Forest Resource Improvement Association of Alberta
Forest Resource Improvement Program

Foothills Growth and Yield Association

Regenerated Lodgepole Pine Trial

CROP PERFORMANCE REPORT

Prepared by:

W.R. (Dick) Dempster, Ph.D.
Research and Development Associate
Foothills Growth and Yield Association

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Foothills Research Institute
P.O. Box 6330
Hinton, Alberta
T7V 1X6

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Executive Summary

The latest (2014) measurement of the Regenerated Lodgepole Pine Trial has allowed regeneration performance to be reported at 14 years since cut and 13 years since planting.

Thinning has now been completed on scheduled plots. Average densities of planted stock have dropped below target planting densities because of mortality, but this is more than offset by natural regeneration. Ingress of pine and regrowth of hardwoods is already occurring on some thinned plots, the latter notably in plots which had been thinned but not previously weeded.

High rates of planting stock mortality continue to occur on mesic/dry Lower Foothills sites. Mortality on these sites is reduced by weeding. Mortality is significantly higher where site preparation was considered unnecessary, than on sites mounded or ploughed to create microsites for planting or dragged to encourage natural regeneration. The overall average current mortality rate (2013 to 2014) across the trial is higher than the mean annual rate since planting. Average periodic annual mortality since 2008 is marginally higher in planted stock than in natural regeneration. In both planted stock and natural regeneration by far the most prevalent mortality factor is *Armillaria*, followed by root collar weevils and lower incidences of western gall rust, browsing and other factors.

Stocking of lodgepole pine natural regeneration is primarily influenced by soil nutrient and moisture regimes and by weeding. Stocking is significantly lower on mounded or ploughed sites than on dragged sites or sites where site preparation was considered unnecessary. Black spruce regeneration is more likely to occur on poor than on medium or rich sites, and the converse is true for white spruce.

In non-weeded plots there is no significant difference in average tree diameter growth between poor, medium and rich sites, either in planted stock or natural regeneration. Site quality is better expressed in weeded plots. The beneficial effect of weeding on diameter is most pronounced on rich sites. Diameter growth of planted stock decreases at higher planting densities.

Average tree height and top height of lodgepole pine are most significantly affected by soil nutrient regime. The effect of weeding is less, but statistically significant. The top height of aspen that survives or re-suckers after weeding is substantially reduced relative to that of non-weeded plots.

As of 2014 the trial has been monitored over the full regeneration phase between harvest and the latest ages allowed for performance assessment under the Regeneration Standard of Alberta. The data and relationships discussed in this and earlier reports are currently being consolidated into a regeneration model that will be available later in 2015 for quantitative forecasting of regeneration performance.

1. Introduction

In the year 2014, 74 of the 102 trial installations were measured in detail, and mortality checks were made on the remainder. During the two-year period 2013-2014, all installations were measured in detail at the end of the 13th growing season following planting. In the following report crop performance variables, unless otherwise stated, are reported at 13 growing seasons so that comparisons of the effects of different sites and treatments are made at the same age of planted stock. Table 1 summarizes the timing of these measurements relative to Timber Year of Cut and years since the last harvesting or site preparation disturbance. Note that the age of 13 growing seasons on average equates to 14 years since Timber Year of Cut. Thus the measurements are representative of the last year permitted for regeneration performance assessment under the Regeneration Standard of Alberta.

Table 1. Chronology of installations at 13 growing seasons after planting

Year of Measurement	# of Installations	Time Period	Elapsed Time
2013	28	Av. years since cut (based on Timber Year of Cut)	13.7
		Av. years since harvesting / site preparation completed	13.5
2014	74	Av. years since cut (based on Timber Year of Cut)	14.3
		Av. years since harvesting / site preparation completed	14.1
All installations	102	Av. years since cut (based on Timber Year of Cut)	14.2
		Av. years since harvesting / site preparation completed	13.9

The planned experimental treatment schedule was not followed in 9 of the 102 installations.

- 1 installation (4-2-0), scheduled for no planting, was planted shortly after trial establishment.
- 6 installations (group 3-4) were completely aerially sprayed with herbicide in 2006.
- 1 installation (4-1- 4444) was partially operationally tended (mechanical brushing and thinning) in 2010. Treatment plots were re-organized to minimize the effect.
- 1 non-planted installation (3-2-0) was destroyed by forest fire, and replaced (by installation 3-2-9). The replacement installation did not receive any tending until 2006.

These installations have been excluded from most of the statistics presented in this report.

The effects of site and treatment factors on regeneration performance were investigated using the flexible REML (Restricted Maximum Likelihood) mixed model fitting technique[1]. The approach is suitable for the trial's split plot design, which nests weeding and thinning treatment sub-plots within installations (whole plots) located on different sites and planted at different densities.

The figures in this report typically show stratum means as vertical bars, with a label above each bar indicating the mean value. Standard errors of the mean are shown as vertical lines. Note that the standard error as calculated here is not necessarily the most suitable basis for determining the significance of differences between means, and is intended only as a general indication of the dispersion of individual sample plot values. The statistical significance of differences between means was more reliably calculated using the REML model fitting technique, in combination with suitable range tests where more than two levels of a factor were included.

2. Thinning

A total of 204 treatment plots (i.e. two in each of 102 installations) were scheduled for thinning in the original experimental design. To date, 202 plots have been thinned in 101 installations. The remaining 2 non-thinned plots that were originally scheduled for thinning are in installation WWC-4-2-0, which was withdrawn from the thinning schedule because its use for studying density management was compromised by inadvertent planting. Of the 101 installations thinned to date, 74 have received full measurements after thinning.

The statistics shown in Figures 1 and 2 are based on 66 installations for which full after-thinning measurements are currently available (plots having treatment violations are excluded). Each installation consists of four treatment plots, and results are shown by the combination of treatments applied: control (C), weeded (W), thinned (T), weeded and thinned (WT).

[1] SAS Institute Inc. 2002. *JMP statistics and graphics guide*, Version 5.

Figure 1 shows average hardwood stems per ha (≥ 1.3m in height) after thinning, as measured in 2013 or 2014. While 83% of thinned (T and WT) plots showed no residual hardwoods after thinning, some showed substantial after-thinning ingress. This apparent rapid regrowth occurred primarily in plots which had been thinned but not weeded, and is already resulting in higher average densities than those observed in plots that had been previously weeded.

Figure 1. Average hardwood densities after thinning

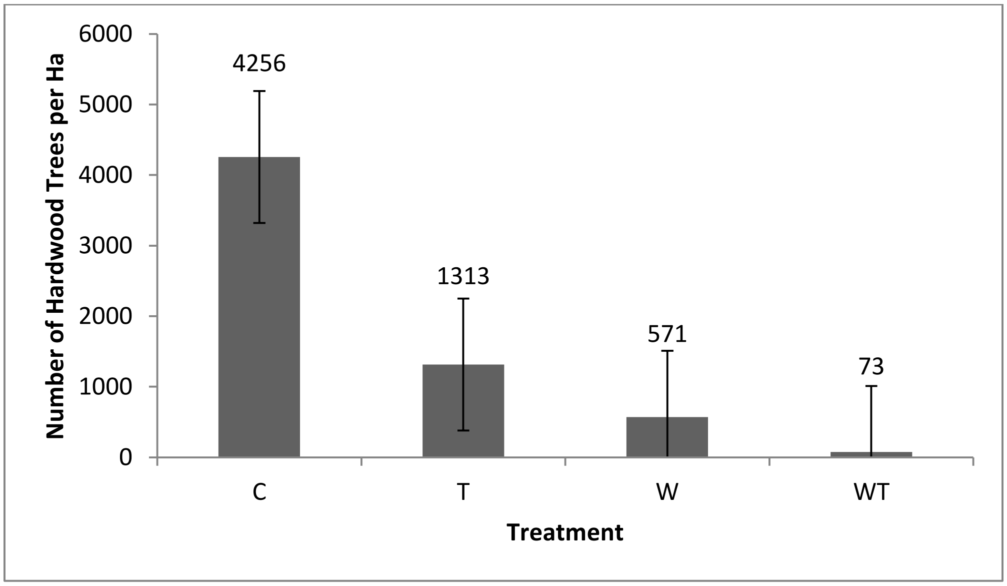


Figure 2 shows the post-thinning densities of planted lodgepole pine and natural coniferous ingress (≥ 30 cm in height) on the thinned portions (*T* and *WT* plots) of the same 66 installations. Average densities of planted stock are below target planting densities because of mortality, but this is more than offset by natural regeneration (as indicated by the total densities shown above each column in the figure).

