Forest Resource Improvement Association of Alberta
Forest Resource Improvement Program

Foothills Growth and Yield Association
(FRIAA Project FOOMOD-01-03)

Regenerated Lodgepole Pine Trial

10-YEAR CROP PERFORMANCE REPORT

Prepared by:

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

February, 2012

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

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Abstract

Member companies of the Foothills Growth and Yield Association (FGYA) installed and planted 102 one-hectare permanent sample plot clusters throughout the Eastern Slopes, in a large replicated field trial designed to monitor stand development of lodgepole pine, planted and naturally regenerated after harvesting, in relation to site, planting density, weeding and thinning. The trial was established between the summer of 2000 and the spring of 2002. 2011 marked the tenth year of its monitoring.

This report presents the latest information on crop performance, including tree height and diameter growth, stand density, mortality and health. The effects of controlled site and treatment factors on growth, natural regeneration and mortality are described. Statistics on competing vegetation and pathogen occurrence, and their relationships to stand development, are summarized.

Implications of results for site preparation, planting, tending and reforestation standards are considered, with the desired intent of promoting broader discussion of their potential application to reforestation policy and practice. Recommendations are made for the trial's thinning treatment and continued measurements, and for analyses to incorporate the results into operational decision-support tools.

1. Introduction

Between the summer of 2000 and the spring of 2002, 9 member companies of the Foothills Growth and Yield Association (FGYA) installed and planted 102 one-hectare research plot clusters throughout the Eastern Slopes, in a large replicated experiment designed to monitor stand development of harvest-origin lodgepole pine. The trial has previously been described in the following documents:

- *Lodgepole Pine Regeneration Project Establishment Report*, Foothills Growth and Yield Association technical report, April 2003;
- *Lodgepole Pine Regeneration Project Crop Performance Report,* Foothills Growth and Yield Association technical report, January 2006;
- *Regenerated Lodgepole Pine Project – Fifth Year Results*, Foothills Growth and Yield Association Quicknote #9, February 2008;
- *Regenerated Lodgepole Pine Trial – Analysis of Crop Performance Five Growing Seasons after Planting*, Foothills Growth and Yield Association technical report, April 4, 2008;
- *Regenerated Lodgepole Pine Trial – 2009 Crop Performance Report,* Foothills Growth and Yield Association technical report, March 1, 2010.

This report describes crop performance as measured to the end of the 2011 growing season.

1.1. Purpose of Project

The long-term project was designed to forecast and monitor the growth and yield of harvest-origin lodgepole pine, in relation to:

- Site;
- Initial spacing of planted stock;
- Natural regeneration;
- Mortality;
- Vegetation control (weeding);
- Density regulation (pre-commercial thinning).

In the shorter-term (until stand ages reach 14 years) the main focus of the project is to provide an improved basis for forecasting achievement of performance targets such as the regeneration standards adopted by FGYA members.

1.2. Experimental Design

The basic balanced experimental split-plot design consists of 90 whole-plots (referred to as "installations"): 5 ecological site classes x 6 planting densities x 3 replications (see Tables 1 and 2). Each 1-hectare installation is split into 4 sub-plots (referred to as "treatment plots"): no treatment ("control"), weed, pre-commercial thin, weed plus pre-commercial thin (see Table 2). 75 installations were planted (one of the density treatments involves no planting). 12 more installations (6 densities x 2 replications) were added in the modal site category to produce a total of 102.

A 0.1ha measurement plot was established in the centre of each treatment plot. Sixteen $10m^2$ regeneration sub-plots were located in each measurement plot to monitor competing vegetation and natural regeneration. Measurements have been conducted as scheduled in Table 3.

The design included provision for pre-commercial thinning treatments to be conducted when the rate of ingress of natural regeneration diminishes and crown closure is approached. This point has been reached in some plots, and in 2011 thinning was undertaken on a pilot basis in one group of installations (Eco-class 4, Group 1) following the routine annual measurements. For analysis of data collected prior to thinning (including all analyses reported below), in each installation data from plots C and T (see Table 2) were merged (no weeding), as were data from plots W and WT (weeded if vegetation exceeded competition thresholds described in the establishment report).

Table 1. Distribution of installations by ecological site class

Class	Ecosite (and Edatope)	WC[1]	SW[2]	# of Installations
1	Bearberry / lichen / hairy wild rye (submesic / subxeric, medium – poor)	b, c	b	18 (3 groups of 6)
2	Labrador tea – mesic (mesic – poor)	d	c	18 (3 groups of 6)
3	Billberry / cranberry / sarsaparilla / rhododendron (mesic / medium)	e	d	30 (5 groups of 6)
4	Honeysuckle / fern (subhygric – rich)	f	e	18 (3 groups of 6)
5	Labrador tea – hygric (hygric – poor)	h	f	18 (3 groups of 6)

Table 2. Treatments

Planting	0 stems/ha - control (no planting) 816 stems/ha 1111 stems/ha 1600 stems/ha 2500 stems/ha 4444 stems/ha
Vegetation management	C no treatment (control) W weed T pre-commercial thin WT weed and pre-commercial thin

Table 3. Measurements

Measurement Category	Growing Season (Planted Stock)										
	0	1	2	3	4	5	6	7	8	9	10
Planting density and site	x										
Coniferous ingress density		x		x		x		x		x	
Coniferous ingress stocking		x		x		x		x		x	
Competition – shrubs and herbs	x	x	x	x		x		x		x	
Competition – deciduous trees	x	x	x	x		x		x		x	
Size and growth	x	x		x		x		x		x	
Mortality incidence and cause		x	x	x	x	x	x	x	x	x	x
Health	x	x		x		x		x		x	

[1] Ecosite code as defined in *Field guide to ecosites of west-central Alberta*, J.D. Beckingham, I.G.W. Corns and J.H. Archibald, Can. For. Serv. Special Report 9, 1996.
[2] Ecosite code as defined in *Field guide to ecosites of southwestern Alberta*, J.H. Archibald, G.D. Klappstein, and I.G.W. Corns, Can. For. Serv. Special Report 8, 1996.

1.3. Latest Measurements

Table 4 shows the status and stand ages of installations at the time of the latest (2011) trial measurement.

"Compromised" status refers to installations in which the planned treatment schedule was not followed:

- 1 installation (eco-class 4, group 2), scheduled for no planting, was planted shortly after trial establishment;
- 12 installations (eco-class 3, groups 4 and 5) were completely aerially sprayed with herbicide in 2006;
- 1 installation (eco-class 4, group 1, density 4444) was partially operationally tended (mechanical brushing and thinning) in 2010.

During 2010 or 2011, all installations have been measured in "full" detail 9 years after planting, as per Table 3. Mortality checks were made each year on every installation. The installation accidentally brushed in 2010 was measured in detail both years. Total numbers of installations measured over the 2 years are shown in Table 5 broken down by status and measurement type.

Table 4. Status and age of installations in 2011

Status	Years Since Harvest	# of Installations	Average Years Since Site Prep	Average # of Growing Seasons since Planting
OK	10	6	10	10
	11	30	11	10
	12	45	12	10
	13	7	11	10
	Sub-total	88	11	10
Compromised	11	10	11	10
	12	3	11	10
	13	1	11	(non-planted)
	Sub-total	14	11	10
Total		102	11	10

Table 5. Number of installations measured in 2010 and 2011

Installation Status	Measurement Type	Measurement Year	
		2010	2011
OK	check	26	62
	full	62	26
	Sub-total	88	88
Compromised	check	0	13
	full	14	1
	Sub-total	14	14
Total		102	102

Data from the "compromised" installations will continue to have utility for modeling, model validation, and other purposes. The stand conditions and crop performance reported below are based on only the installations with full "OK" status, unless otherwise stated. (The over-sprayed installations are included in assessments of some conditions where chemical weeding was demonstrated to have no significant effect, or is otherwise not relevant to the assessment.)

2. Stand Conditions and Crop Performance

2.1. Competing Vegetation

Figures 1 to 7 show histograms of average values and standard errors for various measures of vegetative competition by ecological site class and vegetation treatment, as recorded during the latest detailed plot measurements, which were made in 2010 and 2011. At the time of these measurements between 9 and 12 years had elapsed since site preparation (or harvest where no additional site preparation took place), and in all installations 9 (or more) growing seasons had elapsed since planting.

Figure 1 shows percent deciduous stocking. Stocking percentages are based on the occurrence of aspen, balsam poplar or birch in 0.001 ha regeneration sub-plots, of which there are 64 in each installation. Deciduous tree densities are shown in Figure 2, modal deciduous tree height in Figure 3, and modal basal stem diameter in Figure 4. Percent cover of willow and alder, forbs and grasses are shown in Figures 5, 6 and 7 respectively. The effects of weeding and site class on average levels of other measures of shrub and ground vegetation are summarized in Table 6.

Table 6. Averages of various measures of shrub and ground vegetation by ecological site class and treatment

Ecological Site Class	1		2		3		4		5	
Treatment	**Leave**	**Weed**	**Leave**	**Weed**	**Leave**	**Weed**	**Leave**	**Weed**	**Leave**	**Weed**
% Cover Willow & Alder	6.7	0.9	2.4	1.8	4.0	1.9	7.0	2.5	4.1	1.9
Height Willow & Alder (cm)	102	77	115	97	131	106	212	111	95	72
% Cover Other Tall Shrubs	3.8	3.7	3.8	3.4	6.4	4.6	9.7	2.5	9.9	7.7
Height Other Tall Shrubs (cm)	41	42	40	40	41	38	58	45	43	41
% Cover Forbs	7.6	10.9	12.9	11.1	8.8	10.4	22.6	29.4	11.6	13.4
% Cover Grasses	28.3	30.6	10.0	10.6	17.3	19.2	19.6	28.1	17.2	14.3
% Cover Mosses	5.7	5.2	14.2	16.0	8.7	8.0	8.2	12.5	17.8	18.2
% Cover Lichens	0.7	0.6	1.5	1.4	3.1	2.7	0.4	0.5	0.6	0.6

Weeding has resulted in average stocking levels of deciduous trees being kept below 40%. Levels exceeding twice this value occur in non-weeded plots, especially on rich eco-class 4 sites. Deciduous densities (Figure 2) on weeded plots are usually less than 2500 stems per ha, with modal heights under 1m; but on non-weeded rich (eco-class 4) sites densities average almost 10,000 stems per ha. Deciduous tree height (Figure 3) and stem diameter (Figure 4) are greater on non-weeded versus weeded plots, most significantly in eco-classes 3 and 4. On most sites percent cover and modal height of willow and alder have been significantly reduced by weeding (Figure 5). A different picture has emerged for percent cover of forbs and grasses (Figures 6 and 7 respectively), with no consistently significant differences between the weed and non-weed treatments, but some indication of grasses and forbs actually benefiting from weeding on the more productive and competitive sites.

