survey in order to overcome these limitations. Increased measurement of productivity-related variables like height and diameter growth this early in the regeneration phase is not considered worthwhile.

Some improvements in the efficiency and utility of assessments can be achieved cost effectively within the constraints imposed by funding, staffing, mandated survey procedures and timing:

- Strong emphasis on training, quality control and accountability;
- Utilization of available tools (e.g. site stratification, regeneration models, local knowledge) to prioritize stands requiring ground surveys or walk-through in order to assess ingress not yet detectable from the air;
- Better and more meaningful quantitative linkages between establishment survey data and performance at 12-14 years, as being developed by FGYA regeneration monitoring and modeling research.

As further information becomes available from monitoring, more site-specific adjustment may be justified to stocking targets and minimum height thresholds adopted by the current Reforestation Standard.

8 Forecasting of Growth and Yield

8.1 Trends

Some of the trends observed in recent lodgepole pine research may have implications for timber supply analysis and the use of data from performance surveys to predict MAI:

- Density trends of ingress during the regeneration phase differ from those of planted stock (see Figure 7).
- Mortality rates prior to regular self-thinning may be changing and significantly different from historical rates and rates assumed in existing growth and yield models. Figure 8 shows the possible implications of these trends relative to yield trajectories predicted by TASS and TIPSY (Mitchell & Grout, 1995) and presented as stand density diagrams (Farnden, 1996).
- The proportion of the trees that are included in the estimation of stand top height (100 largest-diameter trees per ha) is dependent on the number of trees per ha, which is highly variable in natural regeneration. Top height in juvenile stands may be more influenced by the proportion of trees included in top height estimation than by expected site or growth factors. True top height (100 largest-diameter trees per ha) may also differ from top height as measured in RSA performance surveys (average of the heights of the largest tree per 100m² plot). These effects may explain anomalies illustrated in Figure 9 that were observed in predictions by GYPSY (Huang, Meng, & Yang, 2009) of site index at young ages in Canadian Forest Service silvicultural trials (Stewart, Jones, & Noble, 2006).
- The density distribution of ingress is asymmetric with a strong positive skew. The average number of trees per 10m² regeneration plot seldom represents the modal (most frequently occurring) density condition (see Figure 10).

Figure 8. Stand density diagram and possible effects of increased pre-thinning mortality