Coniferous ingress densities in non-thinned plots across the trial averaged almost 10,000 trees per ha. The intent of thinning was to reduce combined planted and ingress densities to the target planting density, with the exception of the non-planted plots where the intent was to limit densities to the planting maximum (4,444 trees per ha). Average total coniferous densities after thinning shown in Figure 1 exceed target values. The excess of coniferous trees relative to target densities probably results from a combination of uneven spacing of natural regeneration, caution by field crews not wishing to over-thin, and ingress occurring between thinning and measurement.

3. Effects of Weeding on Hardwood and Herbaceous Vegetation

It is too early to evaluate the effects of thinning on growth of competing vegetation, but weeding was completed by 2006 in most plots and the longer-term effects are increasingly evident. Figure 3 shows the effect of weeding in relation to natural sub-region and soil nutrient class on average percent stocking of hardwoods ≥1.3m in height 13 growing seasons after planting, in non-thinned (C and W) plots.

Figure 2. Average densities of planted and naturally regenerated conifers after thinning

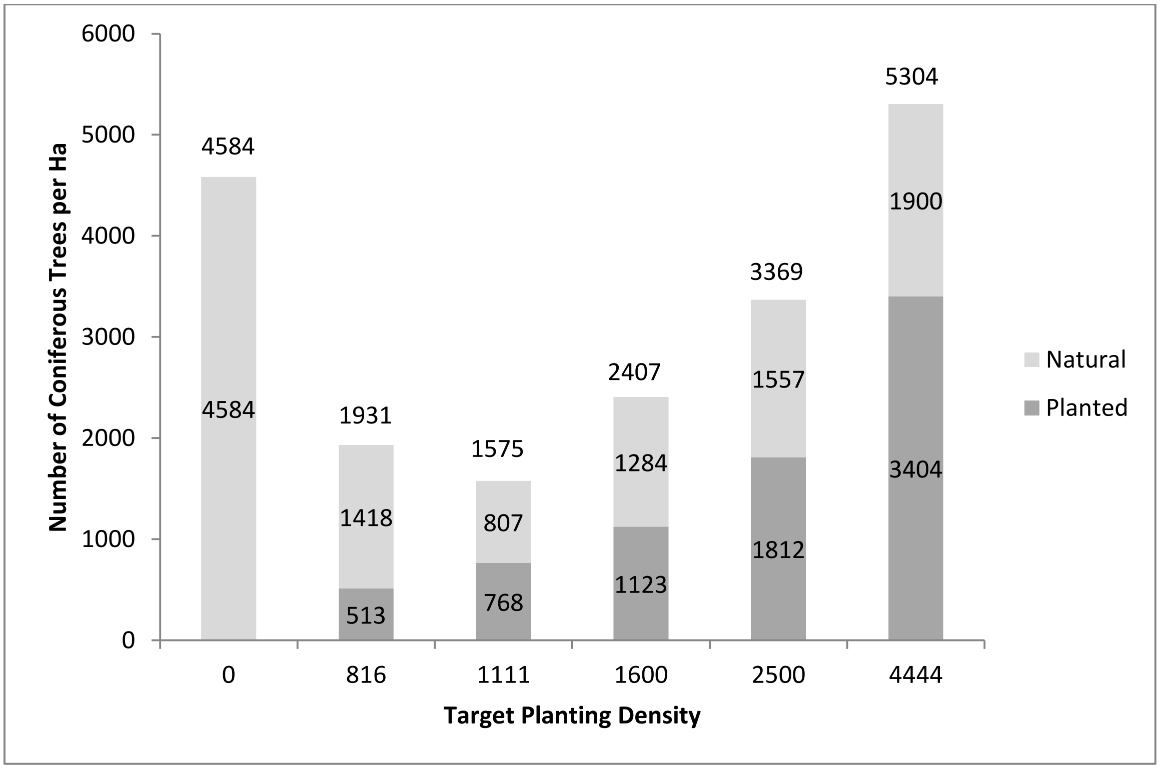
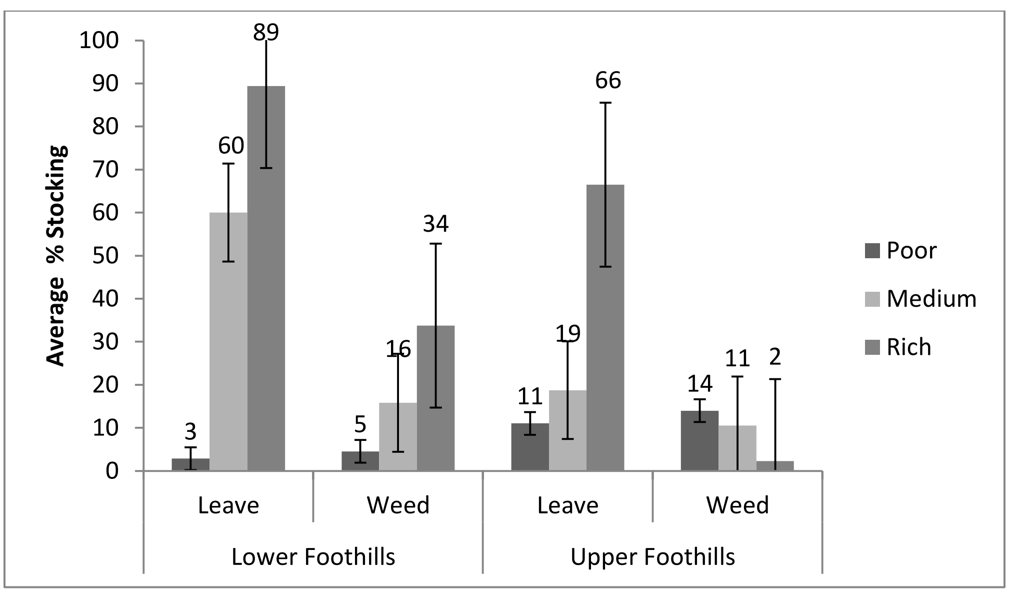


Figure 3. Effect of weeding and site on percent stocking of hardwoods



The decreases in stocking from rich to poor sites, from the Lower to Upper Foothills, and with weeding are statistically significant (probability of chance occurrence <0.0001) and biologically reasonable trends. Hardwood stocking generally remains low after weeding except on rich Lower Foothills sites. Note that the downward trend from rich to poor sites is not shown on weeded plots in the Upper Foothills (where stocking is low and the small non-significant site differences may be artefacts arising from treatment protocols).

Figures 4 and 5 show the effect of weeding on shrub and herbaceous cover 13 growing seasons after planting, in non-thinned (C and W) plots. Whilst reductions in shrub cover following weeding are still evident, there is no statistically significant weeding effect for grass and forb cover averaged across all sites (Figure 4). However, average grass and forb cover on rich moist sites increases after weeding (Figure 5).