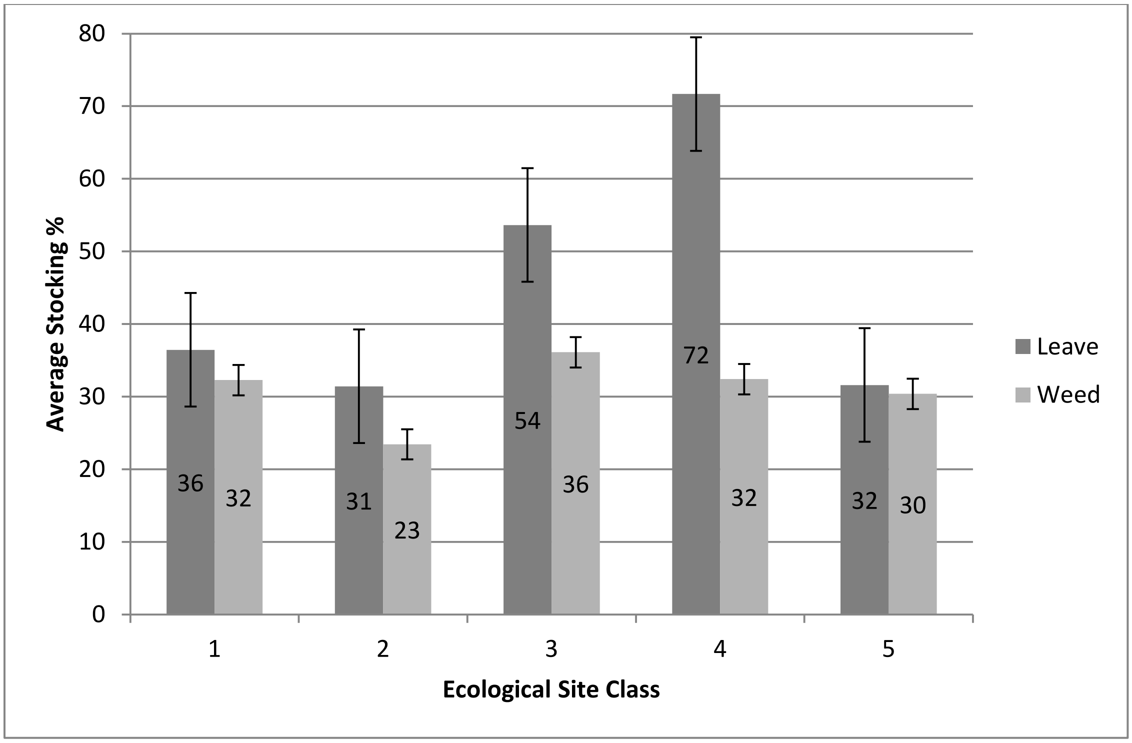

Figure 1. Effect of site and treatment on deciduous tree stocking

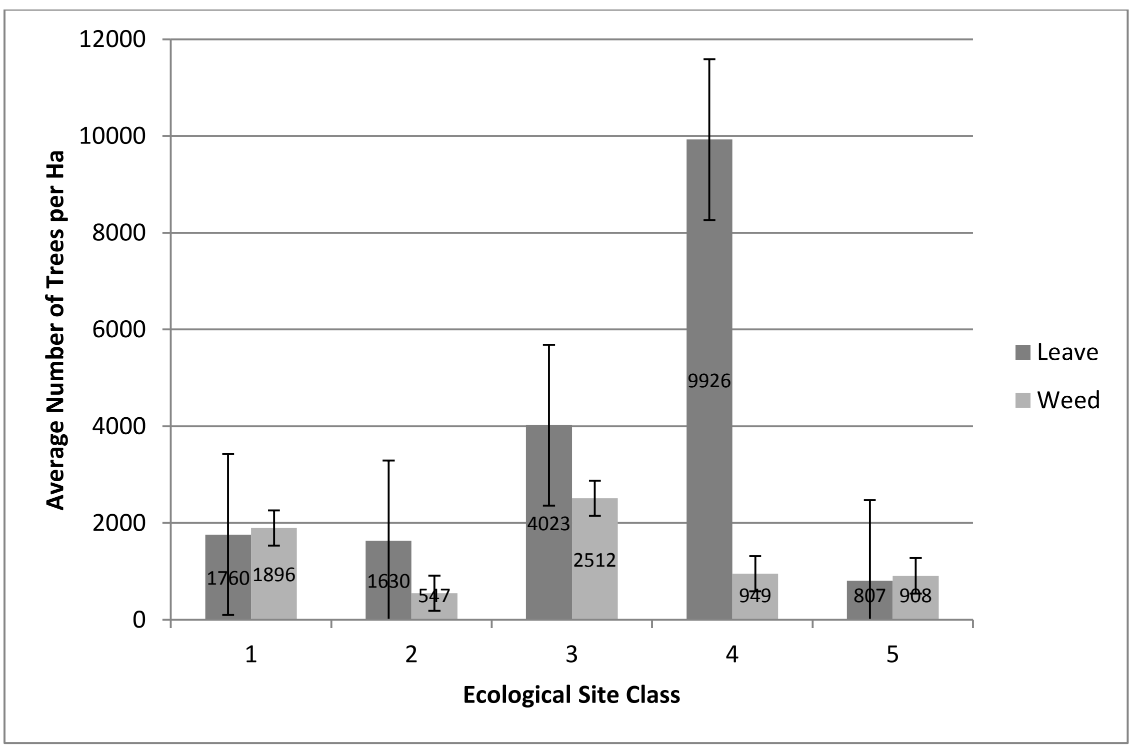

Figure 2. Effect of site and treatment on deciduous tree density

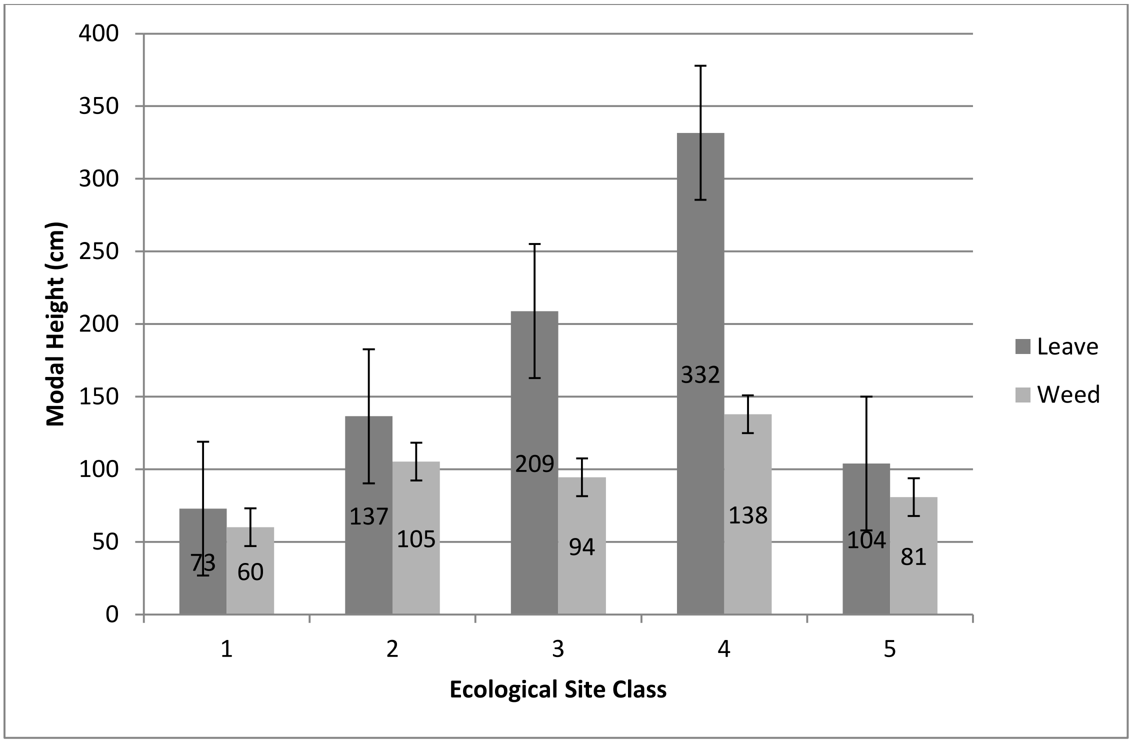

Figure 3. Effect of site and treatment on deciduous tree modal height

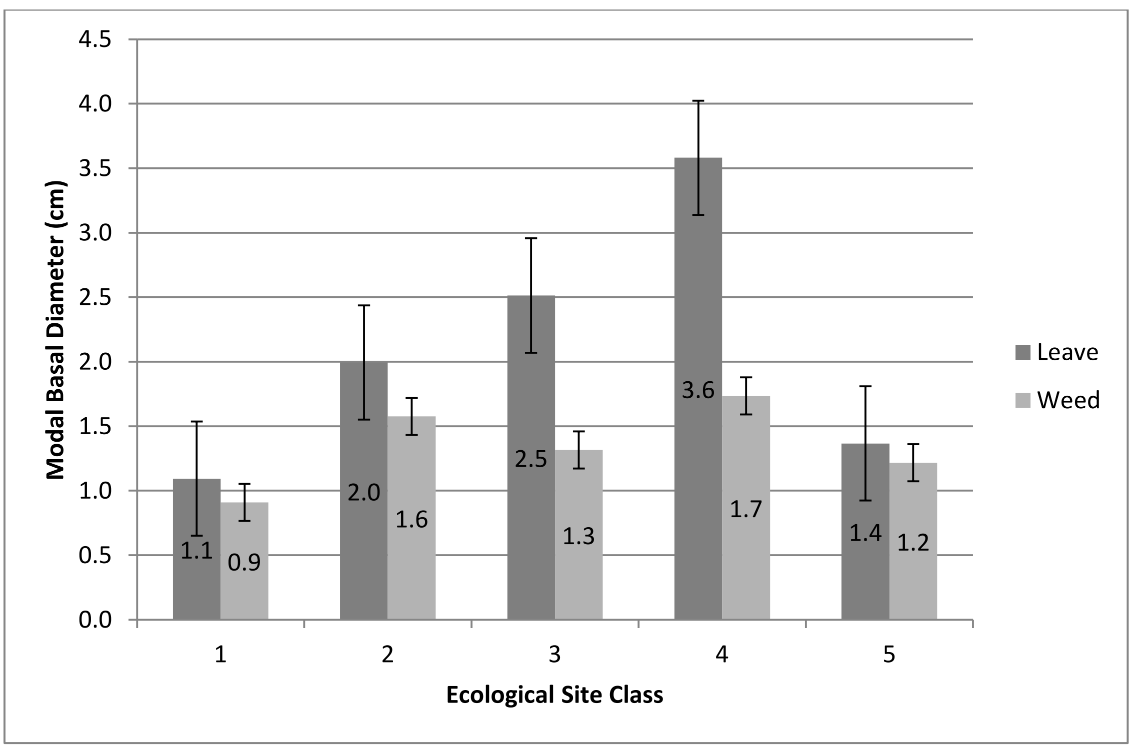

Figure 4. Effect of site and treatment on deciduous tree modal basal diameter

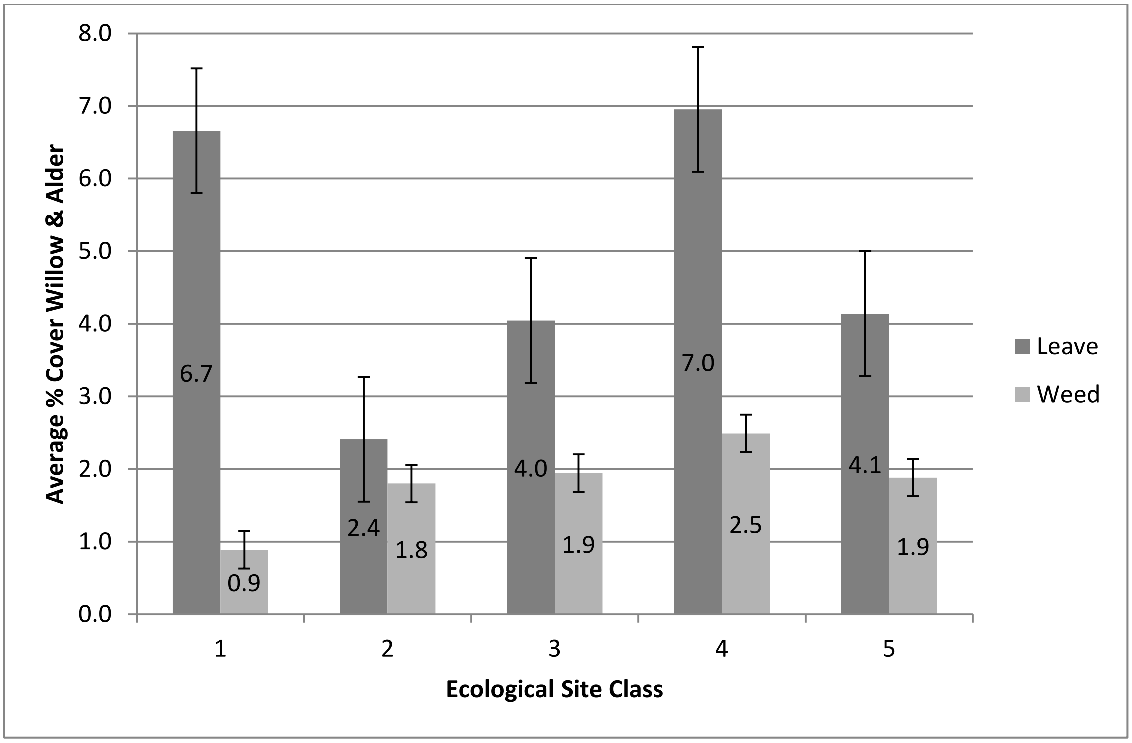

Figure 5. Effect of site and treatment on percent cover of willow and alder

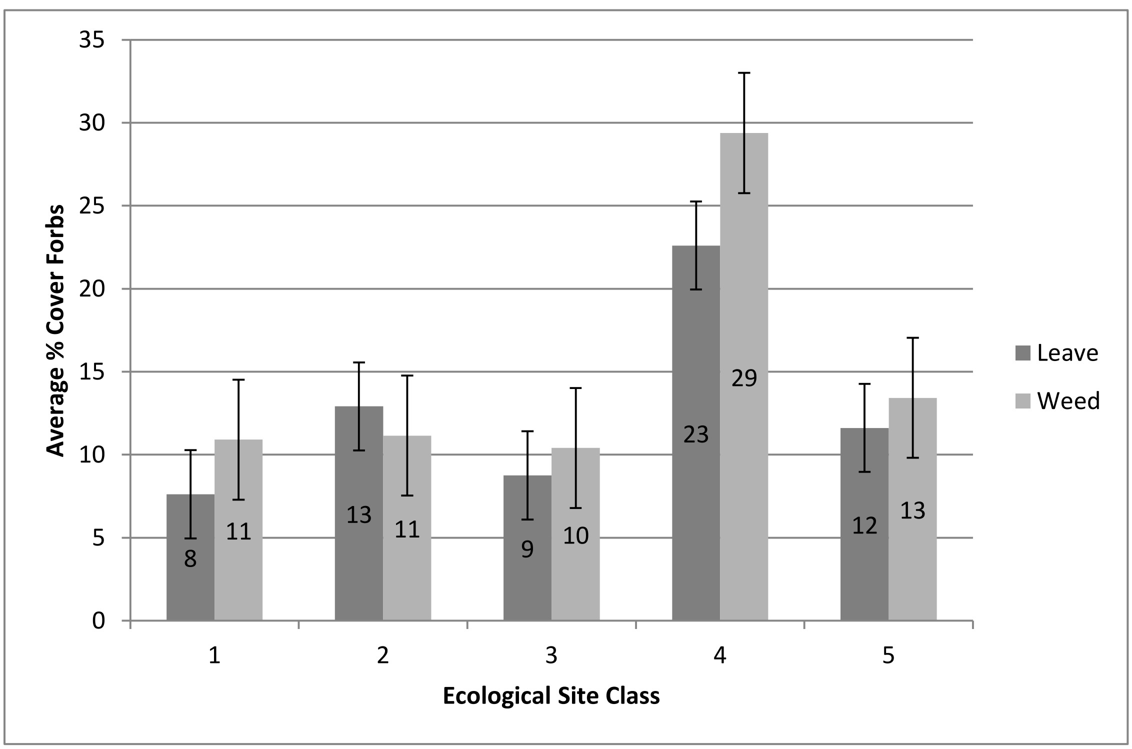

Figure 6. Effect of site and treatment on percent cover of forbs

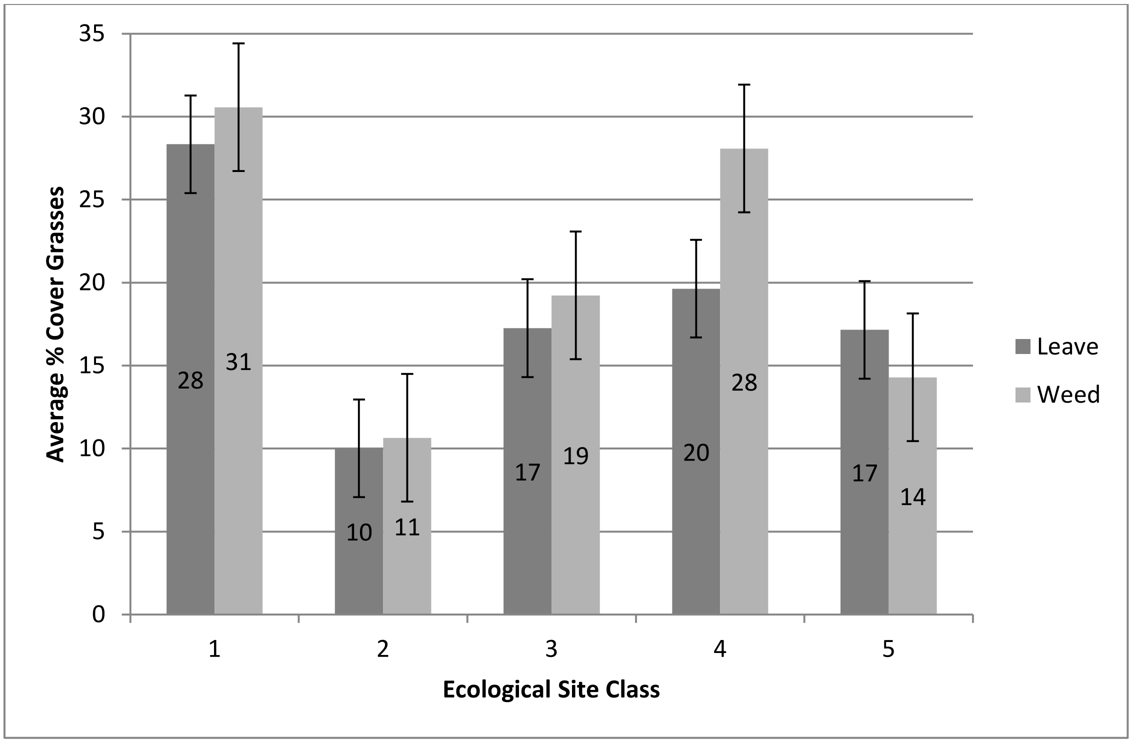

Figure 7. Effect of site and treatment on percent cover of grasses

2.2. Height and Diameter Growth

Figures 8 to 13 summarize height and diameter achievement of planted stock after 9 growing seasons (the latest age at which all plots in the trial were measured in detail), and compares height and diameter of natural regeneration measured at the same time.

