Forest Resource Improvement Association of Alberta
Forest Resource Improvement Program

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

Regenerated Lodgepole Pine Trial

2009 CROP PERFORMANCE REPORT

Prepared by:

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

March 1, 2010

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

Table of Contents

List of Tables

List of Figures

Summary

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 (“installations”) throughout the Eastern Slopes, in a large replicated experiment designed to monitor stand development of harvest-origin lodgepole pine in relation to site, planting density, vegetation control (weeding) and density regulation (pre-commercial thinning).

All installations have now been monitored for 8, and measured in detail for 7, full growing seasons since planting. Performance was assessed after the 2009 field measurements. The following observations are noted.

- Vegetation control by weeding, which was conducted up to 2007, has significantly reduced the cover and growth of deciduous trees and tall shrubs, but there is little remaining impact on grasses and other herbaceous vegetation.
- Ecological site class strongly influences pine height and diameter growth, ingress of natural regeneration, and mortality.
- Vegetation control has significantly increased diameter growth, but has not had a statistically significant effect on height growth, ingress of natural vegetation, or mortality.
- Ingress of natural regeneration has not been significantly affected by weeding, but appears to have been more strongly influenced by site preparation.
- Although planted stock is currently ahead of natural regeneration in height and diameter development, its contribution to the final crop is made uncertain by high levels of mortality and, on many sites, much higher densities of natural regeneration.
- It is not yet possible to confirm mortality trends in natural regeneration, but periodic mean annual mortality has increased since 2006 in both natural regeneration and planted stock.
- The predominant direct causes of mortality, over at least the last two years, have been *Armillaria* root disease and *Hylobius* root collar weevils. The is a strong correlation between mortality and mean annual temperature of the site.

In order to provide an improved basis for forecasting achievement of regeneration targets, data were consolidated into two predictive models, one for planted stock and one for natural regeneration. The high and persistent levels of tree mortality observed in the trial, related to pathogens and climate, have potentially important implications for silvicultural risk management. Development of tools for assessing these risks is a high priority for application of trial results and data from other sources.

Recommendations are made for maintenance of the trial, its continued measurement, and experimental treatments. These include: changing tree tagging protocols to reduce the incidence of missing sample trees, continuation of detailed measurements at two-year intervals, retention of annual mortality checks at least for the naturally regenerated (non-planted) plots, and pre-commercial thinning of a sub-sample of plots within 3 to 5 years.

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

This report describes crop performance to the end of the 2009 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 (i.e. during the current term of FRIAA Project FOOMOD-01-03 ending in 2010) the main focus of the project has been to provide an improved basis for forecasting achievement of performance targets such as the regeneration standards adopted by FGYA members.

1.2. Design and Measurements

The experimental design is described in the project establishment report and will not be repeated in detail here. The original design was balanced at 90 installations. Groups of 6 installations, each installation representing 6 different planting densities, were replicated 3 times on each of 5 ecological site classes. Each 1-ha installation was split into 4 treatment plots representing different vegetation management treatments. 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. The original design was subsequently augmented by 2 additional groups of installations, which were added in the mesic / medium site class.

The pre-commercial thinning treatments will not be conducted until ingress of natural regeneration diminishes and crown closure is approached. For analysis of data collected to date, 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).

Measurements were conducted as scheduled in Table 3.

Table 1. Distribution of installations by ecological site class[1]

Ecosite (and Edatope)		WC	SW	# 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	1. control (no planting) 2. 816 stems/ha 3. 1111 stems/ha 4. 1600 stems/ha 5. 2500 stems/ha 6. 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								
	0	1	2	3	4	5	6	7	8
Planting density and site	x								
Coniferous ingress density		x		x		x		x	
Coniferous ingress stocking		x		x		x		x	
Competition – shrubs and herbs	x	x	x	x		x		x	
Competition – deciduous trees	x	x	x	x		x		x	
Size and growth	x	x		x		x		x	
Mortality incidence and cause		x	x	x	x	x	x	x	x
Health	x	x		x		x		x	

This report summarizes measurements conducted since 2006, i.e. at the end of the 2007, 2008 and 2009 growing seasons. The numbers of installations (1-hectare plot clusters) measured during this period and included in the data summaries are shown in Tables 4 through 7. Note that a total of 90 installations, of which 75 were planted, were measured each year. Detailed measurements were taken in alternate years.