Figure 4. Effect of weeding on herbaceous and shrub cover – all sites

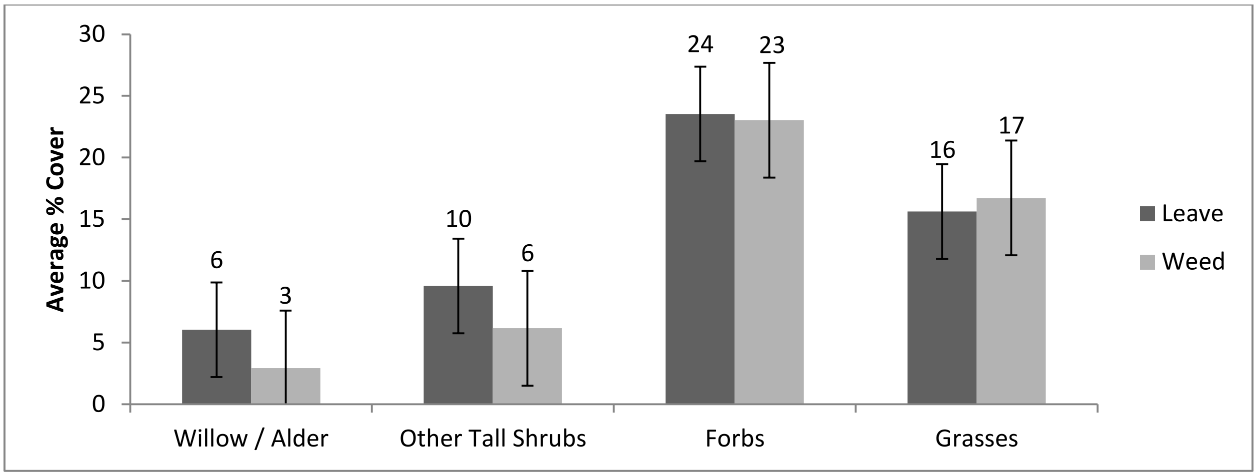
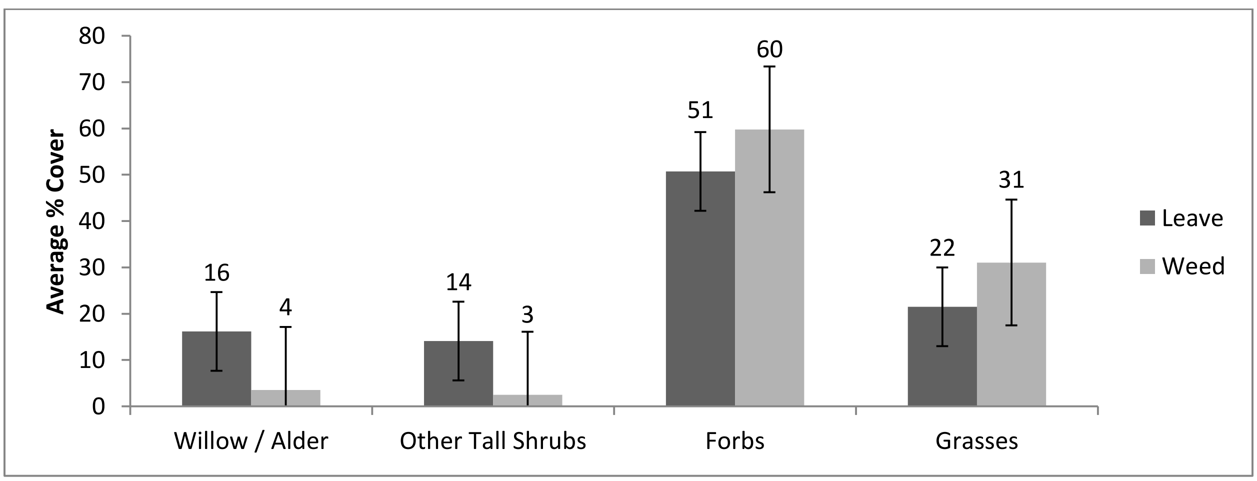


Figure 5. Effect of weeding on shrub and herbaceous cover – rich sub-hygric sites



4. Mortality of Lodgepole Pine

Figure 6 shows mean annual mortality rates of planted lodgepole pine in non-thinned plots averaged by natural sub-region, soil moisture regime and weeding treatment. *Mean* annual rates are based on cumulative mortality from planting until (and including) the 2014 measurement. The highest rates of mortality occur on mesic/dry Lower Foothills sites. In the Lower Foothills sub-region the differences shown between soil moisture regimes (mesic/dry and moist) and between weeding treatments (leave and weed) are statistically significant (probabilities of occurring by chance less than 0.0001 and 0.05 respectively). In the Upper Foothills no statistically significant differences were found for these factors.

Figure 6. Mean annual mortality rates of planted lodgepole pine

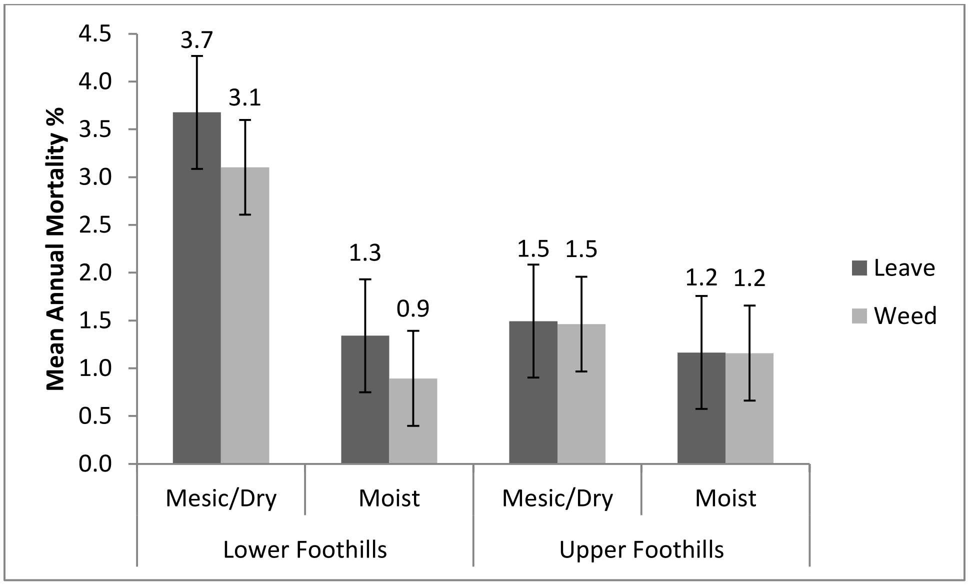


Figure 7 shows current annual mortality rates of planted lodgepole pine in non-thinned plots averaged by natural sub-region, soil moisture regime and weeding treatment. *Current* rates are the percentage of trees that died between measurements in 2013 and 2014. Note the greater differentiation between the *leave* and *weed* treatments compared to mean and previous rates, and the increased rates in non-weeded Lower Foothills plots. Effects of sub-region, moisture regime and weeding are all statistically significant (probability of chance occurrence always < 0.05). The overall average current rate across the trial is 2.4%, and higher than the mean annual rate since planting of 1.7%. The difference is significant at the 0.05 probability level.

Figure 7. Current mortality rates of planted lodgepole pine

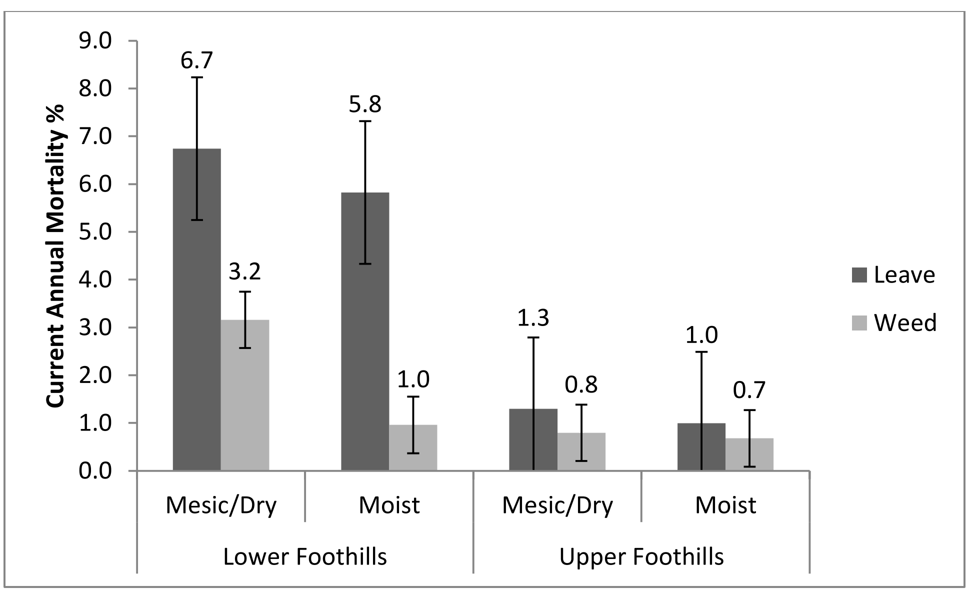


Figure 8 shows an apparent relationship between mortality of planted stock and site preparation method. Mortality is significantly higher on sites where site preparation was considered unnecessary, than on sites mounded or ploughed to create microsites for planting or dragged to encourage natural regeneration (probability of chance occurrence <0.0001). Site preparation method was not experimentally controlled in the RLP trial, so it is possible, indeed likely, that site preparation and site quality effects are confounded. However, the observed effect was not fully explained in terms of the soil-site classification, leaving the possibility that site preparation itself has had a beneficial effect on survival. A fuller discussion of site preparation effects is provided elsewhere.[2]

Figure 8. Mean annual mortality of planted lodgepole pine by site preparation method