Site class has exerted a significant effect on both height and diameter growth in both planted and natural stock. This is probably a direct effect of site productivity for planted stock, but the effect on natural regeneration appears to have been also influenced by faster rates of ingress on some sites than others.

Height of planted stock, and of natural regeneration in most site classes, has been affected only marginally by weeding, with the most pronounced and significant effect occurring in natural regeneration in eco-class 4 (see Figure 9). Diameter growth of both planted and naturally regenerated stock is significantly affected by weeding, but the magnitude of the effect is less than might be expected.

Planted stock is well ahead of natural regeneration in terms of average height and diameter. Trends in average height growth over the last 4 growing seasons for which measurement are available on all plots (see Figure 12) might be interpreted to suggest that planted stock are growing faster, but the divergence in average height appears to be more related to the ingress of small naturally regenerated trees that has occurred during this period (described below in Section 2.3). Figure 13 shows a slightly more parallel trend by comparing maximum (instead of average) plot heights between planted and natural stock, and suggests that natural regeneration is lagging about 2 years behind planted stock.

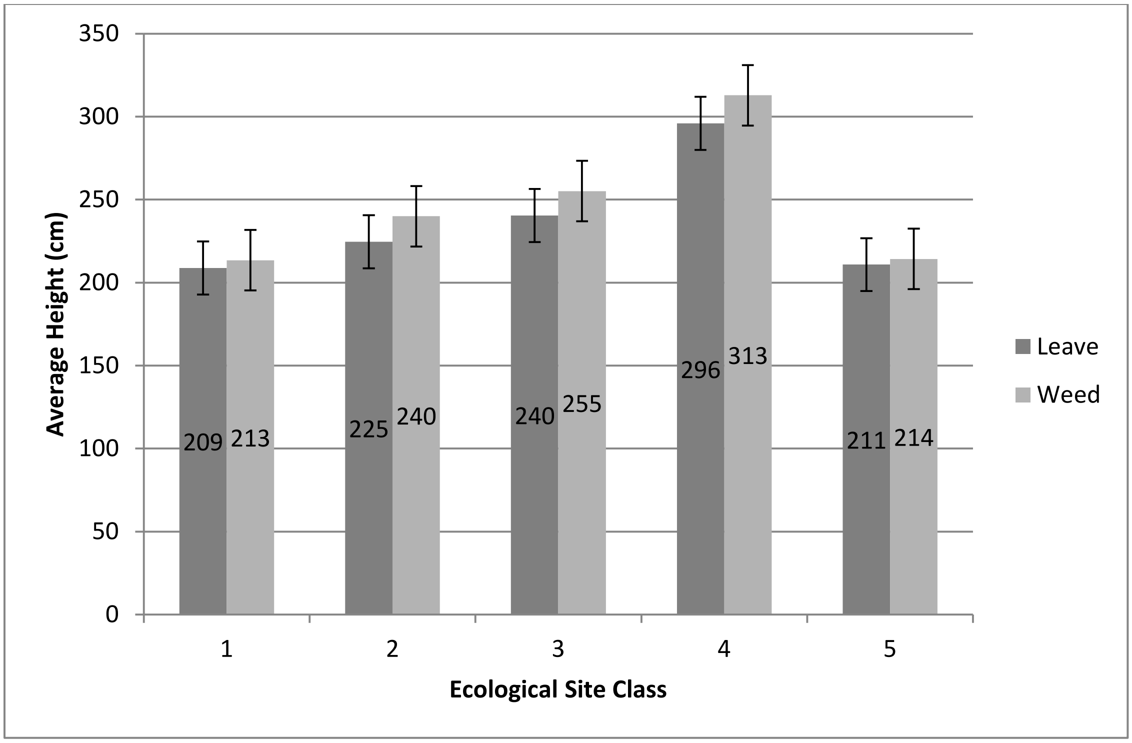

Figure 8. Effect of site and treatment on average height of planted stock 9 growing seasons after planting

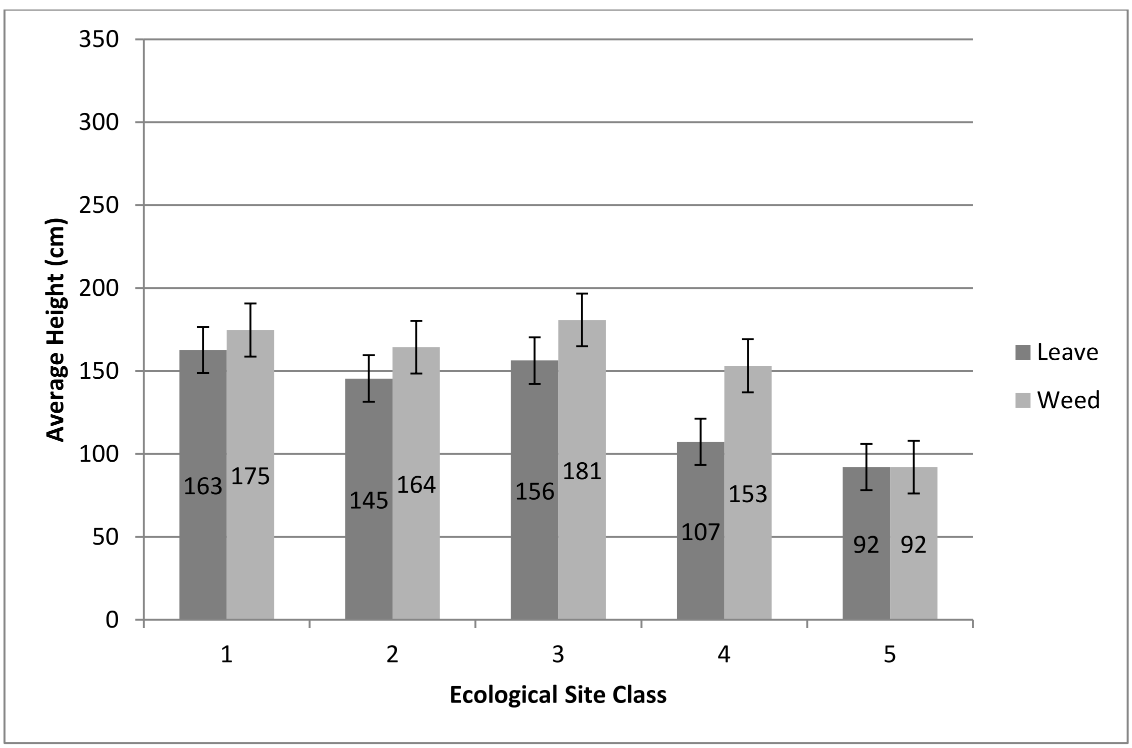

Figure 9. Effect of site and treatment on average height of naturally regenerated lodgepole pine

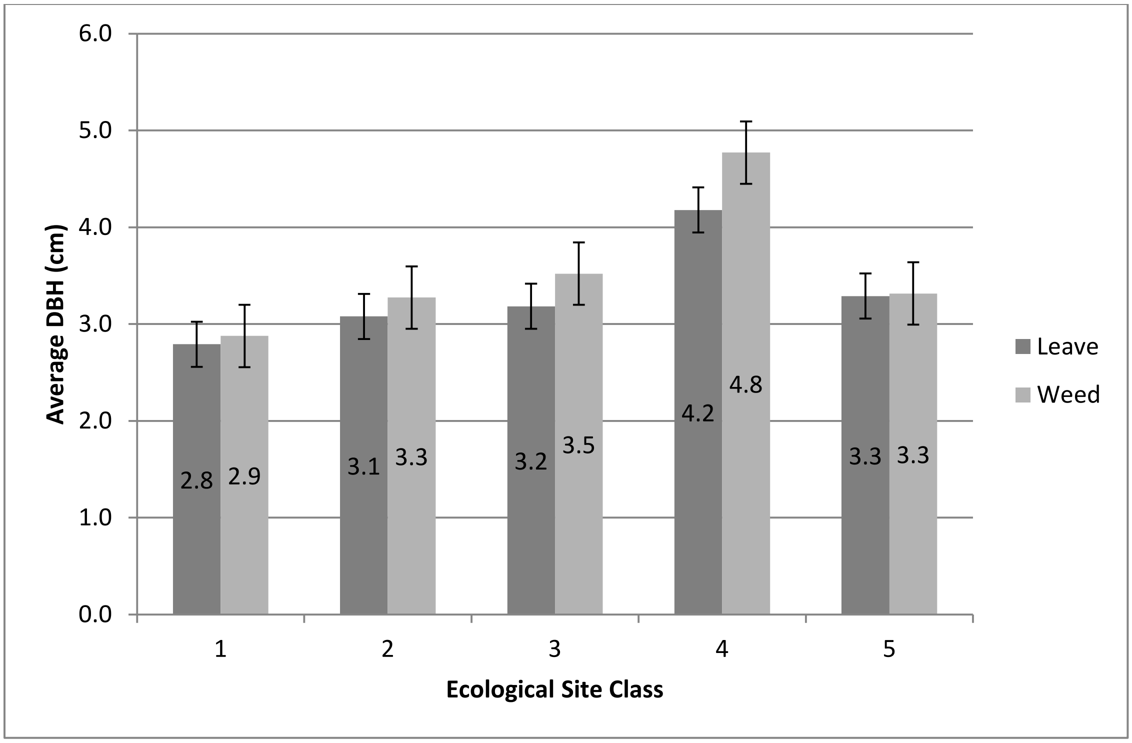

Figure 10. Effect of site and treatment on average DBH of planted stock 9 growing seasons after planting

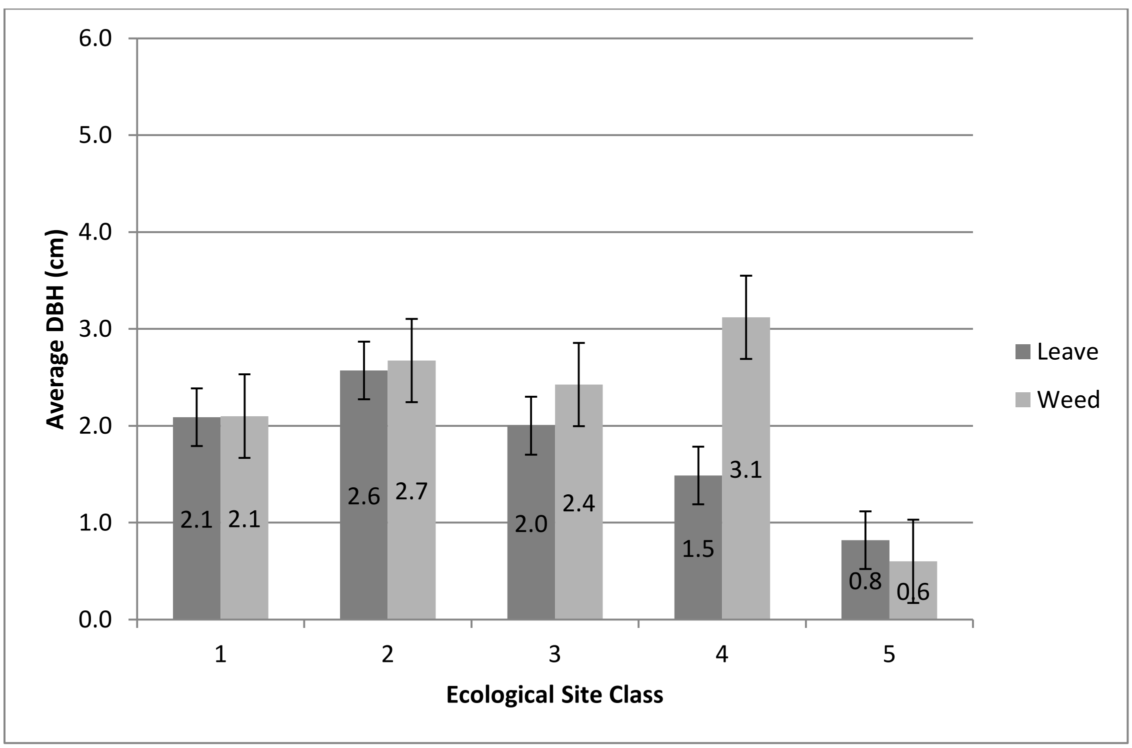

Figure 11. Effect of site and treatment on average DBH of naturally regenerated lodgepole pine

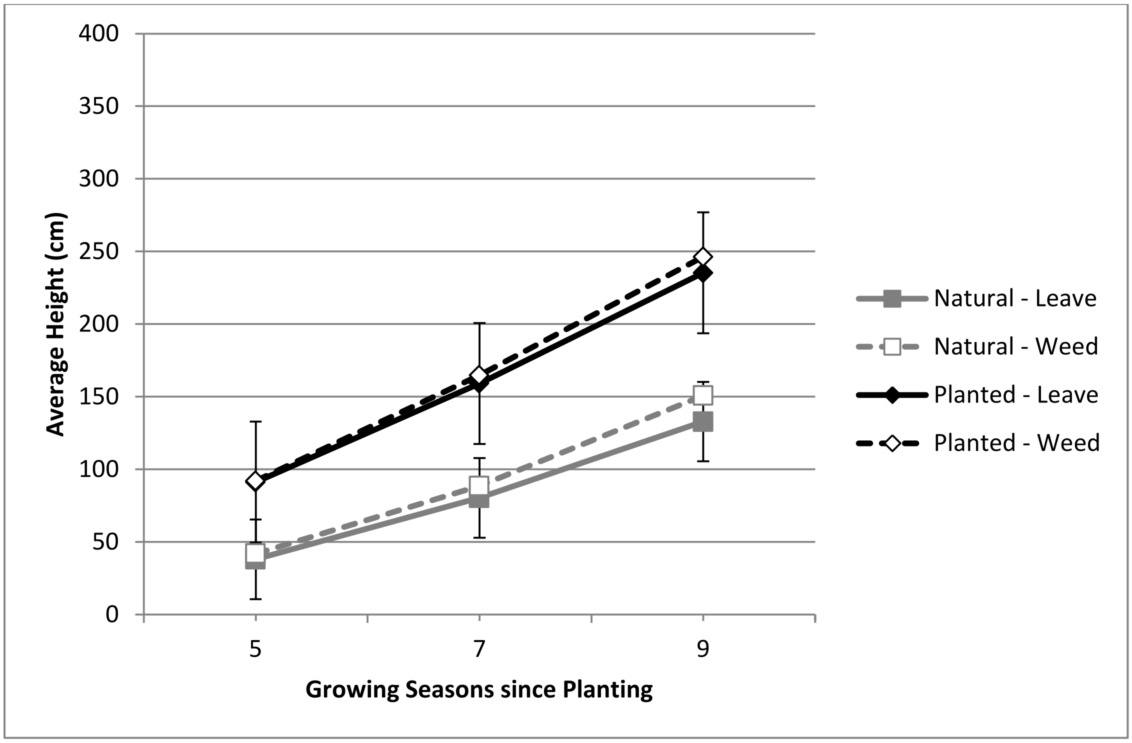

Figure 12. Average height trends with age and treatment in planted stock and natural regeneration