[1] WC = *Field guide to ecosites of west-central Alberta*, J.D. Beckinhham, I.G.W. Corns and J.H. Archibald, Can. For. Serv. Special Report 9, 1996.
SW = *Field guide to ecosites of southwestern Alberta*, J.D. Beckingham, G.D. Klappstein, and I.G.W. Corns, Can. For. Serv.

Twelve of the total 102 installations have been excluded. These were extra replicates that were added to the original project design, but were operationally over-sprayed in August 2006.

Table 4. Number of all installation measurements by year and stand age

Years since harvest	Measurement year			Total
	2007	2008	2009	
6	6			6
7	31	6		37
8	45	31	6	82
9	8	45	31	84
10		8	45	53
11			8	8
Total	90	90	90	270

Table 5. Number of detailed installation measurements by year and stand age

Years since harvest	Measurement year			Total
	2007	2008	2009	
7	5	6		11
8	19	26		45
9	3	26	5	34
10		5	19	24
11			3	3
Total	27	63	27	117

Table 6. Number of detailed installation measurements by year and time since site preparation

Years since site preparation	Measurement year			Total
	2007	2008	2009	
7	14	9		23
8	13	40		53
9		14	14	28
10			13	13
Total	27	63	27	117

Table 7. Number of detailed measurements by year and time since planting

(planted installations)

Growing seasons since planting	Measurement year			Total
	2007	2008	2009	
7	24	51		75
9			24	24
Total	24	51	24	99

2. Stand Conditions and Crop Performance

2.1. Competing Vegetation

Figures 1 to 16 summarize deciduous tree, shrub, herb and moss occurrence by ecological site class and vegetation treatment as recorded during the latest detailed plot measurements, which were made in 2008 and 2009. At the time of these measurements most plots were 7, and a few were 9, growing seasons after planting.

Figure 1 and 2 show percent deciduous stocking in planted and non-planted installations averaged by site ("EcoClass") and treatment. Stocking percentages are based on the occurrence of aspen, balsam poplar or birch in 0.001 ha regeneration sub-plots, of which there were 64 in each installation. Weeding has resulted in average stocking levels usually being kept below 40%. Levels exceeding twice this value have occurred in non-weeded plots, especially on rich EcoClass 4 sites. Deciduous densities (Figures 3 and 4) are usually less than 2000 stems per ha on weeded plots, though there are exceptions, and on most installations height (Figures 5 and 6) and stem diameter (Figures 7 and 8) of deciduous competition are less on weeded than non-weeded plots. Percent cover and modal height of willow, alder and other tall shrubs are also generally lower on weeded versus non-weeded plots (Figures 9 – 11).

The remaining impact of weeding on average levels of cover by short shrubs, forbs, grasses and mosses is low and statistically insignificant, though there were significant site effects (Figures 12 - 16).