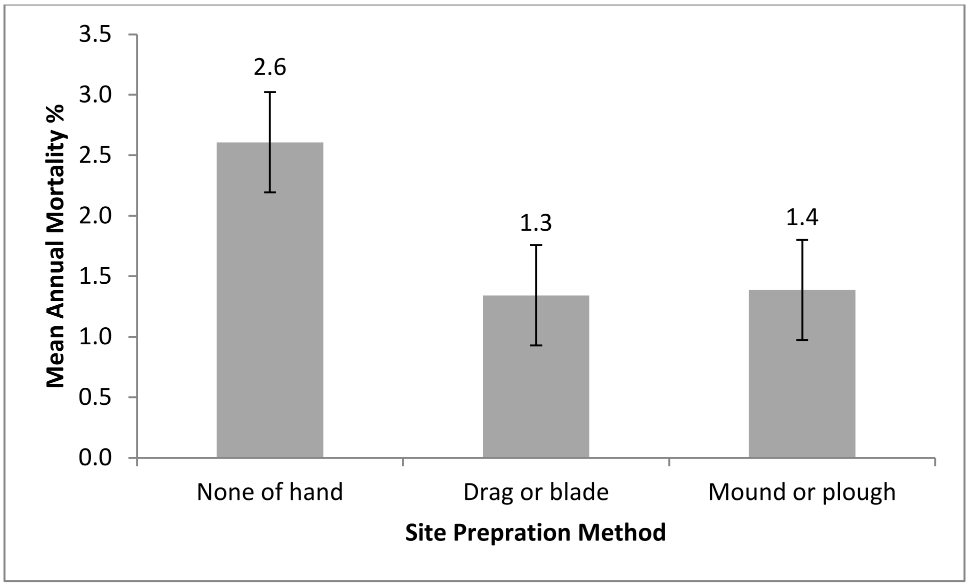


Figure 9 compares average periodic annual mortality rates for the period 2008 – 2014 between planted and naturally regenerated stock. One extreme outlier non-planted plot, plus two planted plots also having extremely high mortality rates, were excluded from the comparison. (All three excluded outliers are in the Lower Foothills, were not weeded, and have in common 100% hardwood stocking. Although they were excluded as being atypical, their inclusion or exclusion does not change the ranking of results between seedling origins or weeding treatments.) Periodic mortality is somewhat higher in planted stock (average 1.6%) than in natural regeneration (average 0.9). The average difference is only marginally significant (probability of chance occurrence 0.06). Average current annual mortality (i.e. mortality occurring between 2013 and 2014) as shown in Figure 10 is also higher in planted stock than in natural regeneration (average 1.8% versus 1.3%), but this difference is not statistically significant. The difference in average mortality of natural regeneration in weeded versus non weeded plots (1.9% versus 0.8%) is not quite significant at the 0.05 probability level.

[2] *Effects of site preparation on ingress, growth and mortality of lodgepole pine regeneration.* FGYA Technical Note, July 2014.

Figure 9.Comparison of periodic mortality between planted and naturally regenerated stock

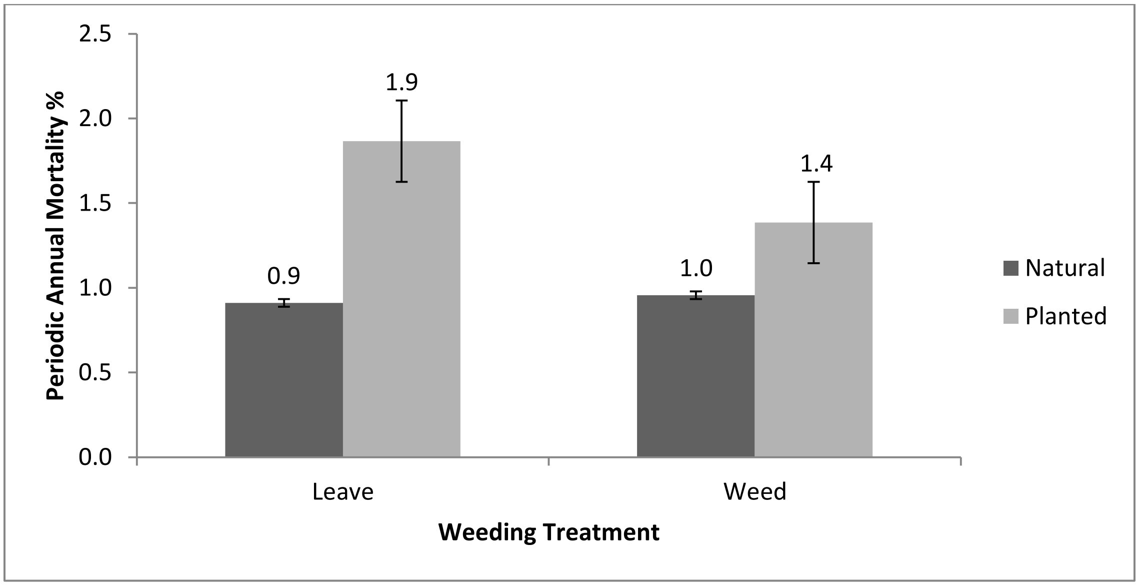
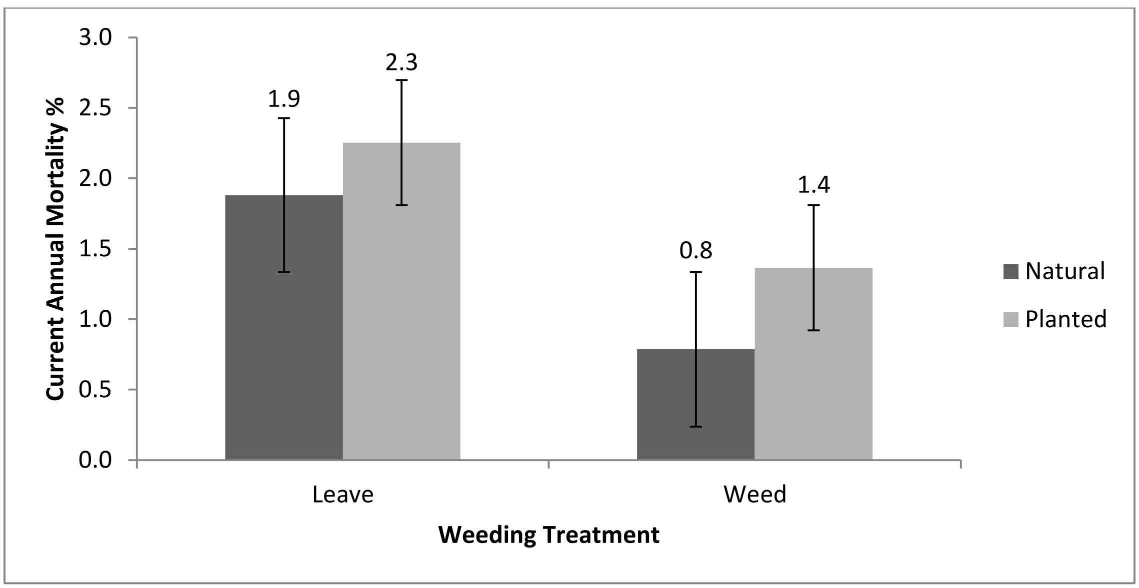


Figure 10. Comparison of current mortality between planted and naturally regenerated stock

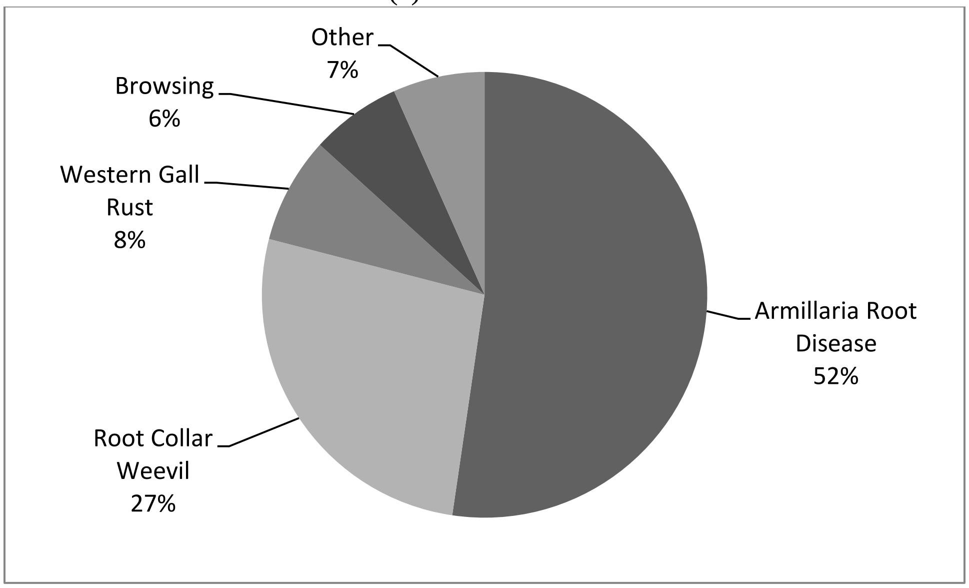


Apparent causes of mortality are shown in Figures 11 and 12. These are based on the health codes assigned to dead trees observed on the plots in 2014. The summaries are for all trial installations, including those with treatment violations noted previously. Only the C and W (i.e. non-thinned) plots are included, to remove the effect of tree selection protocols used in thinning. Each dead tree was assigned a maximum of two mortality factors based on observed signs and symptoms. The relative frequency of each factor is the number of times it was observed expressed as a percentage of all observations.