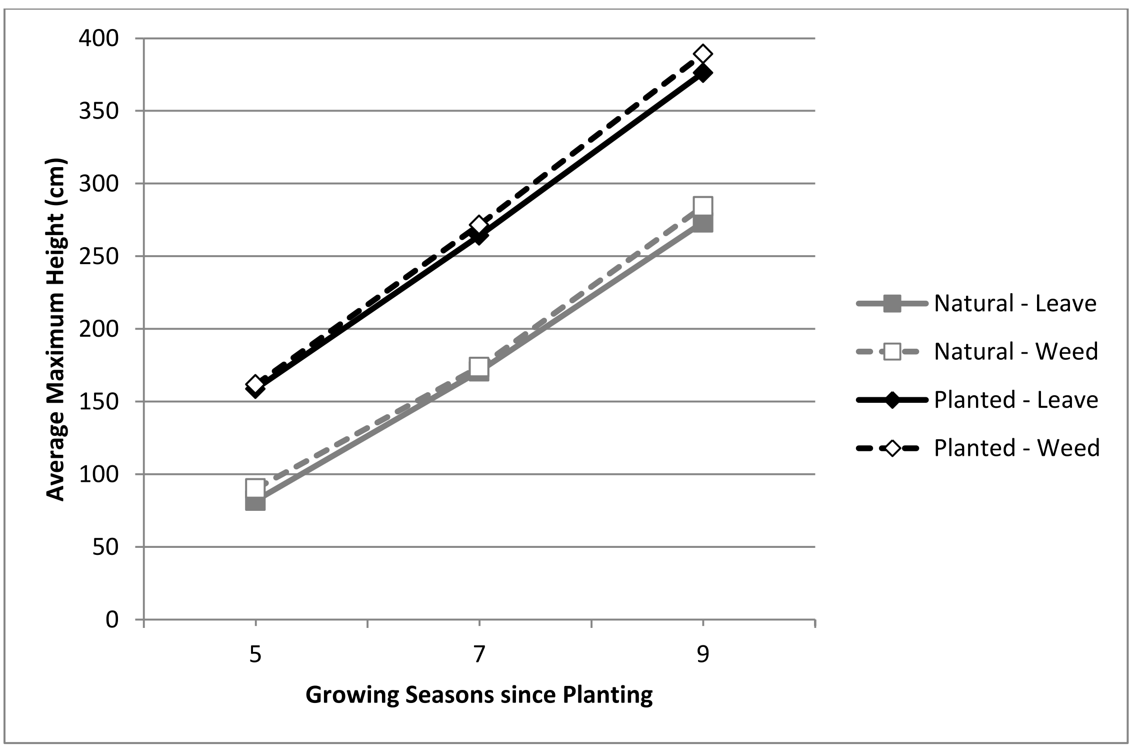

Figure 13. Maximum height trends with age and treatment in planted stock and natural regeneration

No consistent trends have yet been observed of height growth of planted stock with planting density. As might be expected, there is some evidence of an overall decrease in average DBH at higher densities, but to date this trend is variable and inconsistent between site classes. The relationship is expected to strengthen with age as intra-specific competition increases, and will be explored further when data become available in 2012 for all installations to 11 growing seasons since planting.

Table 7 summarizes correlations between tree size (height and diameter of lodgepole pine sample trees) and various measures of the cover and size of deciduous tree, shrubs, and ground vegetation. Only correlations significant at the 95% probability level (i.e. less than 1 in 20 probability of occurring by chance) are shown.

Note that the majority of correlations for planted stock are positive i.e. height and diameter of planted stock increase with the size and amount of potentially competing vegetation. This result suggests that the correlations are more influenced by site productivity than competition effects. The only exception is percent cover of grasses. Fewer relationships have so far been identified in natural regeneration, which has fewer observations and is less advanced. The 2 significant correlations are negative i.e. height of natural regeneration is inversely related to deciduous tree density and cover of tall shrubs.

Table 7. Statistically significant correlations between size of lodgepole pine and measures of competing vegetation

Stock Type	Crop Variable	Competition Variable	# of Observations	Correlation Coefficient	Significance[3]
Planted	Average height	Modal height of willow & alder	140	0.349	***
		Modal height of other tall shrubs	145	0.375	***
		% cover - forbs	148	0.308	***
		Modal height of forbs	147	0.403	***
		% cover - grasses	148	-0.171	*
		Deciduous tree stocking %	148	0.186	*
		Deciduous tree modal height	136	0.295	***
		Deciduous tree modal basal diameter	135	0.331	***
	Average DBH	Modal height of other tall shrubs	145	0.373	***
		% cover - forbs	148	0.332	***
		Modal height of forbs	147	0.296	***
		Deciduous tree modal basal diameter	135	0.231	**
Natural	Average height	% cover - tall shrubs	26	-0.406	*
		Deciduous trees per ha	26	-0.427	*

2.3. Stand Density

Analysis of factors affecting stand density was preceded by an examination of the variable's statistical distribution, which has implications for the interpretation and application of results. Whereas density (stems per ha) of planted trees were estimated by counting all trees on each 0.1 ha measurement plot, density of ingress was estimated by determining the proportion of 0.001 ha regeneration sub-plots stocked

[3] Probability of occurring by chance less than 1 in 20 (*), 1 in 100 (**), or 1 in 1000 (***)

with at least one tree, and counting the number of trees per stocked plot. The overall distribution of coniferous ingress trees per stocked regeneration plot is shown in Figure 14. The distribution is highly skewed and non-normal. Unlike in a normal distribution, the average density value (14 trees per plot) is quite different from the modal (most commonly occurring) value (1 tree per plot) and the median value (8 trees per plot) at the middle of the density range. This reversed J-shaped distribution can result in a small number of regeneration plots with very high counts inflating the average value so that it does not represent the stand condition applying over most of the whole-plot (or in the case of operational regeneration surveys, over most of the cut-block). This effect was partially addressed in the analyses of natural regeneration reported below by:

- Capping unusually high tree counts per regeneration plot at 80;
- Calculating median as well as average counts for every installation / treatment combination (each based on 32 regeneration plots);
- Assessing and reporting stocking percent (i.e. the proportion of regeneration plots containing at least one tree) as well as density.

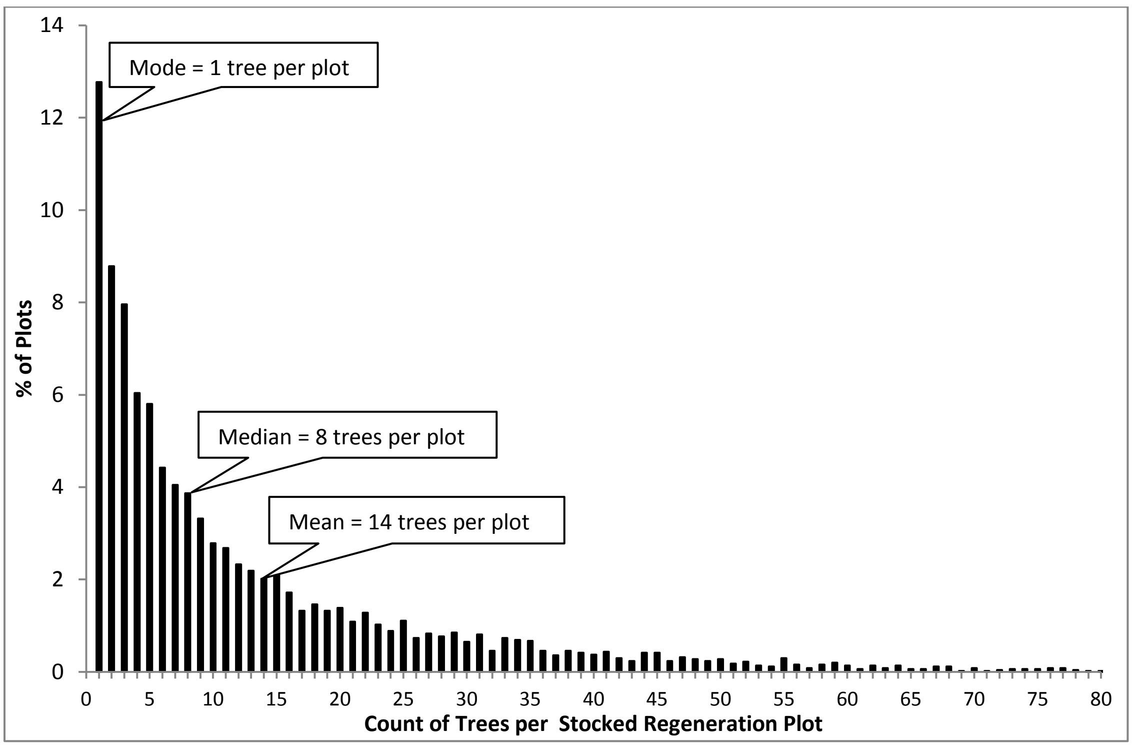

Figure 14. Overall distribution of number of naturally regenerated coniferous trees (30cm+) per stocked 10m^2 regeneration plot

Table 8 summarizes by ecological site class and target planting density the stems per ha (SPH) of surviving planted stock after 9 growing seasons (the latest age at which all plots in the trial were measured in detail), and shows the density and stocking of natural regeneration measured at the same time. The measurements were taken between 9 and 11 years following site preparation and 9 to 12 years following harvest. Statistics for natural regeneration are based on live coniferous trees (30cm+ in height).

Further density summaries are shown, again by target planting density, but with ecological site classes grouped into those with generally good and poor potential for natural regeneration in Figures 15 and 16 respectively. The average median SPH for natural regeneration (more conservative than average mean SPH) were used in Figures 15 and 16 and when calculating total conifer SPH in Table 8.

Tables 17 and 18 show major effects of site, but (with the possible exception of eco-class 4) little significant effect of weeding on stocking and density of coniferous natural regeneration measured at the same time as planting stock 9 growing seasons after planting.

Table 8. Density of planted stock and ingress (trees 30cm+) 9 growing seasons after planting

Ecological Site Class	Target Planting Density	Planted Stock		Natural Regeneration				Total Conifer SPH
		Av. SPH Planted	Av. SPH Surviving	Av. Mean SPH	Av. Med. SPH	Av. % Stocked	% SR	
1	0	0	0	30,557	27,271	96	100	27,271
	816	804	604	11,974	8,719	88	83	9,323
	1111	1,101	839	20,703	15,698	97	100	16,537
	1600	1,590	1,260	25,969	23,167	98	100	24,427
	2500	2,498	1,896	18,990	14,698	98	100	16,594
	4444	4,393	3,183	10,771	9,130	87	67	12,313
	Subtotal	1,731	1,297	19,827	16,447	94	92	17,744
2	0	0	0	12,859	12,411	86	67	12,411
	816	820	672	18,974	17,380	99	100	18,052
	1111	1,110	902	14,156	13,339	89	83	14,240
	1600	1,598	1,347	10,521	9,313	80	67	10,660
	2500	2,500	2,028	15,281	12,911	95	100	14,940
	4444	4,441	4,117	17,927	16,500	79	67	20,617
	Subtotal	1,745	1,511	14,953	13,642	88	81	15,153
3	0	0	0	19,422	17,195	96	100	17,195
	816	822	646	16,510	12,932	91	83	13,578
	1111	1,104	912	10,984	9,516	83	50	10,427
	1600	1,593	1,284	14,115	10,677	95	100	11,961
	2500	2,493	1,921	17,266	14,797	92	100	16,718
	4444	4,441	3,564	10,531	8,135	89	83	11,699
	Subtotal	1,845	1,469	14,533	11,915	91	85	13,385
4	0	0	0	5,484	4,172	67	50	4,172
	816	820	553	3,646	2,271	64	33	2,824
	1111	1,109	950	3,474	2,526	65	33	3,476
	1600	1,600	1,222	1,401	906	44	0	2,128
	2500	2,499	2,020	3,776	3,078	55	33	5,098
	4444	4,436	3,246	4,344	2,875	68	50	6,121
	Subtotal	1,685	1,296	3,534	2,527	60	31	3,823
5	0	0	0	3,385	1,542	53	0	1,542
	816	823	689	6,401	3,656	81	33	4,345
	1111	1,109	950	3,766	2,448	56	33	3,398
	1600	1,594	1,463	6,875	5,078	89	100	6,541
	2500	2,500	2,138	2,125	1,531	58	17	3,670
	4444	4,440	3,933	3,552	2,375	68	17	6,308
	Subtotal	1,744	1,529	4,351	2,772	67	33	4,301
Total		1,750	1,423	11,586	9,592	80	65	11,015

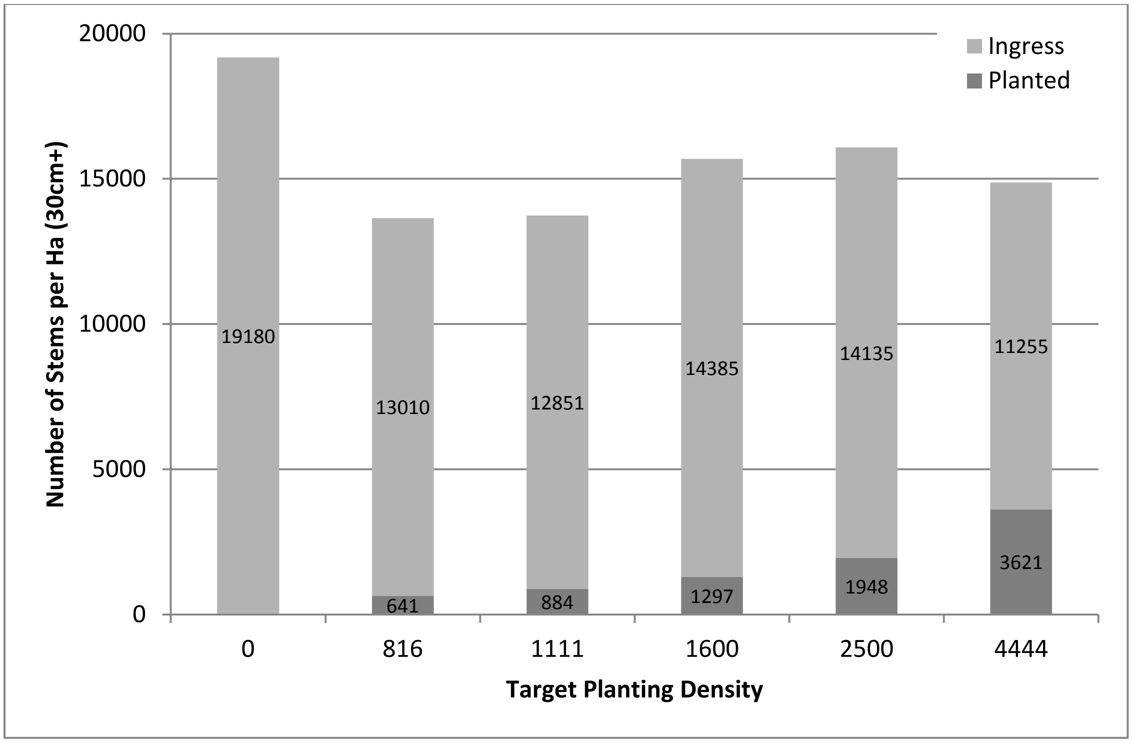

Figure 15. Average densities of planted stock and ingress 9 growing seasons after planting on ecological site classes with generally good potential for natural regeneration (eco-classes 1, 2 and 3)