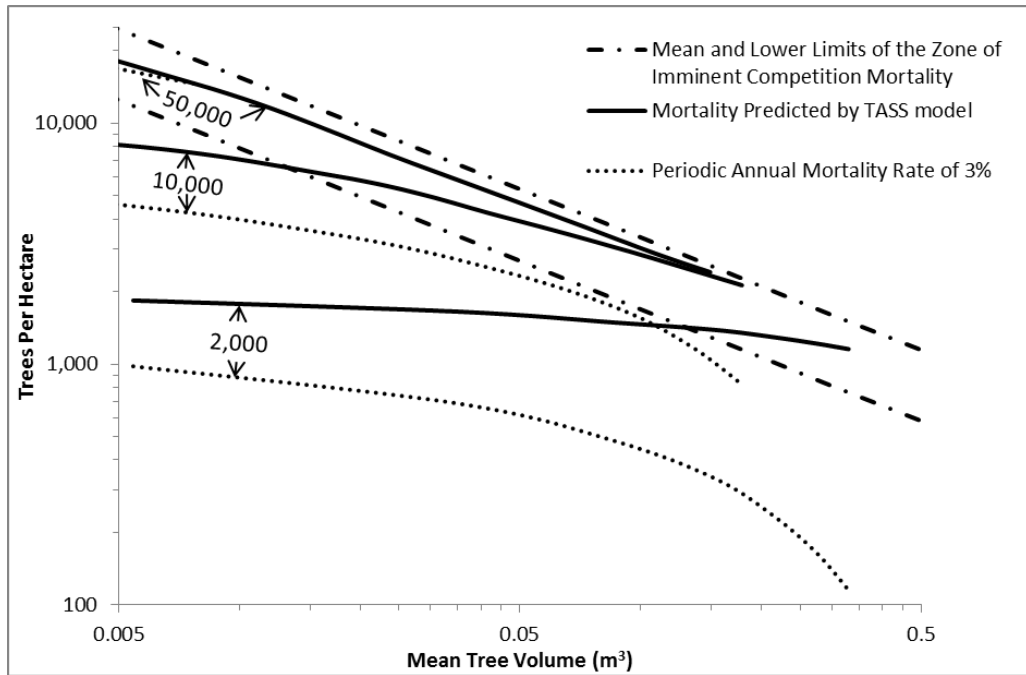


Figure 9. Bias observed in the Canadian Forest Service Gregg River Spacing Trial resulting from predicting site index predictions at young ages with GYPSY: results summarized by spacing density (left) and site quality (right)

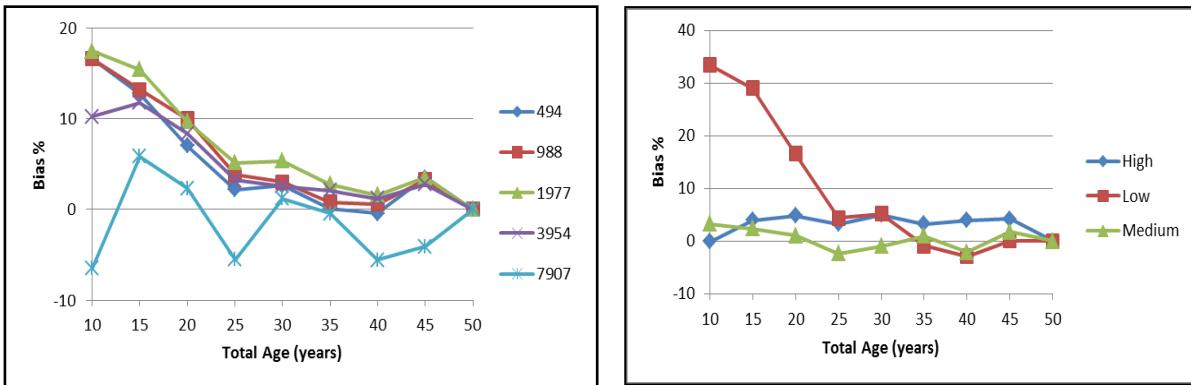
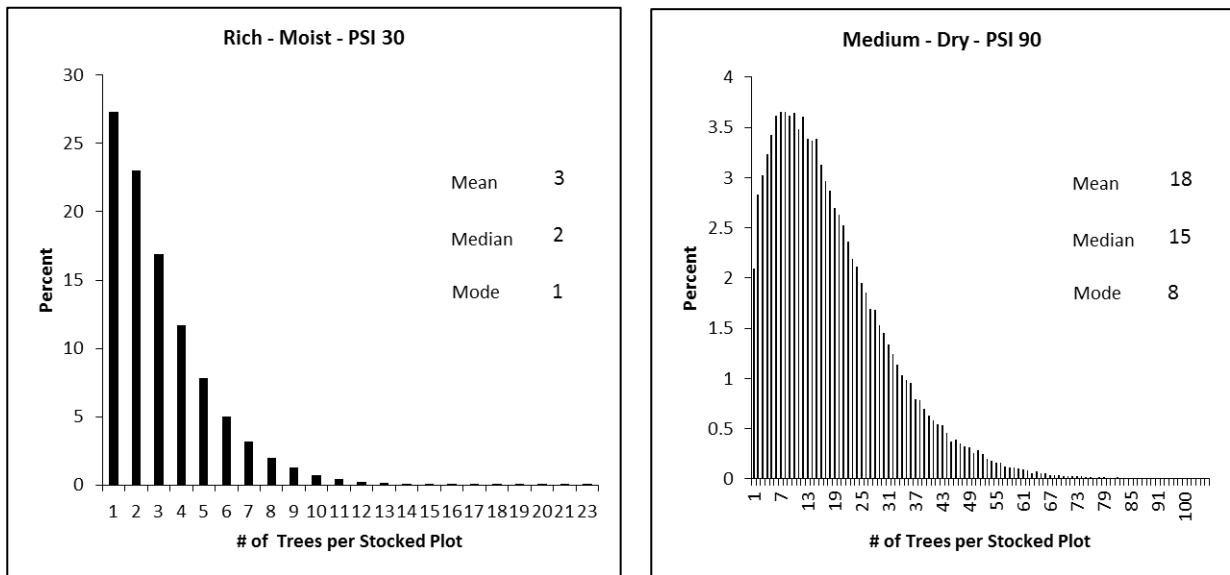