Figure 11 shows the mortality factors observed in 2014 for trees that were alive in 2008. In both planted stock and natural regeneration by far the most prevalent factor is *Armillaria* (over 50%), followed by root collar weevils (over 25%) and lower incidences of western gall rust, browsing and other factors. Figure 12 shows the same categories observed in 2014 for trees that have died since 2013. Note that *Armillaria* and root collar weevils remain the prevalent factors, but the proportions of western gall rust, browsing and other factors are higher than those shown previously.

Figure 11. Relative frequencies of mortality factors based on trees alive in 2008

(a) Planted stock



(b) Natural regeneration

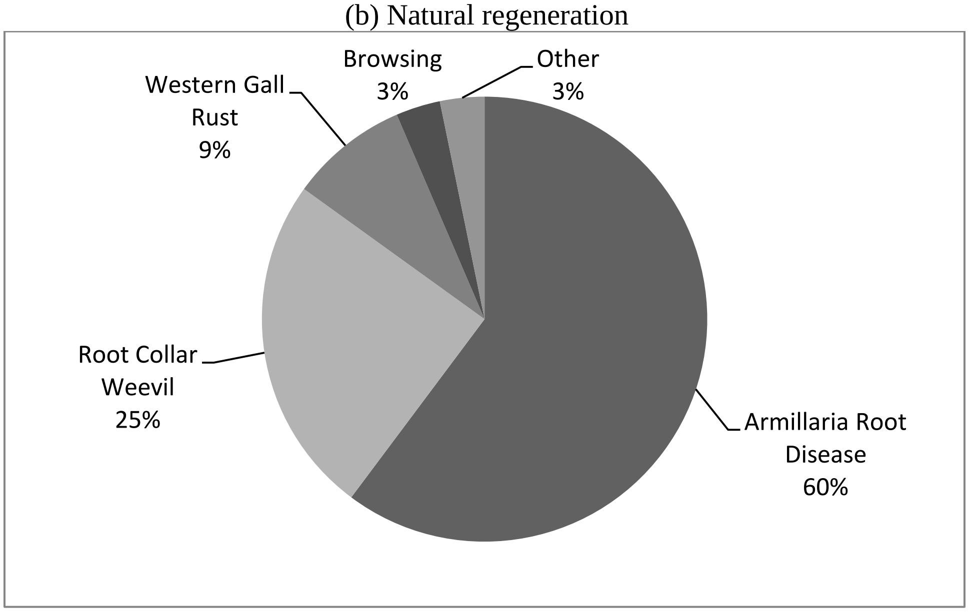
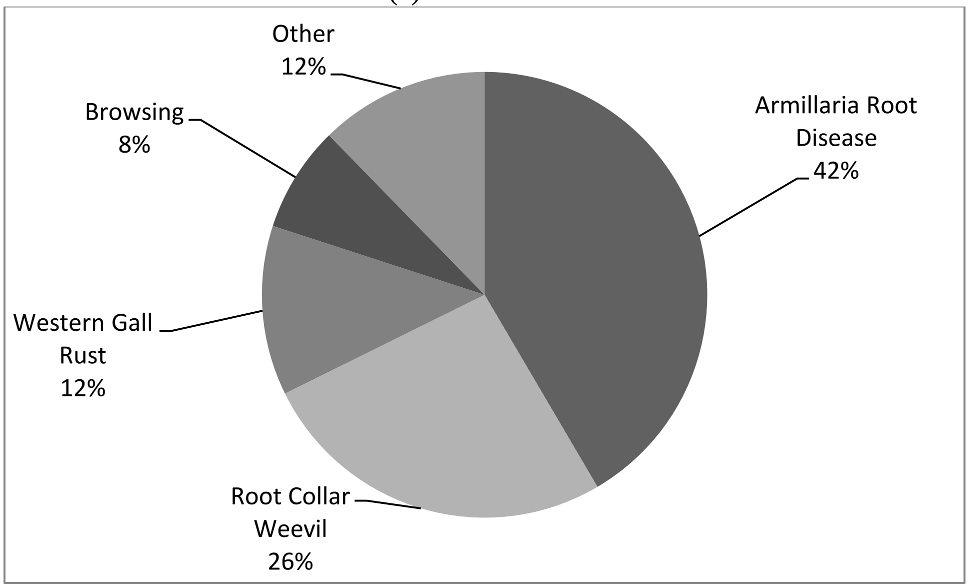
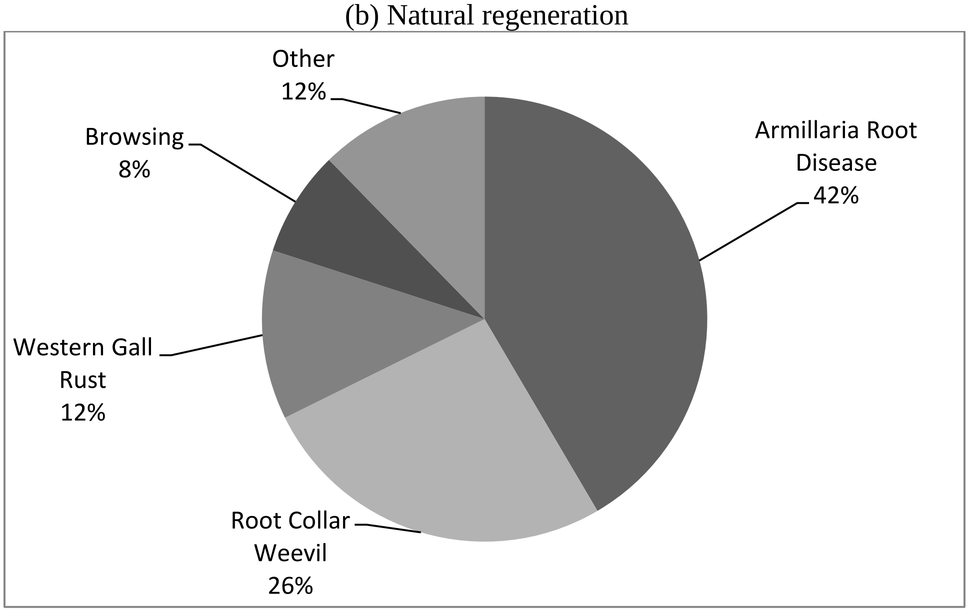


Figure 12. Relative frequencies of mortality factors based on trees alive in 2013

(a) Planted stock



(b) Natural regeneration



5. Density and Stocking of Natural Regeneration

Figure 13 shows the average number of naturally regenerated coniferous trees per ha (all species, height $\geq$ 30cm) occurring 13 growing seasons after installations were planted (i.e. approximately 14 years after cut). Averages and standard errors are shown by soil nutrient class and weeding treatment for non-thinned (C and W) plots only. (See Figure 2 for densities after thinning of W and WT plots.) Variability in density is high, density distributions tend to be skewed and non-normal, and effects of weeding uncertain. Percent stocking demonstrates clearer trends. Figure 14 shows percent stocking of lodgepole pine natural regeneration (height $\geq$30cm) by site and treatment. Here a trend of increased stocking following weeding has emerged, especially on rich sites. The effects of both nutrient regime and weeding are statistically significant (probability of chance occurrence < 0.0001 and < 0.01respectively). Stocking is also influenced by soil moisture regime, with significantly higher levels of pine ingress occurring on mesic / dry sites versus moist sites.