Figure 1. Deciduous stocking in planted plots

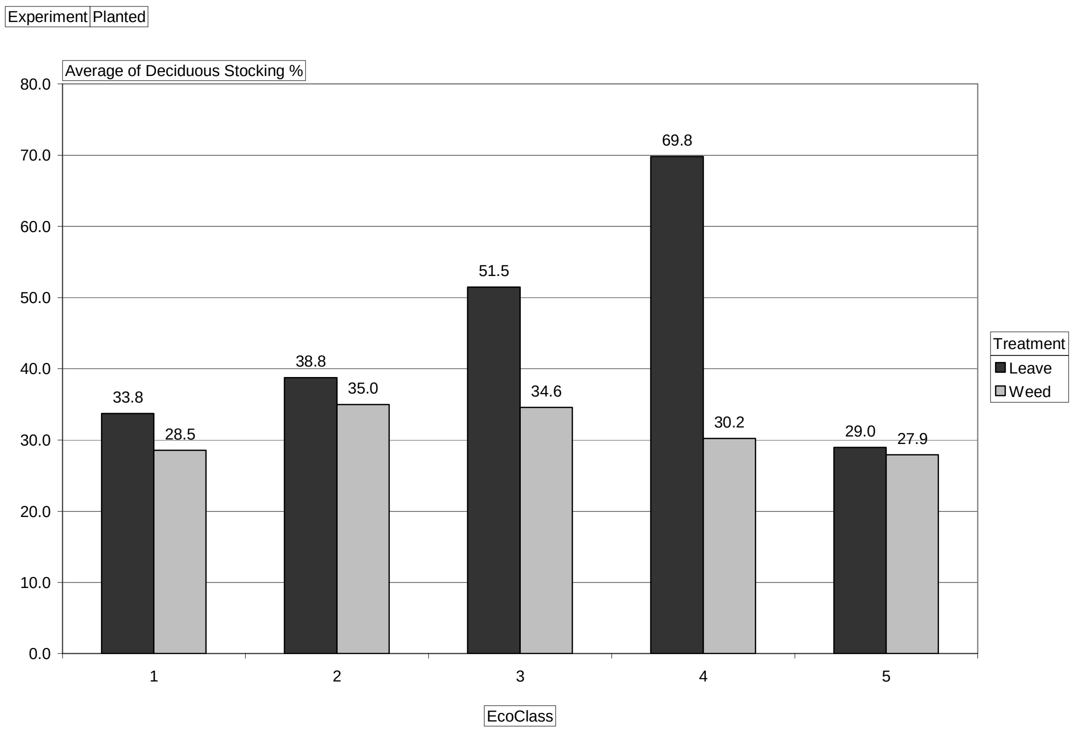


Figure 2. Deciduous stocking in non-planted plots

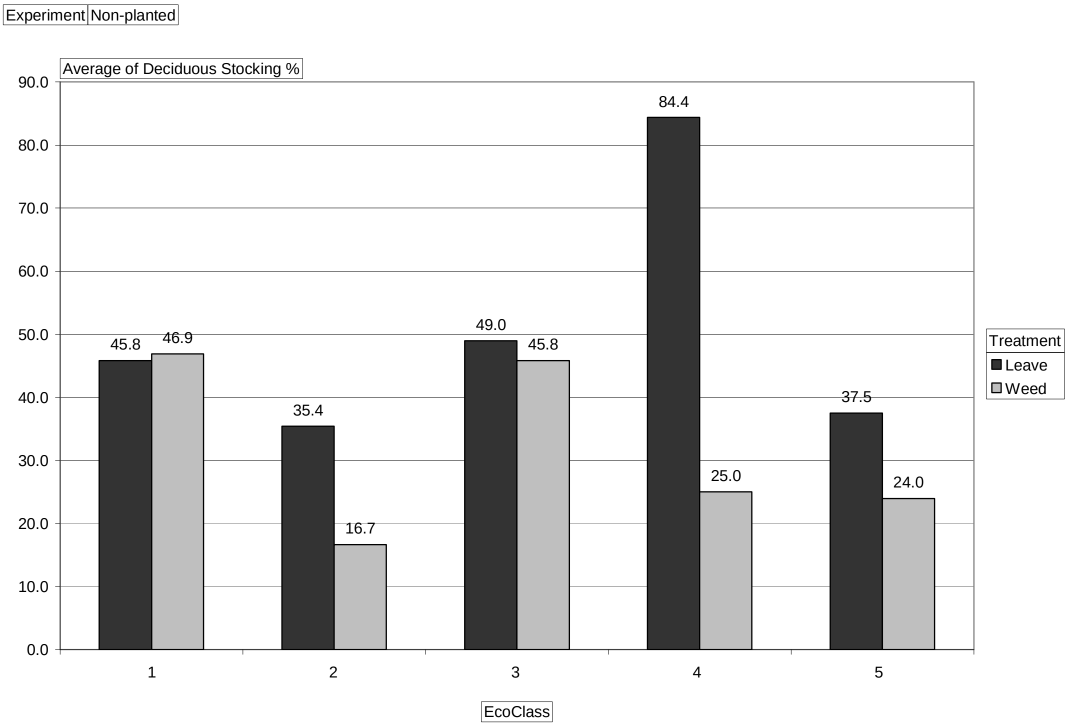