Figure 10. Density distributions for natural regeneration 12 years after harvest modelled for two sites with different pine stocking indices (PSI)



8.2 Discussion

Discussion was focused on GYPSY, the growth and yield projection system validated and approved for use in Alberta by the Alberta government (Huang, Meng, & Yang, 2009).

GYPSY is recognized as a major advance in growth and yield forecasting. However, application and testing of the model since its initial validation have indicated weaknesses, some of which are particularly relevant to reforestation standards and practice. Areas of identified concern are:

- Managed stands (as distinct from fire-origin stands on which model was primarily based);
- Responses to silvicultural treatments (including not only mid-rotation and multiple interventions which were not expected to be reliably projected, but also early density management: planting density, tending, and pre-commercial thinning);
- Late-rotation mortality (lower than expected possibly because sampling in old stands is restricted to those that have survived);
- Multi-aged and other complex stand structures (such as those that may arise in mixed species stands following mountain pine beetle attack);
- Use of historic data to predict the future (e.g. suspected changes in juvenile mortality linked to climate change are not captured by modelling density trends over previous centuries)
- Aggregation of species (although species were grouped based on biological and mensurational similarities, there is some concern about combining balsam fir with white spruce and balsam poplar with aspen);
- Tree improvement and the interaction of improved planted stock with unimproved natural regeneration are not modelled;
- Ingress of natural regeneration (GYPSY and some other models cannot predict resulting increases in stand density during first 2 decades following disturbance);
- Quality and suitability of data being used to drive yield forecasts (e.g. performance survey data collected early in the rotation);
- Top height in juvenile stands (probably highly influenced by the proportion that it represents of all trees in the stand - this effect is not modelled);

- Other uncertainties about the link between information collected in performance surveys and the later data from permanent sample plots captured in growth and yield models;
- Differences in stand growth and yield responses that have implications for management decisions but are not captured by RSA stratification.

8.3 Conclusions and Recommendations – Forecasting Growth and Yield

Commitment is required to appropriately designed monitoring programs as the long-term means for addressing inevitable uncertainty in growth and yield projections. Emphasis should be placed on obtaining more data points over time (i.e. multiple observations on the same sample plots) especially to monitor the development of young stands from performance survey age (12 - 14 years) into the mid-growth phase (30 years).

In the shorter-term, there are data and assessment methods that can be used to further investigate the trends observed in the RLP trial data (Section 8.1) and, at least on an interim basis, can be carefully applied to most of the known or suspected limitations in growth and yield predictions identified in the preceding discussion (Section 8.2).

Growth and yield predictions about future stand conditions are inevitably uncertain. Application of models should always be accompanied by caution, good silvicultural knowledge, and consideration of the risks involved. Management decisions should be based on a balanced assessment of the best forecasting tools and knowledge currently available, appropriate caution taking into account risk and uncertainty, and monitoring to continually improve forecasts by comparing actual and predicted results. The need for balance is exemplified in the challenge imposed by the Alberta Reforestation Standard that requires predicting yield from juvenile stand data. Juvenile top height measurements that are translated into site index and yield increases, possibly resulting from climate change or management interventions, should be interpreted with due consideration of mortality risk and with caution in regard to uncertainties about the dynamics of young stands.