Figure 13. Average densities of coniferous ingress by site and treatment

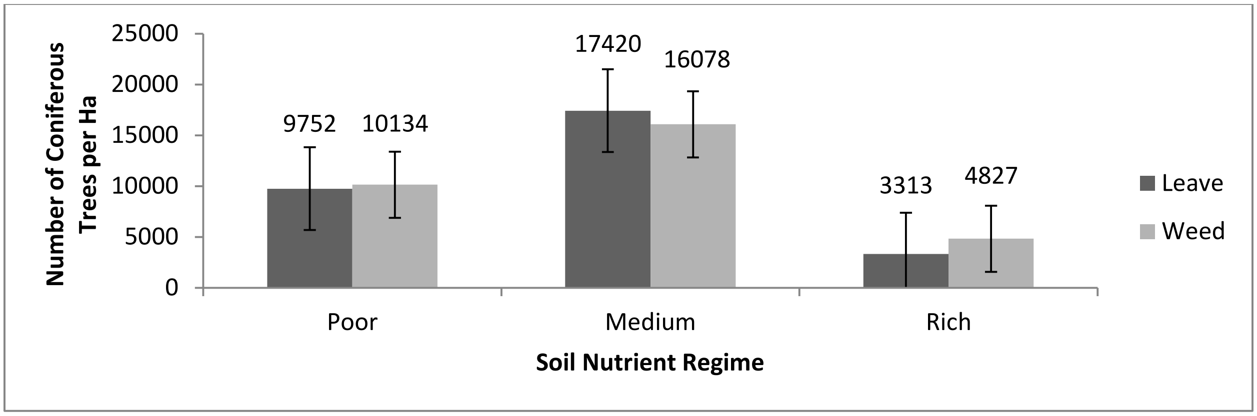


Figure 14. Percent stocking of lodgepole pine ingress by site and treatment

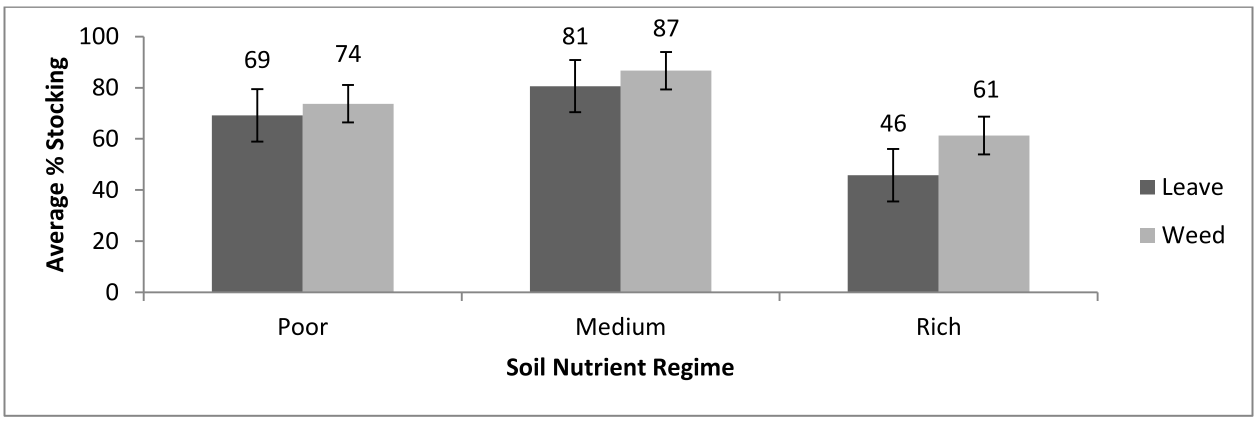


Figure 15 compares average stocking rates of lodgepole pine, whites spruce, black spruce and all conifers combined (height ≥30cm). Averages are shown by soil nutrient class. Note that black spruce is more likely to occur on poor than on medium or rich sites, and the converse is true for white spruce. Ingress of black spruce on poor sites is often high enough to compensate for marginal levels of pine stocking. However, the variation in stocking of both spruce species is high, especially when considered relative to their low average stocking rates. A fuller discussion of non-pine species is provided elsewhere.[3]

Figure 16 shows an apparent relationship between stocking of pine regeneration and site preparation method. As mentioned previously, site preparation method was not experimentally controlled in the RLP trial, so it is possible, indeed likely, that site preparation and site quality effects are confounded. However, percent stocking is significantly lower on sites mounded or ploughed to create microsites for planting, than on sites dragged to encourage natural regeneration or on sites where site preparation was considered unnecessary. The effect occurred within all three soil nutrient regimes, and could not be fully explained by the soil-site classification.

[3] *Forecasting aspen and spruce regeneration in juvenile lodgepole pine stands*. 2014. FGYA Technical Note.

Figure 15. Percent stocking of coniferous ingress by species and site

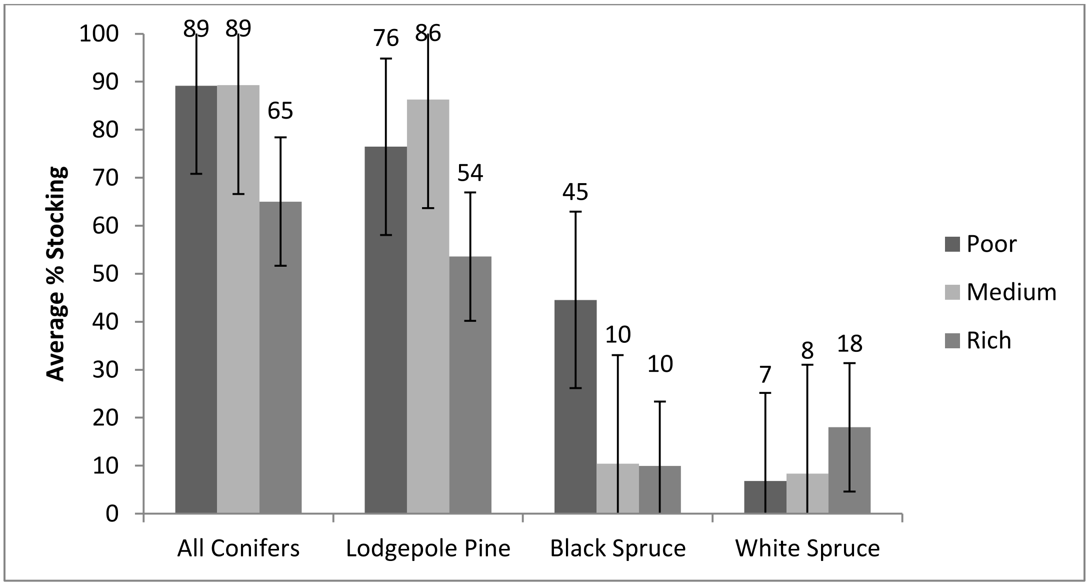
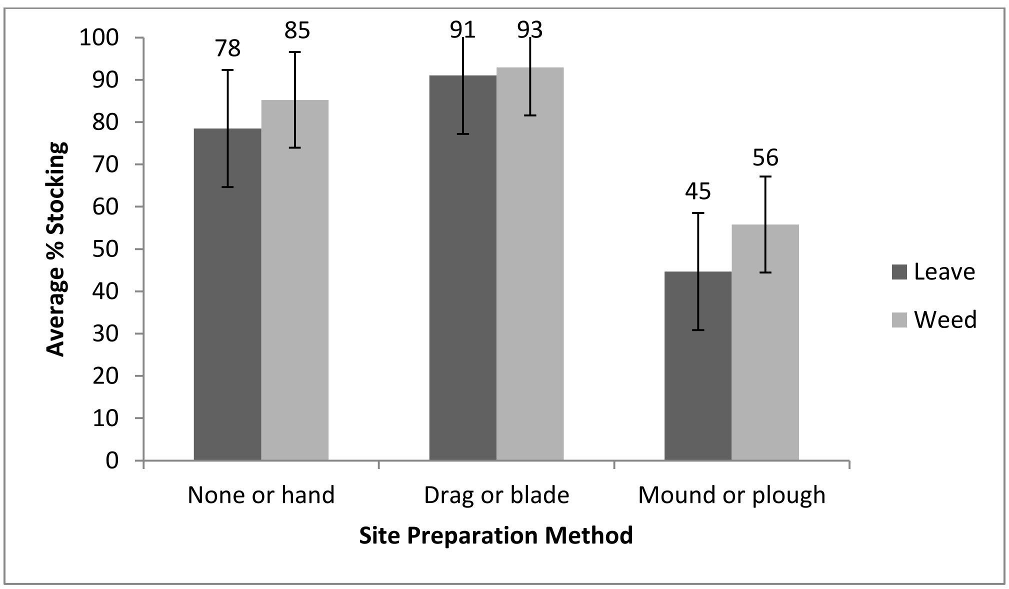