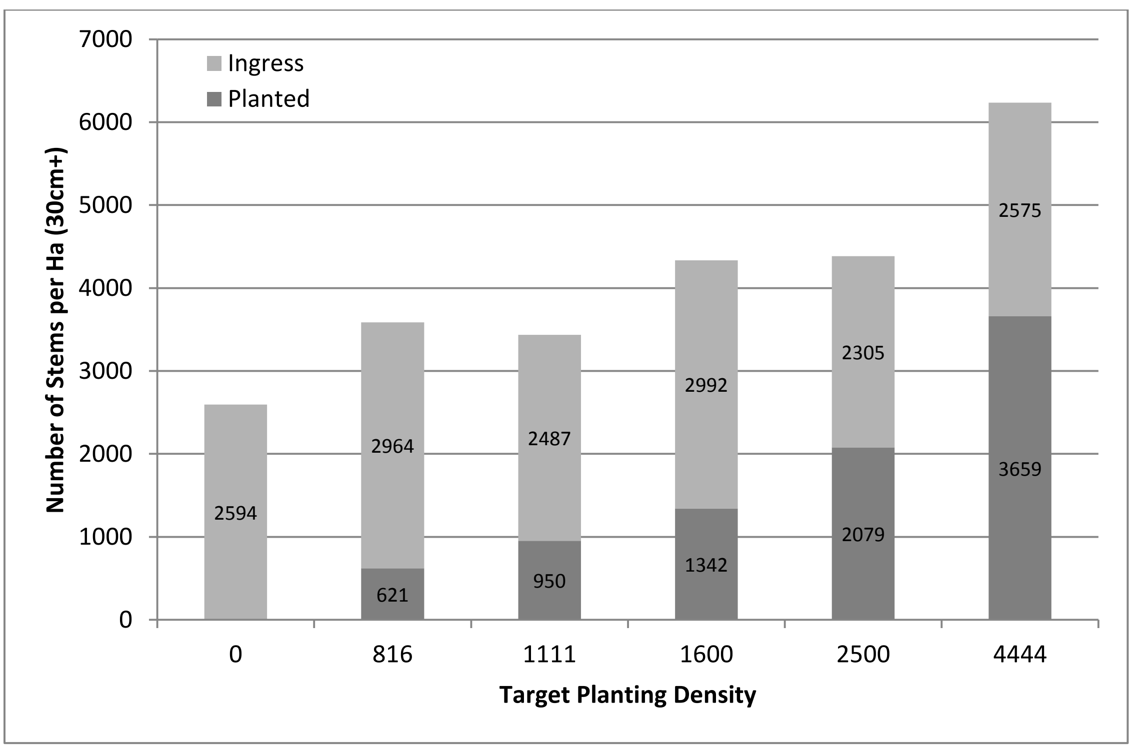

Figure 16. Average densities of planted stock and ingress 9 growing seasons after planting on ecological site classes with generally poor potential for natural regeneration (eco-classes 4 and 5)

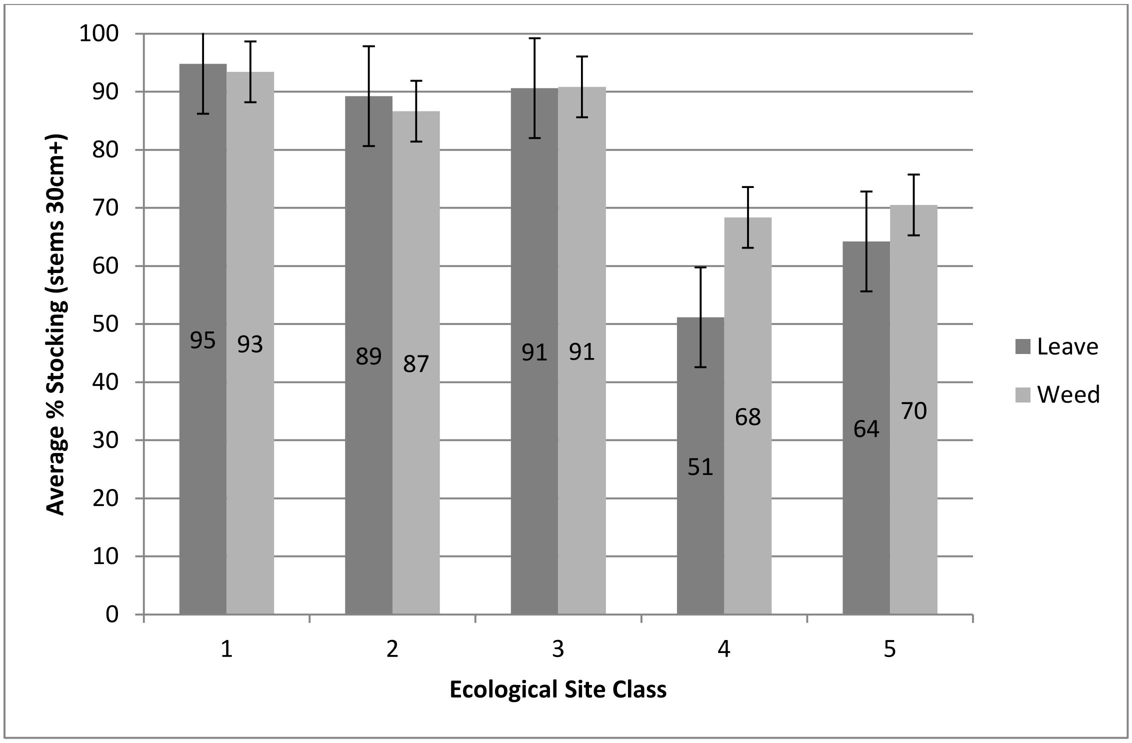

Figure 17. Effect of site and treatment on percent stocking of coniferous natural regeneration (9 growing seasons after planting of sites)

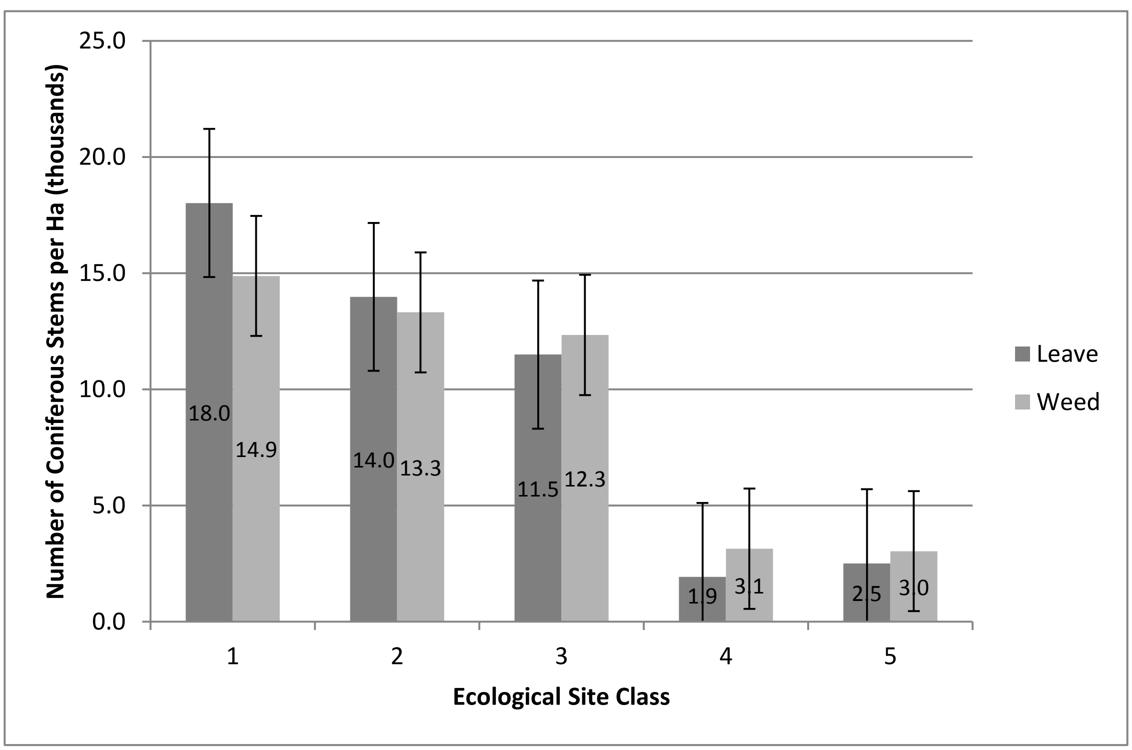

Figure 18. Effect of site and treatment on density of coniferous ingress (based on stocking and capped median counts of ingress per stocked plot 9 growing seasons after planting of sites)

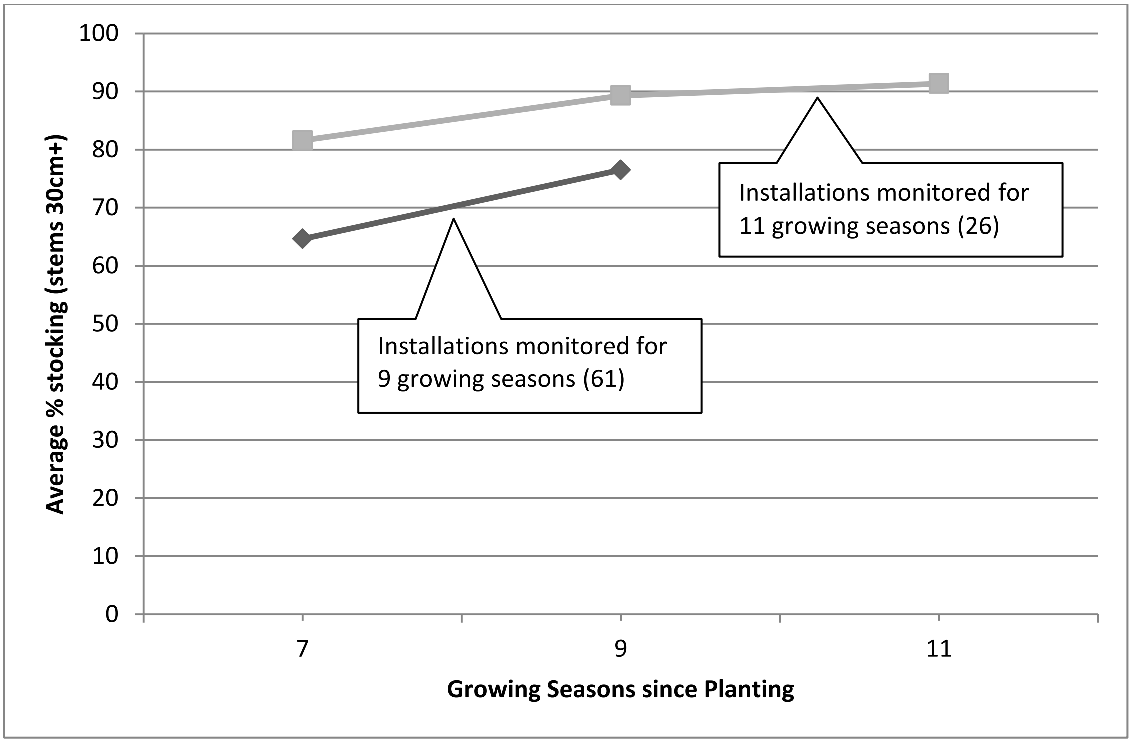

Figure 19. Trends in ingress of coniferous natural regeneration - percent stocking

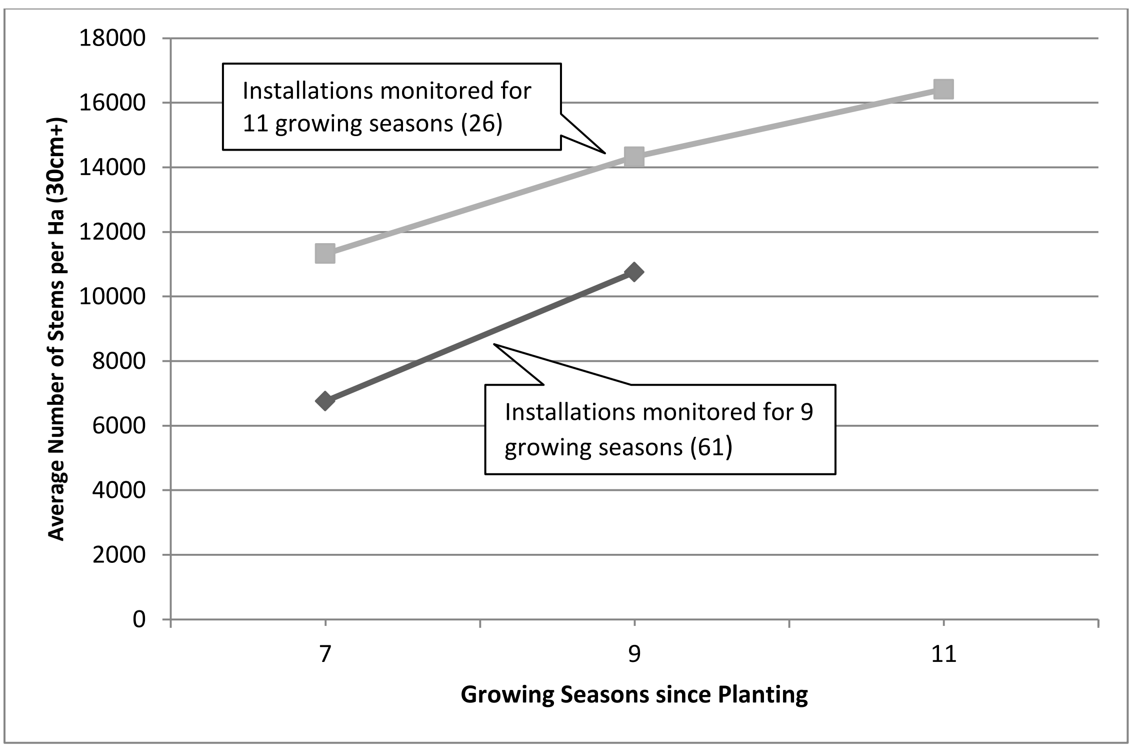

Figure 20. Trends in ingress of coniferous natural regeneration - stems per ha (based on stocking and non-capped average counts per stocked plot)

Trends over time (including the latest measurements of the oldest installations that have been monitored for 11 growing seasons) suggest that overall percent stocking is approaching culmination (Figure 19), although ingress of stems per ha (30cm+ in height) is still increasing by about 1000 stems per year. Results illustrate the difficulty of judging regeneration success at earlier ages. Coniferous stocking % (trees 30cm+) of natural ingress in the 2 years following the 7th growing season since trial establishment[4] increased (or remained at 100%) in 92% of all installations.