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10 References

- Alberta Environment and Sustainable Resource Development. (2012). *Alberta timber harvest planning and operating ground rules framework for renewal*. Available from <http://srd.alberta.ca/LandsForests/ForestManagement/ForestManagementManualsGuidelines.aspx>.
- Alberta Environment and Sustainable Resource Development. (2013). *Reforestation standard of Alberta*. Government of Alberta, Department of Environment and Sustainable Resource Development, Edmonton, Alberta.
- Alberta Sustainable Resource Development. (2006). *Alberta forest management planning standard*. Available from <http://srd.alberta.ca/LandsForests/ForestManagement/ForestManagementManualsGuidelines.aspx>.
- Alberta Sustainable Resource Development. (2009). *Alberta forest genetic resource management and conservation standards manual*. Available from <http://srd.alberta.ca/LandsForests/ForestManagement/ForestManagementManualsGuidelines.aspx>.
- Alberta Sustainable Resource Development. (2009). *Pest ID cards*. Alberta Environment and Sustainable Resource Development, Edmonton, Alberta.
- Archibald, J. H., Klappstein, G. D., & Corns, I. G. (1996). *Field guide to ecosites of southwestern Alberta*. Special Rep. 8, Canadian Forest Service, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.
- Beckingham, J. D., Corns, I. G., & Archibald, J. H. (1996). *Field guide to ecosites of west-central Alberta*. Special Rep. 9. Canadian Forest Service, Northwest Region, Northern Forestry Centre, Edmonton, Alberta.
- Cleary, M., van der Kamp, B., & Morrison, D. (2008). *British Columbia's southern interior orests: Armillaria root disease stand establishment aid*. BC Journal of Ecosystems and Management, 9(2): 60-65.
- Dempster, W. R. (2012). *Regenerated lodgepole pine trial 10-year crop performance report*. Foothills Growth and Yield Association Tech. Rep. Available from <http://foothillsri.ca/resource/regenerated-lodgepole-pine-trial-10-year-crop-performance-report>.
- Dempster, W. R., & Wiens, D. (2011). *Mapping the risk of climate-linked mortality*. Foothills Growth and Yield Association Tech. Note 2011-1. Available from <http://foothillsri.ca/resource/mapping-risk-climate-linked-mortality-lodgepole-pine-regeneration>.
- Farnden, C. (1996). *Stand density management diagrams for lodgepole pine, white spruce and interior Douglas-fir*. Inf. Rep. BC-X-360. Canadian Forest Service, Pacific Forestry Centre, Victoria, Canada.
- Foothills Growth and Yield Association. (2011). *Progress and achievements of the Foothills Growth and Yield Association: the first decade April 2000 - March 2010*. Available from <http://foothillsri.ca/>

resource/progress-and-achievements-foothills-growth-and-yield-association-first-decade-april-2000.

- Heritage, S., & Moore, R. (2001). *The assessment of site characteristics as part of a management strategy to reduce damage by Hylobius*. Forestry Commission Inf. Note. Available from: www.forestry.gov.uk/publications.
- 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. Rep. Pub. No. T/216.
- 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.
- Johnstone, W. D. (1976). *Ingress of lodgepole pine and white spruce regeneration following logging and scarification in west-central Alberta*. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-170.
- Mather, W. J., Simard, S. W., Heineman, J. L., & Sachs, D. L. (2010). *Decline of planted lodgepole pine in the southern interior of British Columbia*. Forestry Chronicle, 86:(4)484-497.
- McCulloch, L., Aukema, B., White, K., & Klingenberg, M. (2009). *British Columbia's northern interior forests: Warren root collar weevil stand establishment aid*. BC Journal of Ecosystems and Management, 10(2): 105-107.
- Mitchell, K. J., & Grout, S. E. (1995). *User's guide for producing managed stand yield tables with WinTIPSY Version 1.3 under Microsoft Windows*. . B.C. Ministry of Forests, Res. Branch, Victoria, BC.
- 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, Alberta.
- Wang, T., Hamann, A., Spittlehouse, D., & Aitken, S. (2006). *Development of scale-free climate data for western Canada for use in resource management*. International Journal of Climatology, 26(3): 383-397.