Figure 16. Percent stocking of lodgepole pine ingress by site preparation method



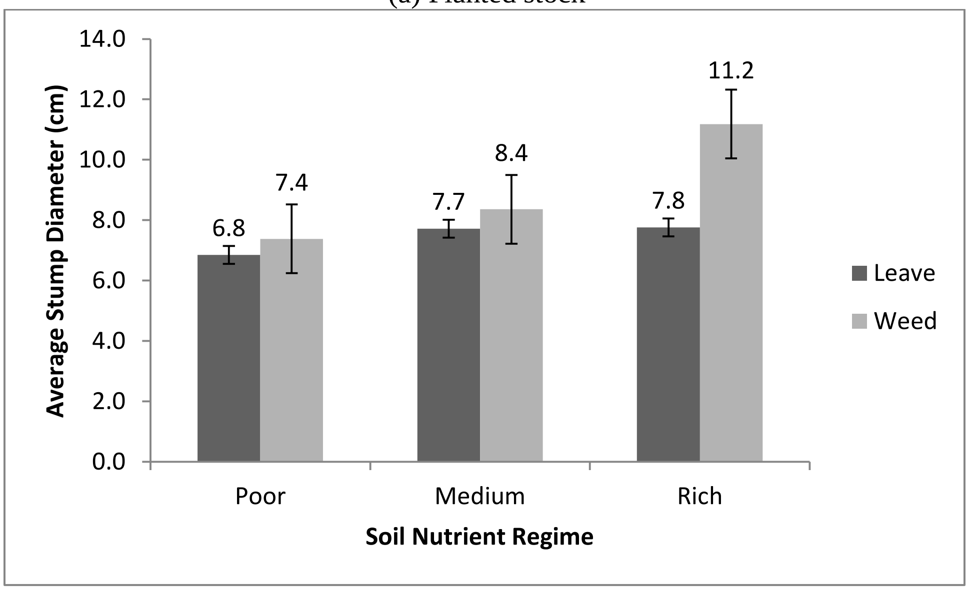
6. Diameter and Height

The statistics presented in this section all apply to non-thinned (C and W) plots 13 growing seasons after planting. (Not all thinned plots have been measured since thinning, so it is not yet possible to provide a full assessment of post-thinning stand conditions, and it will be two years before an initial assessment can be made of thinning response.) The statistics are based on lodgepole pine sample trees only, all $\geq$30cm in height, with the exception of Figure 22, which compares top heights of lodgepole pine, aspen, black spruce and white spruce.

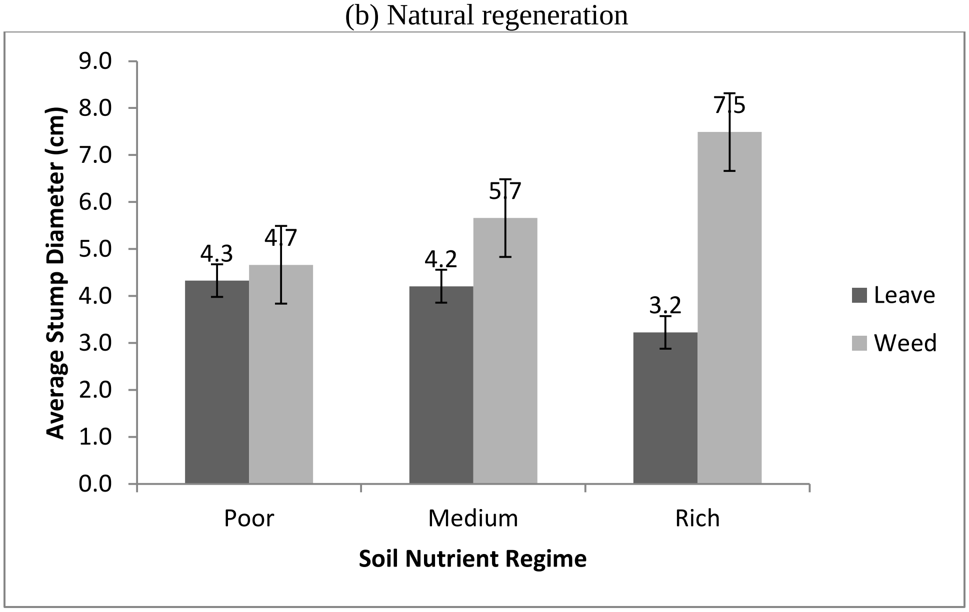
Figure 17 shows the effects of site (soil nutrient regime) and weeding on average tree stump diameter (measured at 30cm height) of planted and naturally regenerated stock. In non-weeded plots there is no significant difference in average tree diameter between poor, medium and rich sites, either in planted stock or natural regeneration. Site quality is better expressed in weeded plots. The effect of nutrient regime in weeded plots is highly significant for planted stock (probability of chance occurrence >0.0001). The beneficial effect of weeding is, as would be expected, most pronounced on rich sites. The results for natural regeneration show similar trends to those for planted stock, but with reduced levels of statistical significance because of a smaller sample size.

Figure 17. Effect of site and weeding on stem diameter

(a) Planted stock



(b) Natural regeneration



As shown in Figure 18, diameter growth of planted stock decreases at higher planting densities and increases with weeding. The effects of both density and weeding are statistically significant (probabilities of chance occurrence <0.01 and <0.0001 respectively). The decrease in individual tree diameters is not reflected in basal area per ha, because it is more than offset by the higher planting densities.

Average tree height of planted stock (Figure 19) and top height of planted installations (Figure 20) are significantly affected by soil nutrient regime (probability of chance occurrence <0.0001), with all three site classes being significantly different from each other. Both average height and top height show increases with weeding. The increases in top height are relatively small, but still significant at the 0.05 probability level. Top height of planted stock is compared with that of natural regeneration in Figure 21.