Table 9 indicates a number of competition variables that are negatively correlated with ingress of natural regeneration across all site classes combined, the most significant ones being the density and size of deciduous trees, height of tall shrubs, and percent cover and height of forbs.

Table 9. Statistically significant correlations between ingress of coniferous natural regeneration and measures of competing vegetation

Crop Variable	Competition Variable	# of Observations	Correlation Coefficient	Significance
Stocking % (coniferous stems 30cm+)	% cover - willow & alder	174	-0.187	*
	Modal height of willow & alder	165	-0.347	***
	% cover - other tall shrubs	174	-0.212	**
	Modal height of other tall shrubs	171	-0.480	***
	% cover - forbs	174	-0.322	***
	Modal height of forbs	173	-0.252	***
	% cover - mosses	174	0.194	*
	Deciduous trees per ha	174	-0.258	***
	Deciduous tree modal height	161	-0.424	***
	Deciduous tree modal basal diameter	158	-0.385	***
Mean # of coniferous stems per ha (30cm+)	% cover - willow & alder	174	-0.194	*
	Modal height of willow & alder	165	-0.181	*
	% cover - other tall shrubs	174	-0.234	**
	Modal height of other tall shrubs	171	-0.341	***
	% cover - forbs	174	-0.402	***
	Modal height of forbs	173	-0.190	*
	% cover - lichens	174	0.180	*
	Deciduous tree modal height	161	-0.272	***
	Deciduous tree modal basal diameter	158	-0.278	***

A significant proportion (about one-third)[5] of the variation in coniferous ingress stocking percent 9 growing seasons after trial establishment can be explained by dropped cone density measured at (or shortly after) establishment. Cones were originally counted on subplots with a 1m radius centred on each regeneration plot. A simple cone density index was computed as the average count (rounded to an integer) based on 32 sub-plots measured in each installation / treatment combination. Figure 21 shows the trend in average values and standard errors of stocking with cone density index.

[4] Typically equates to 8 or 9 years since harvest.
[5] R^2 = 0.313 for regression of stocking % on cone density index based on all valid observations (144) across all sites and treatments and including outlier values.

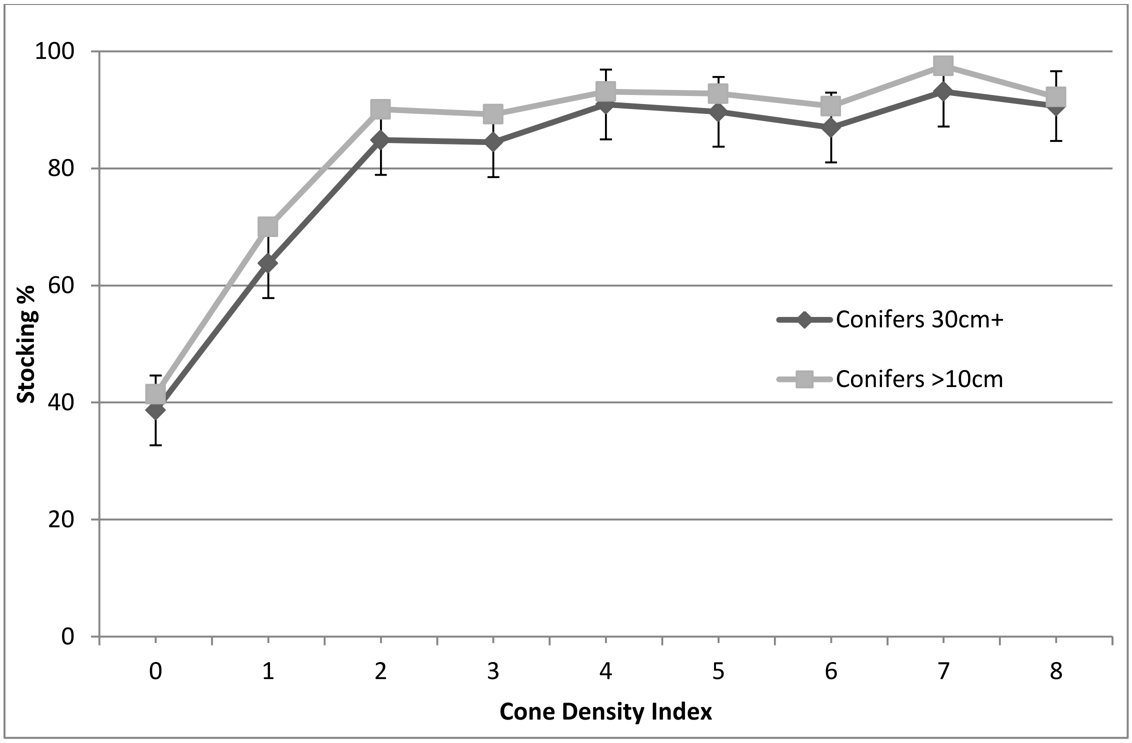

Figure 21. Relationship between cone density measured at stand establishment and coniferous stocking percent after 9 growing seasons

2.4. Mortality

Mortality is monitored by tracking the status of tagged sample trees. Missing trees create uncertainty in the estimation of mortality levels, because it is not known for sure whether these trees have died. The problem was initially assessed 2 years ago during analysis of the 2009 measurements, by calculating the potential magnitude of the resulting error. Results are shown in Figure 22. Mean annual mortality percent averages by site class over 8 growing seasons were computed without missing trees, and the additional mortality percentages computed assuming all missing trees were dead. Missing trees represented an uncertainty in the estimation of average mortality by site class ranging from 0.05 to 0.024%. The potential errors are small and less than normal sampling error. Nevertheless, since 2009 the following steps have been taken to minimize the associated uncertainty:

- Field contractors and auditors made a focused effort to locate missing trees;
- Where missing trees were found alive, previous mortality calculations were corrected;
- For modeling survival and mortality, half the missing trees were assumed dead and the other half alive.

Mortality statistics reported below incorporate the latest (2011) data corrections, and are based on the assumption that all missing trees have died.

Figure 23 indicates a significant effect of site on the mean annual mortality of planted stock 10 growing seasons after planting, but no significant effect of weeding. Figure 24 shows trends by site class in cumulative mortality since the third growing season, and Figure 25 compares periodic annual mortality between the first and second five growing seasons. Average five-year periodic annual mortality has either not changed significantly or (in site classes 2, 3 and 4) has increased from the first to the second period.

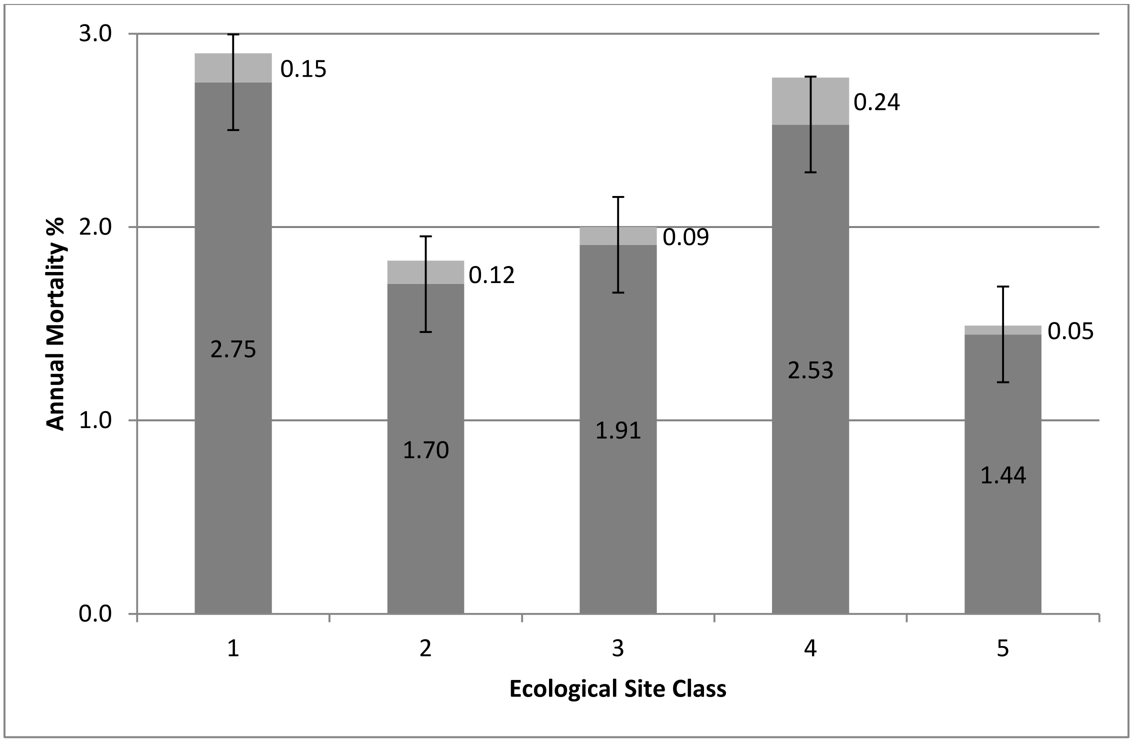

Figure 22. Uncertainty in estimation of mean annual mortality resulting from missing trees (based on data collected in 2009)

Figure 26 may suggest that mortality is lower in natural regeneration than in planted stock provided it is weeded. However, such a conclusion would be premature. Because of the continuing of ingress and selection sample ingress trees, it is still too early to accurately assess mortality in natural regeneration, and to reliably compare it with mortality in planted stock.

The primary direct cause of mortality that has been measured over the last 2 years continues to be root disease (mostly *Armillaria* spp.), followed by root collar weevils (mostly *Hylobius warreni*)) and rusts (mostly *Endocronartium harknessi*). Figure 27 shows the percentages attributed to these and other causes of all lodgepole mortality in the trial (including "compromised" installations) that has been recorded since 2009.

Mortality of planted stock is positively correlated (i.e. increases) with deciduous tree stocking and density, but interestingly is negatively correlated with the presence of willow, alder, other tall shrubs, forbs and mosses (see Table 10). A strong relationship was found between mortality and mean annual temperature. Responses of mortality to temperature differ between ecological site classes, but overall mortality increases with temperatures over about 2^{o}C (see Figure 28). This relationship is described in detail elsewhere.[6]

[6] Dempster, R. and Hamann, A. 2012. *Mortality of planted and naturally regenerating lodepole pine increases with temperature in Alberta, Canada.* Manuscript in prep.

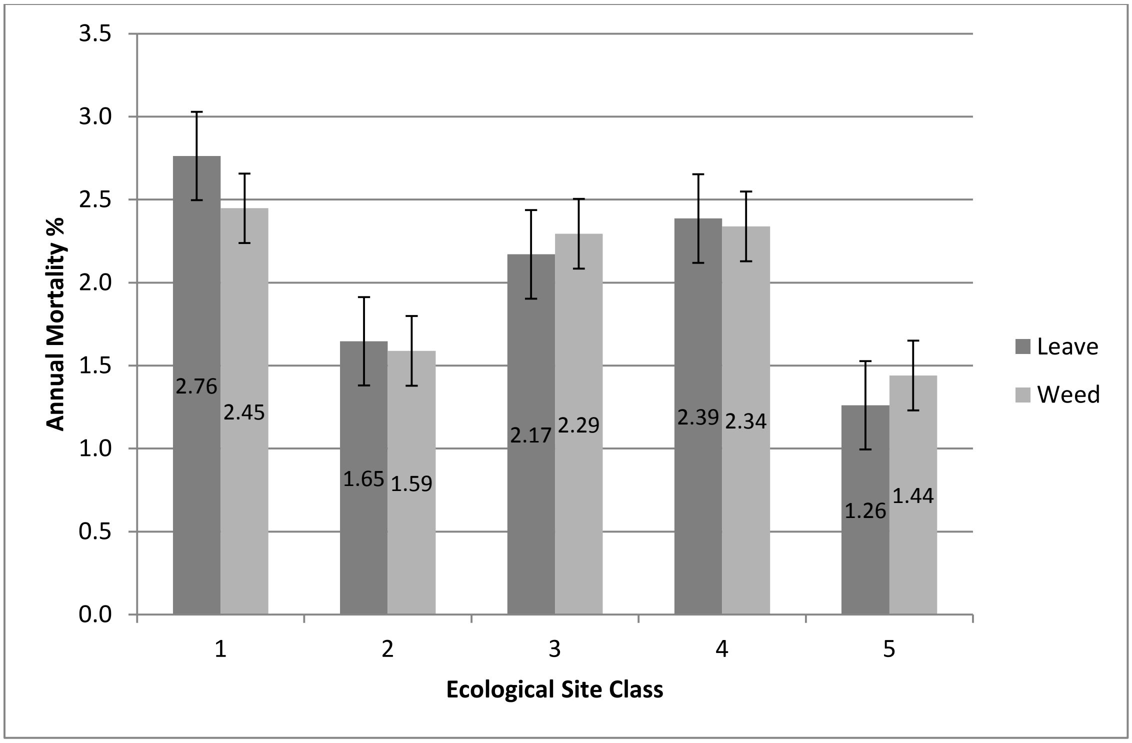

Figure 23. Effect of site and treatment on mean annual mortality of planted stock over first 10 growing seasons since planting