Figure 3. Deciduous density in planted plots

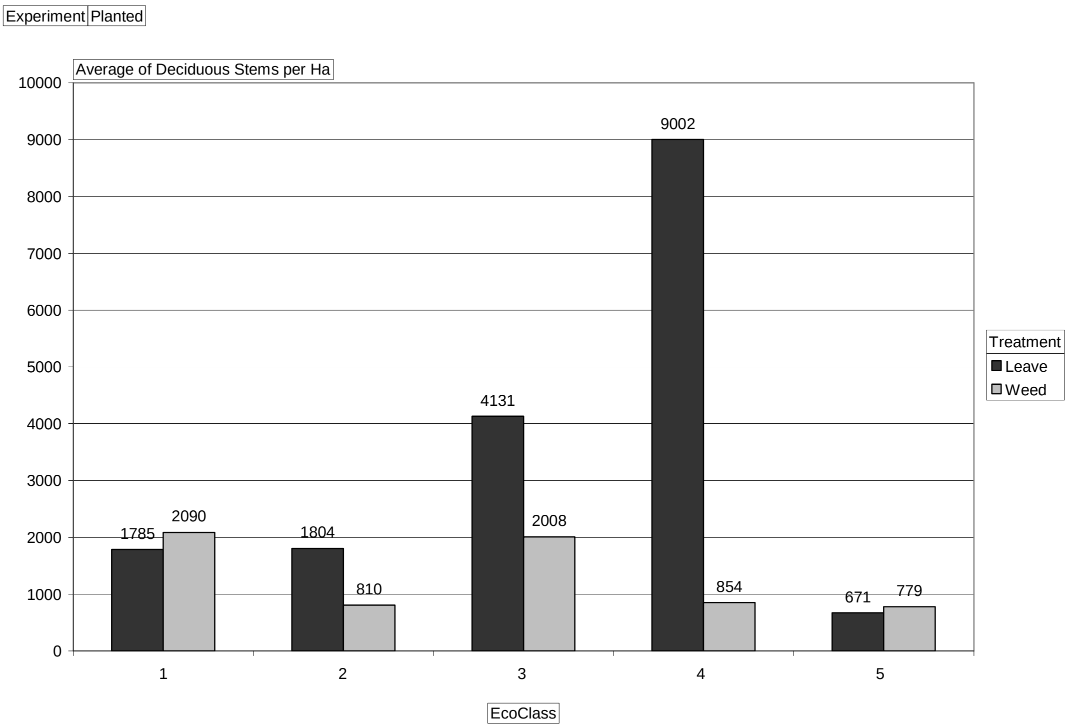


Figure 4. Deciduous density in non-planted plots