Figure 18. Effect of planting density and weeding on diameter of planted stock

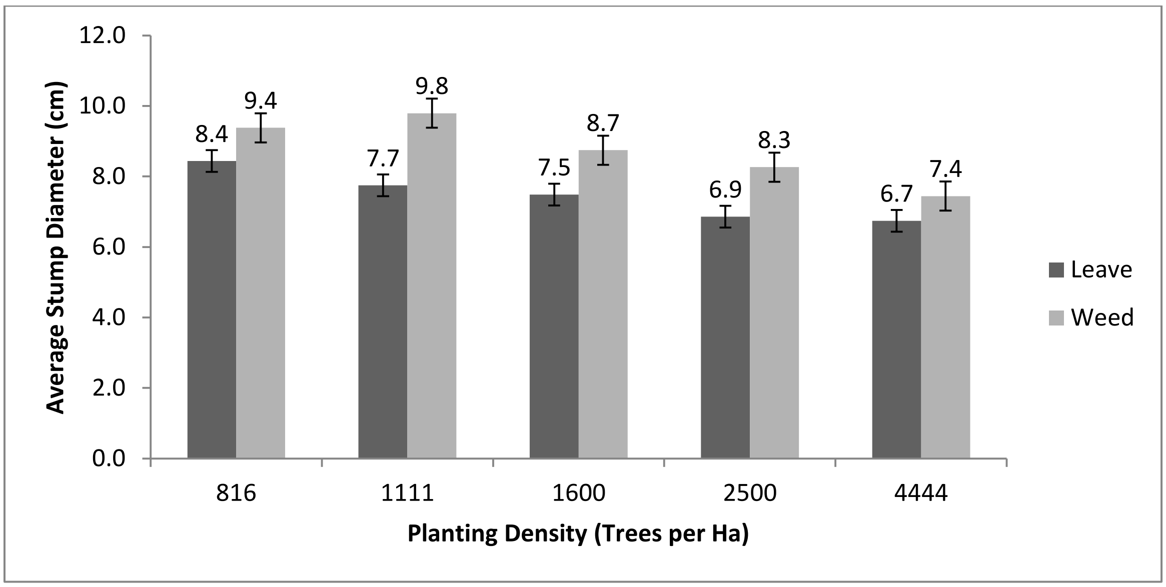


Figure 19. Effect of site and weeding on average height of planted stock

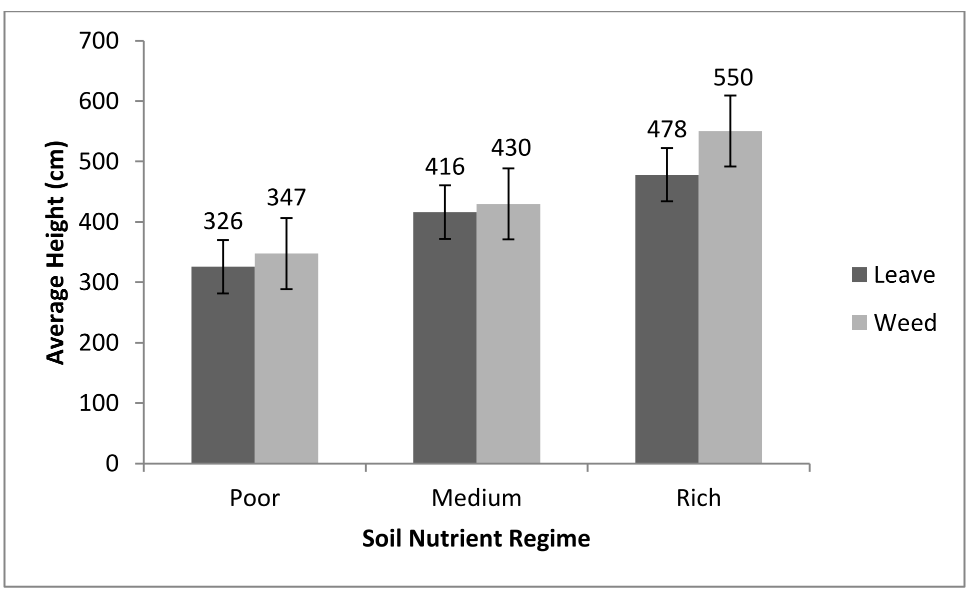


Figure 20. Effect of site and weeding on top height of planted stock

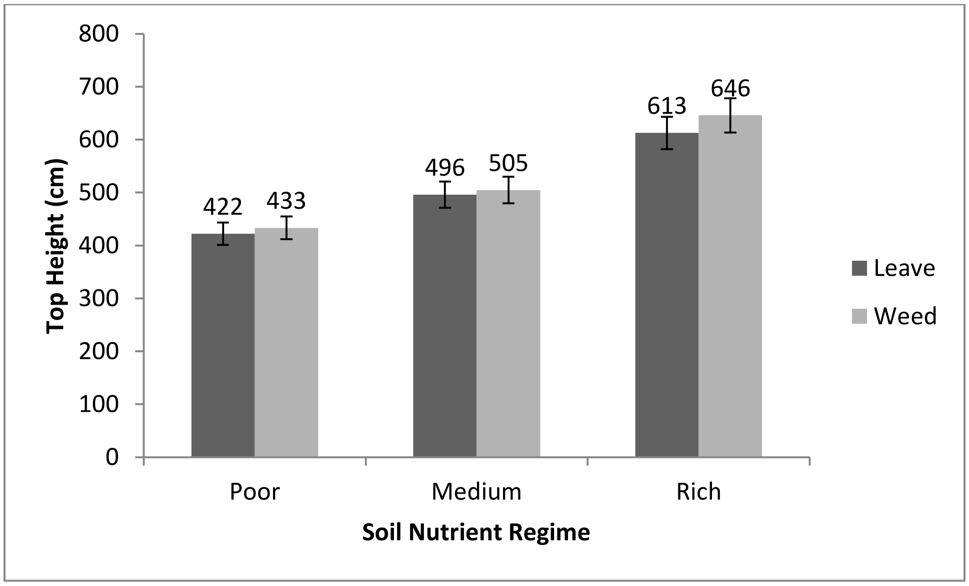


Figure 21. Comparison of top height between planted stock and natural regeneration

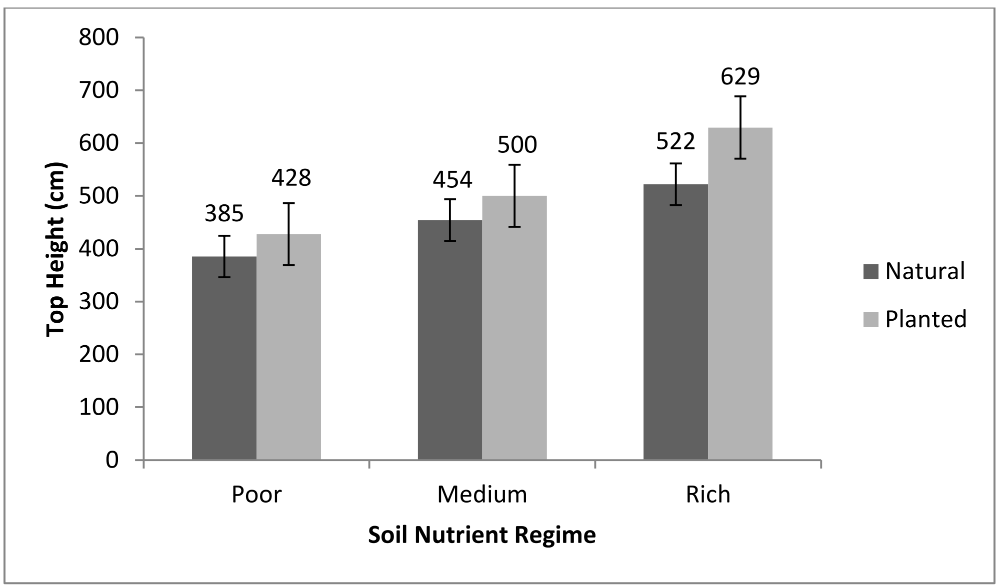
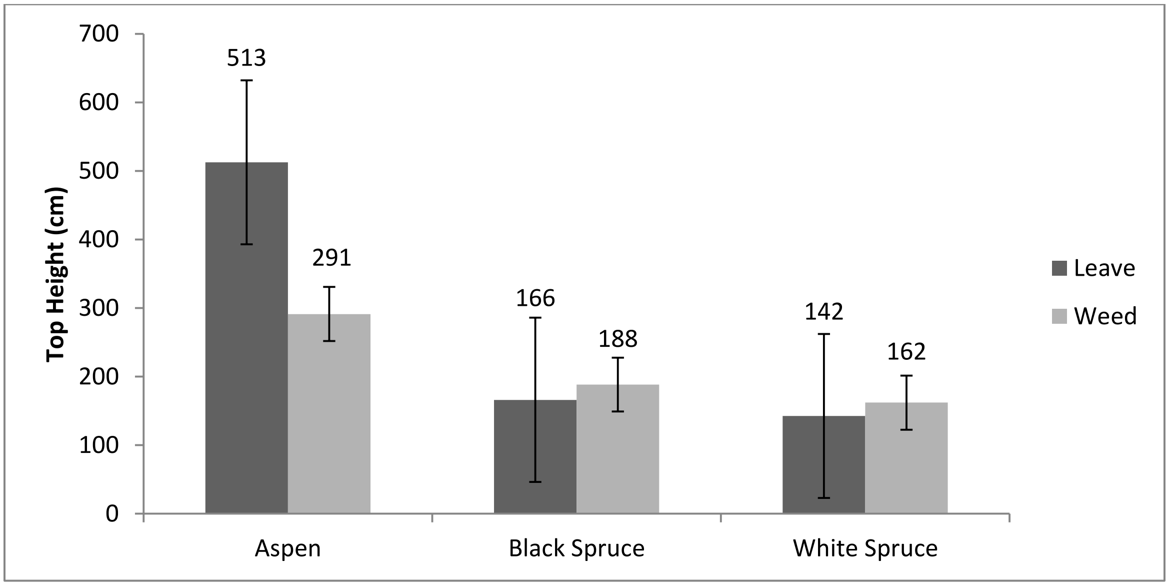


Figure 22 shows the average top heights of aspen and spruce natural regeneration by weeding treatment. Note that the top height of aspen that survives or re-suckers after weeding is substantially reduced relative to that of non-weeded plots.

7. Covariates

Sections 4 to 6 above describe the relationships between lodgepole pine regeneration performance variables, and categorical site and treatment factors shown to influence performance. These relationships are currently being consolidated into a regeneration model that will be available later in 2015 for

Figure 22. Top height of non-pine species by weeding treatment



quantitative forecasting of regeneration performance. Several continuous site and stand variables were also observed to be related to performance. Some (e.g. aspen and pine stocking indices) have already been found useful as covariates for improving forecasts based on the categorical factors. Table 2 summarizes correlations found between lodgepole pine performance 13 years after planting (mortality, percent stocking, trees per stocked regeneration plot, average diameter stump height, average tree height, and top height) and 7 continuous variables: soil LFH thickness, aspect[4], elevation, ground cones per m^2 at establishment, aspen stocking index[5], and lodgepole pine stocking index[6].

Table 2. Correlations between lodgepole pine performance and continuous variables

X-variables	Mean annual mortality	% stocking	# trees per stocked plot	Average diameter (stump ht)	Average tree height	Top height
LFH thickness	ns	-	-	ns	-	-
Aspect	ns	ns	ns	ns	ns	ns
Elevation	-	ns	ns	-	-	-
% slope	ns	ns	+	-	-	-
Cones per m^2	+	+	+	ns	-	-
Aw stocking index	ns	-	-	-	ns	+
Pl stocking index	ns	+	+	ns	ns	ns

- Significant negative correlation (performance variable decreases with increase in x-variable)
+ Significant positive correlation (performance variable increases with increase in x-variable)
ns Correlation non-significant at 0.05 probability level

[4] Cosine of aspect, incorporating a phase shift of 45 degrees, after Beers *et al*,1966, *Aspect transformation in site productivity research*. J. For. 64(10): 691–692.
[5] Proportion of regeneration plots stocked with aspen ($\geq$1.3m) 8 years after cut.
[6] Proportion of regeneration plots stocked with lodgepole pine ($\geq$0.3m) 8 years after cut.