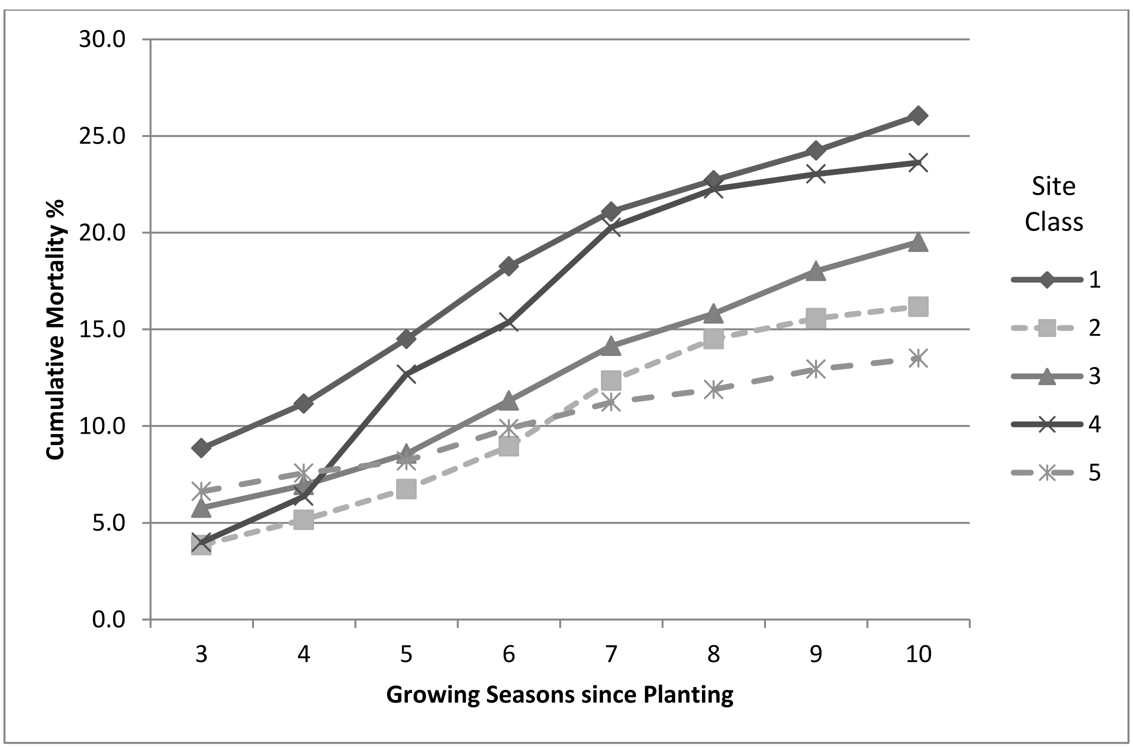

Figure 24. Mortality trends with age and ecological site class in planted stock

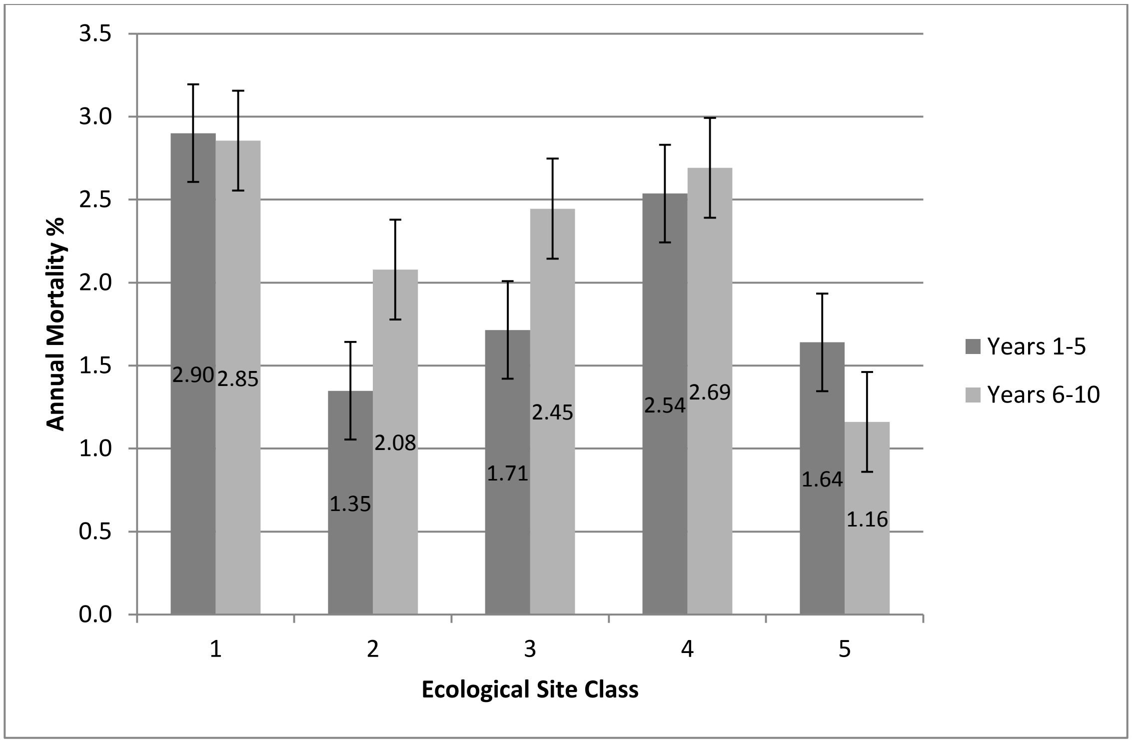

Figure 25. Comparison of average periodic annual mortality between first and second five years since planting

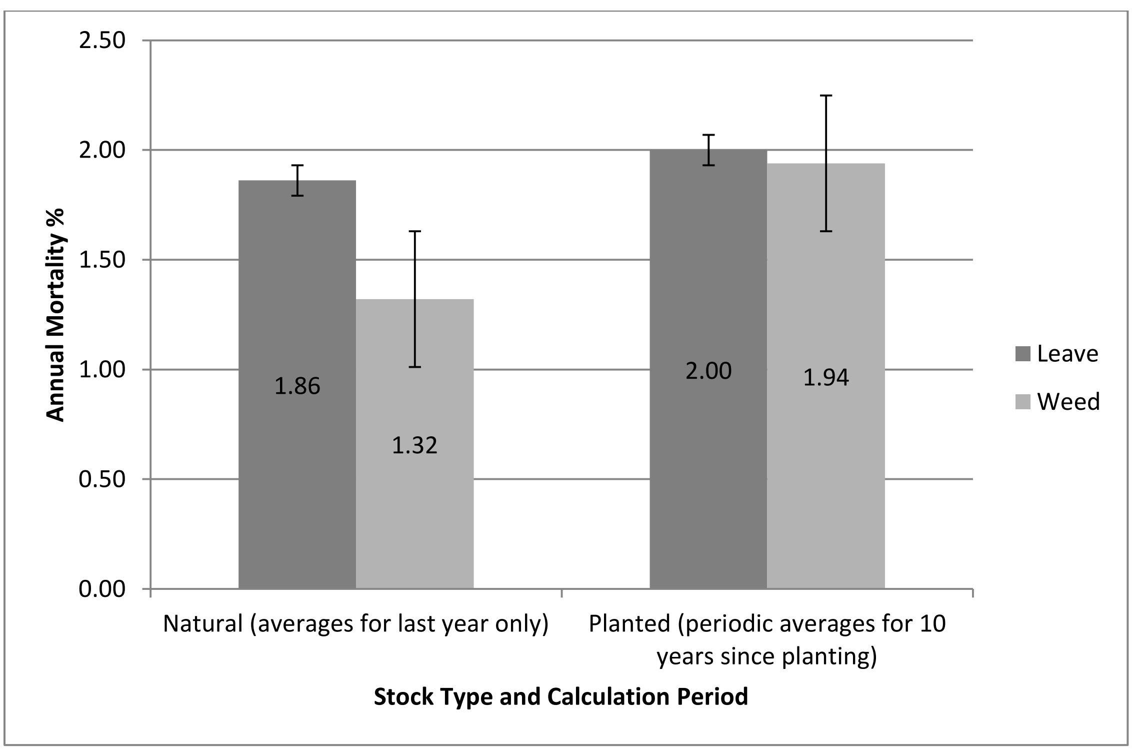

Figure 26. Comparison of periodic mean annual mortality by treatment and between naturally regenerated and planted stock

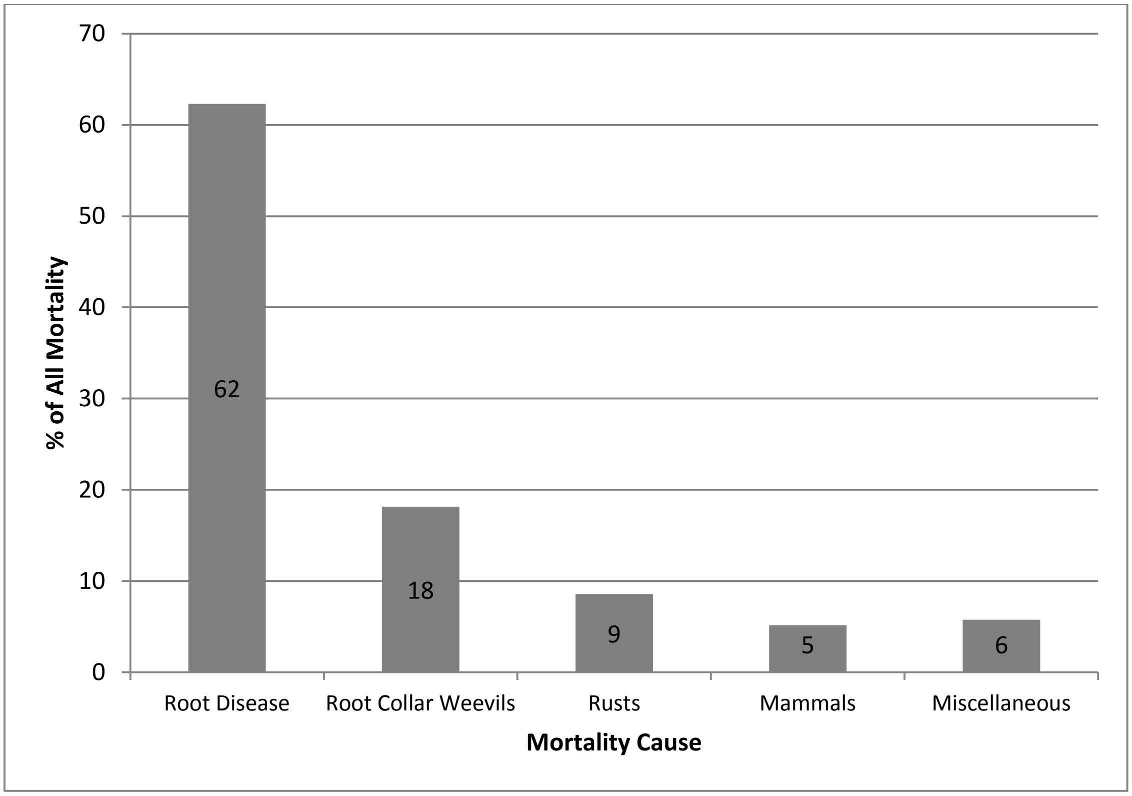

Figure 27. Apparent causes of tree mortality observed in the last two years (since 2009)

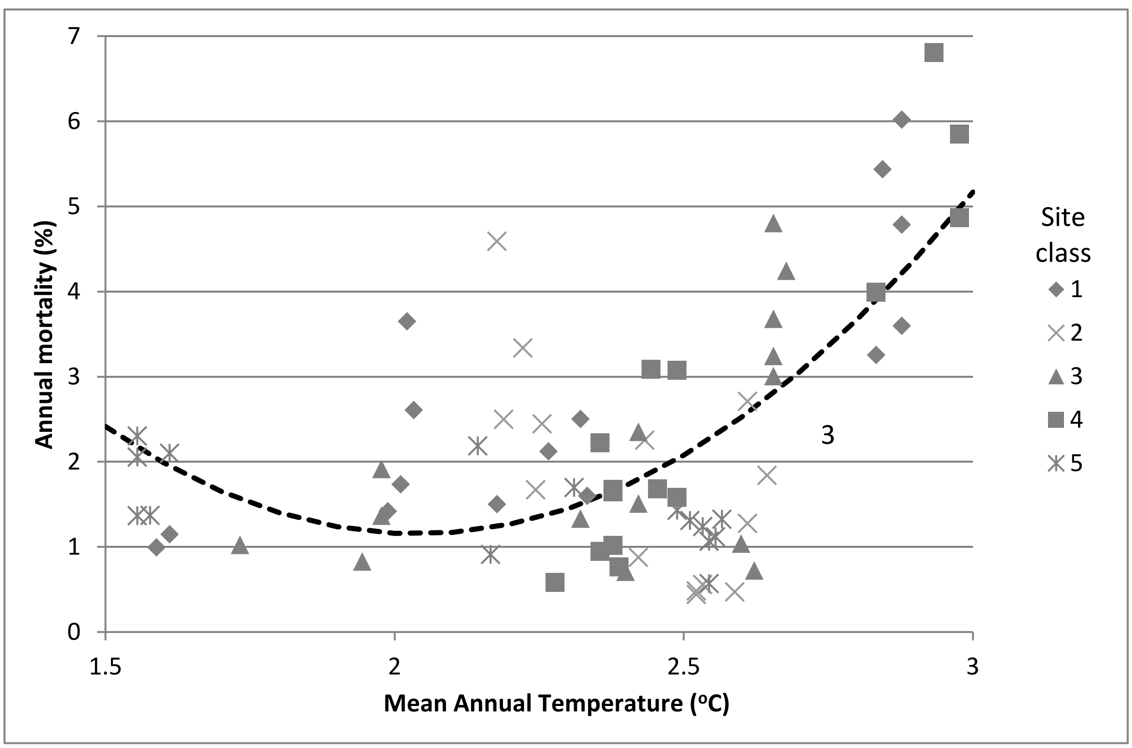

Figure 28. Scatter diagram and overall trend of mean annual mortality 8 growing seasons after planting against average mean annual temperature in planted installations

Table 10. Statistically significant correlations between mean annual mortality of planted stock and measures of competing vegetation

Competition Variable	# of observations	Correlation Coefficient	Significance
Deciduous tree stocking %	148	0.360	***
Deciduous trees per ha	148	0.205	*
% cover - willow & alder	148	-0.203	*
% cover - other tall shrubs	148	-0.237	**
Modal height of forbs	147	-0.211	*
% cover - mosses	148	-0.314	***

2.5. Health

The reported occurrence of the 3 pathogens most frequently causing mortality has increased in the last few years. Figure 29 compares the percentage of installations with the pathogens present in the 7th and 9th growing seasons. Figure 30 makes a similar comparison of the percentage of trees (including both live and dead) reported as infected.

Alberta Sustainable Resource Development has expressed interest and concern regarding the regional incidence of hail damage. Figure 31 summarizes the incidence and extent of hail damage observed in latest full measurements of installations (2010 and 2011).

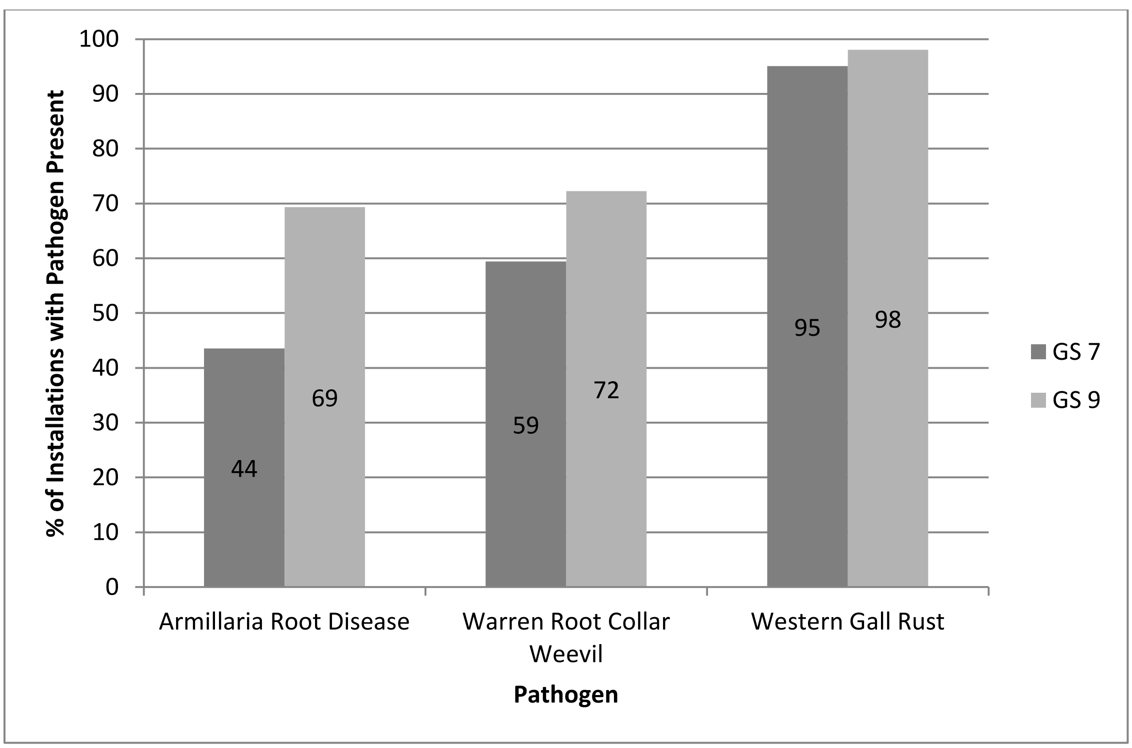

Figure 29. Percentage of installations where prevalent mortality agents were observed in growing seasons (GS) 7 and 9

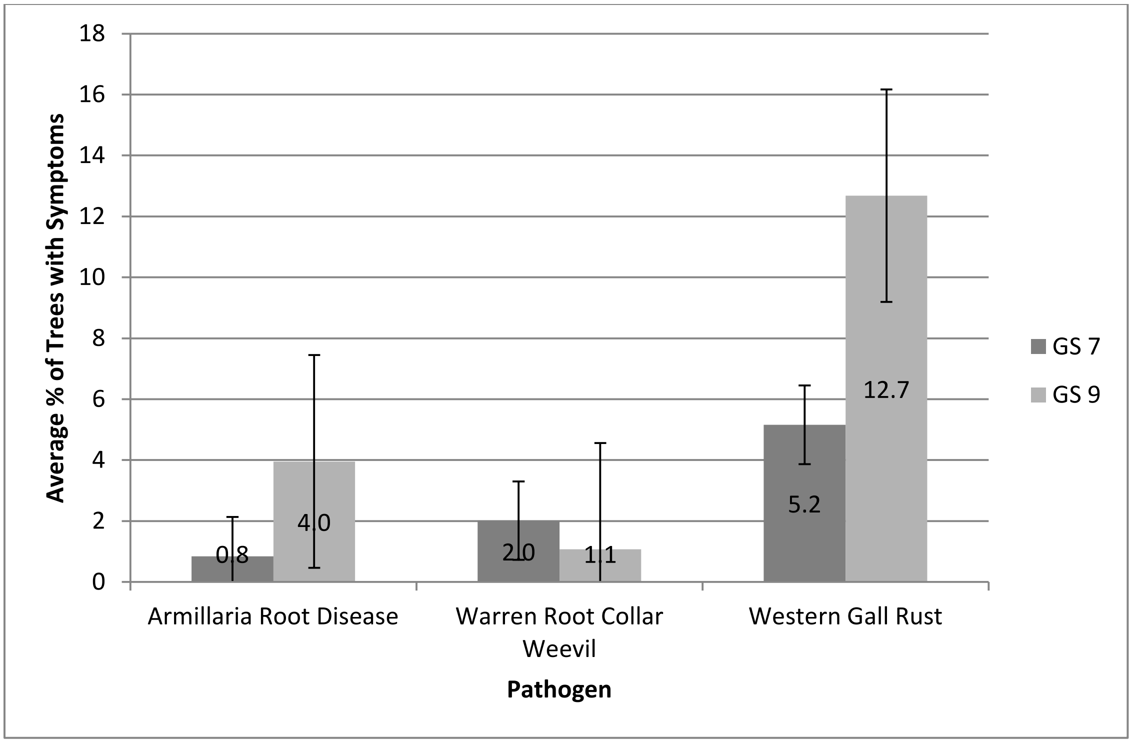

Figure 30. Percentage of trees with symptoms of prevalent mortality agents in growing seasons (GS) 7 and 9

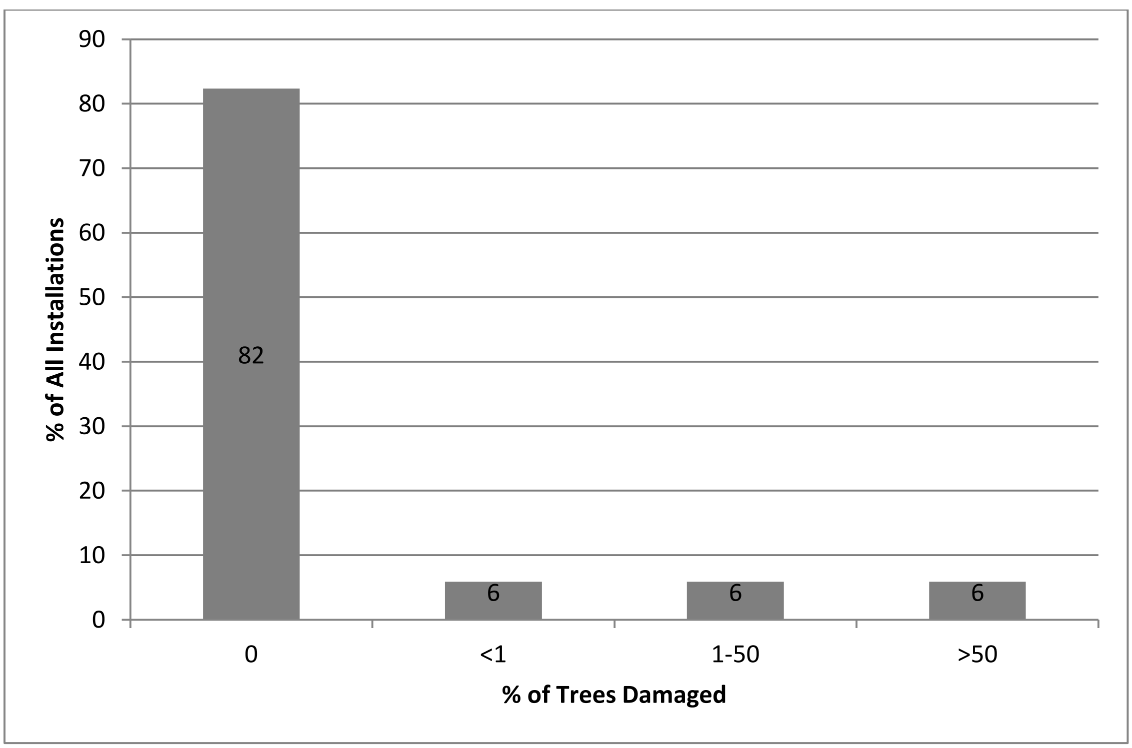

Figure 31. Incidence and extent of hail damage observed in latest full measurements of installations (2010 and 2011)

3. Implications of Results

Observed high and persisting rates of natural regeneration, but also of disease and mortality, merit consideration of the implications of trial results for site preparation, planting, tending and reforestation standards.

3.1. Site Preparation

The trial has demonstrated that stocking of coniferous natural regeneration is a function of site, dropped cone density, and time since disturbance. Processing of trees at roadside (versus topping and de-limbing at stump) is now the most usual harvesting system among FGYA members. The method does not consistently ensure good dispersal of seed-bearing cones. Silviculturists frequently rely on planting or fill-in on sites where, with adequate cone dispersal, natural regeneration would be abundant. The trial results suggest that reduction of reliance on planting on such sites may be facilitated by assessing cone distributions, and only where they are found to be inadequate either planting seedlings (see Section 3.1 below) or mechanically dispersing slash and cones as part of the site preparation. The relationship illustrated in Figure 21 between cone density and subsequent coniferous stocking offers a potential basis for identifying where such dispersal would be necessary.

3.2. Planting

Although planting may be initially reassuring to practitioners, regulators and the public alike, the trial results suggest that on many sites the operation may be unnecessary to meet reforestation targets and possibly even damaging to forest health.

The results support reports in the literature[7] of the risks of planting pine soon after harvest, when opportunistic pathogens like *Armillaria* and *Hylobius* are most abundant and when trees physiologically stressed by planting, climate or other factors are most likely to succumb to them. Lodgepole pine in pure stands has long been recognized as more liable to disease loss than when in mixed stands.[8] Protraction of lodgepole pine ingress into the second decade following disturbance has been demonstrated to be usual not only following harvesting,[9] but also following natural fire-disturbance.[10] It may well be an adaptation of the species to early mortality risks that silviculturists should not ignore.

Critical review is therefore warranted of the current practice of prompt post-harvest planting with lodgepole pine on sites where there are high probabilities of either good natural regeneration or serious health risks. Where good potential for natural regeneration exists the focus should be on encouraging it (see Section 3.1 above). Where abundant natural regeneration is uncertain and mortality risks are high, planting of alternative species or mixtures may be the more prudent strategy.

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[7] Cerezke, H. F. (1973). Survival of the Weevil, Hylobius warreni in lodgepole pine stumps. *Can. J. For. Res.*, 3:367-372.
Cleary, M., van der Kamp, B., & Morrison, D. (2008). British Columbia's southern interior forests: Armillaria root disease stand establishment aid. *BC Journal of Ecosystems and Management*, 9(2): 60-65.
[8] Nordin, V. J. (1954). Forest pathology in relation to the management of lodgepole pine in Alberta. *Forestry Chronicle*, 299-306.
[9] Johnstone, W. D. (1976). *Ingress of lodgepole pine and white spruce regneration following logging and scarification in west-central Alberta.* Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Information Rep. NOR-X-170.
[10] Alfero, R., Axelson, J., & Hawkes, B. (2009). *The dendroecology of stand dynamics of a selection of permanent sample plots, Alberta.* Hinton, Alberta: Foothills Research Institute.

Different species have different adaptations to survive physiologically stressful conditions. Whereas lodgepole pine relies on rapid early growth and high densities to offset mortality, spruces may survive unfavourable conditions by reduced growth. Unfortunately, no data are currently available for direct comparison of the survival of planted white and black spruces with that of lodgepole pine on the sites studied in this project.

3.3. Tending

The protracted nature of ingress may require tending practices to be modified on competitive highly productive sites (i.e. eco-class 4) if more reliance were to be placed on natural regeneration versus planting. However, the trial results tend to support the view widely held by field foresters that, regardless of tending, lodgepole pine natural regeneration cannot be relied on to reforest either rich sites or poor hygric sites (eco-class 5). On such sites planting of climax spruce species or mixtures is probably preferable. The main opportunities for increased reliance on natural regeneration are on eco-classes 1, 2 and 3, and results suggest that, with appropriate initial site preparation and adequate dropped cone densities, many of these sites may not require weeding.

An arguably more fundamental policy issue is the possibility that widespread removal of young aspen may not be effective for sustained-yield management of foothills forests, where sustention of pine yields is threatened by mountain pine beetle and climate change, but habitat suitability for aspen is forecast to improve.[11]

3.4. Reforestation Standards

Trial results illustrate the danger of relying on establishment surveys conducted 4-8 years following harvest to judge reforestation success. Alberta's yield-based reforestation standards and focus on regeneration performance at 12-14 years provide an excellent opportunity to avoid over-reliance on earlier establishment targets. Regeneration modeling and continued measurement of the trial are providing an improved basis for linking stocking targets at "establishment" (4-8 years) to performance standards.

4. Priorities for Project Continuation

4.1. Thinning

The project design calls for pre-commercial thinning of the designated treatment plots where natural regeneration has resulted in the target density being exceeded. It is desirable to thin before significant crown-competition occurs, but not until ingress of natural regeneration is complete or at least declining. The trial is now approaching this stage. In 2011 thinning was undertaken on a pilot basis in one group of installations. The remaining designated plots should be thinned within the next 2 years (2012, 2013).

4.2. Measurement

Continuation of essentially the same data collection protocol as applied over the last few years (see Table 3) is recommended for another 3 to 4 years until all installations have reached a stand age of at least 14 years (see Table 4 for current stand ages). This will provide complete data coverage to the end of the regeneration survey age range permitted for performance assessment in Alberta. While detailed measurements every alternate year are acceptable for most variables, annual checks have proven

[11] Mbogga, M., Wang, X., & Hamann, A. (2010). Bioclimatic envelope model predictions for natural resource management: dealing with uncertainty. *Journal of Applied Ecology*, 47, 731-740.

invaluable for monitoring mortality incidence and cause, and their continuation for the next few years would be very useful.

Continuity and consistency of measurement methods is very important for the remainder of the regeneration phase i.e. until installations reach stand age 14. Therefore no major changes in protocols are recommended. The only exception is the monitoring of top height, as commenced on a pilot basis in 2011 and documented in the field manual.[12]

4.3. Analysis

Trial measurements to growing season 7 have been incorporated into a preliminary regeneration model. Modeling of data beyond this age was delayed pending field checking and correction of data for growing season 9 (completed in 2011), and evaluation of the model against operational regeneration survey data (a test was conducted in 2011). Fieldwork scheduled for July to September in 2012 will complete full measurements for all plots to at least 11 years since harvest, thus providing data to within a year of the operational performance assessment window. A high priority will be given to modeling these data and incorporating them into a user-friendly decision-support tool.

[12] *Foothills Growth and Yield Association regenerated lodgepole pine trial – field manual for measurements and maintenance*, Version 4.0. July 15, 2011.