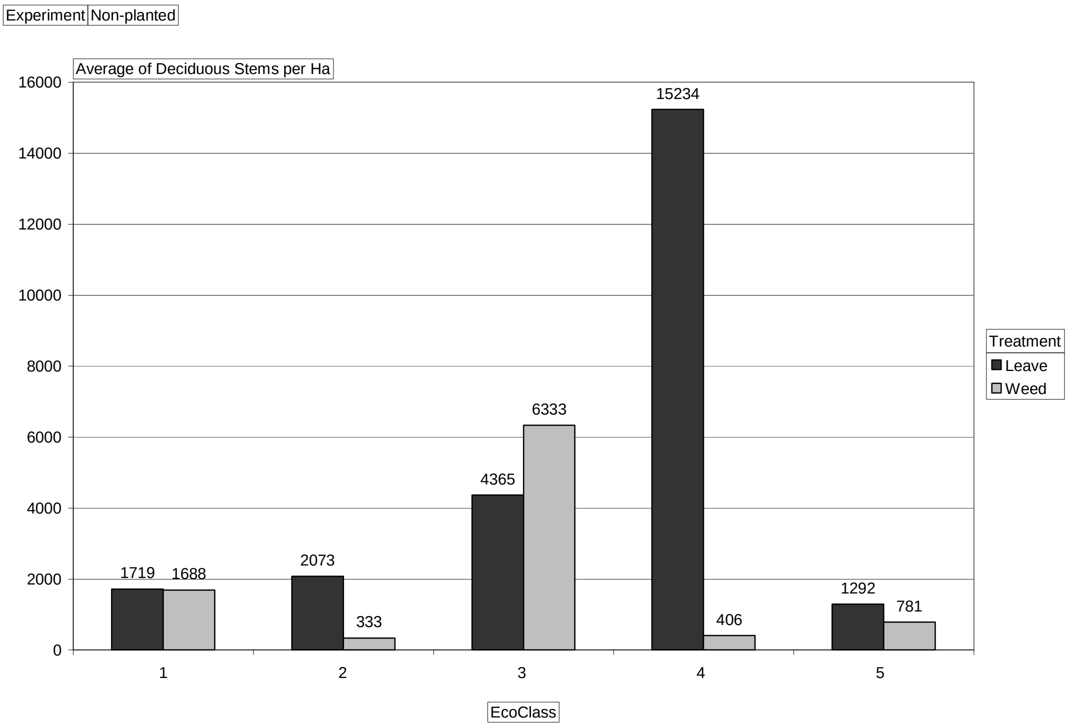


Figure 5. Deciduous height in planted plots

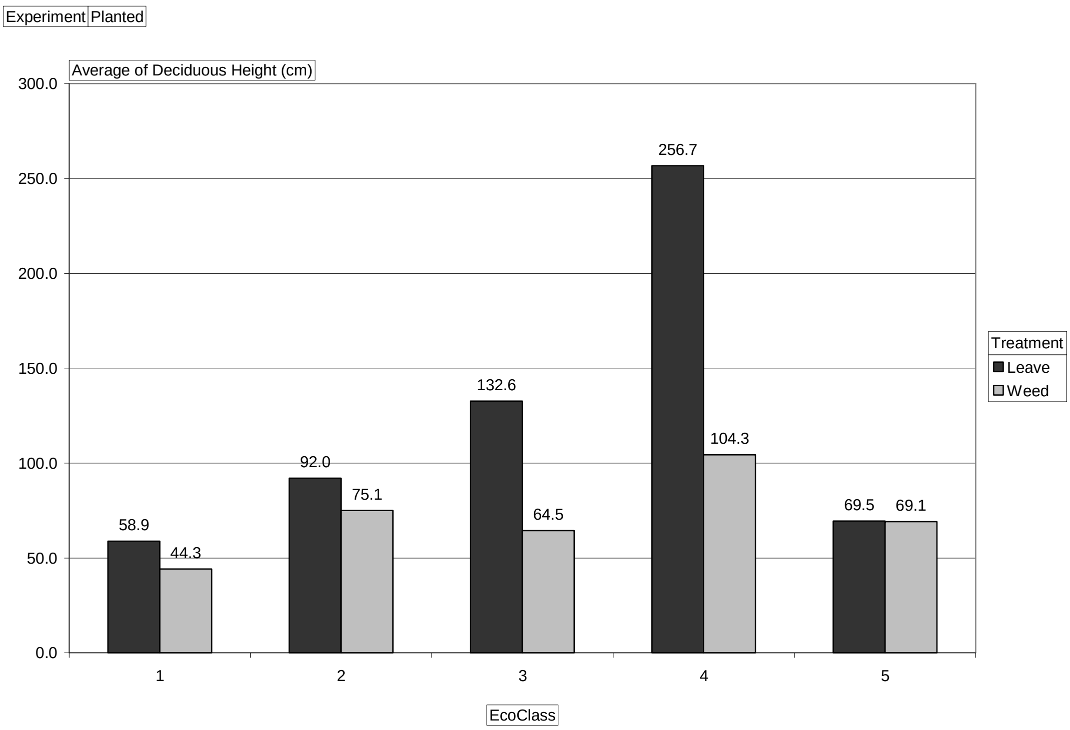


Figure 6. Deciduous height in non-planted plots

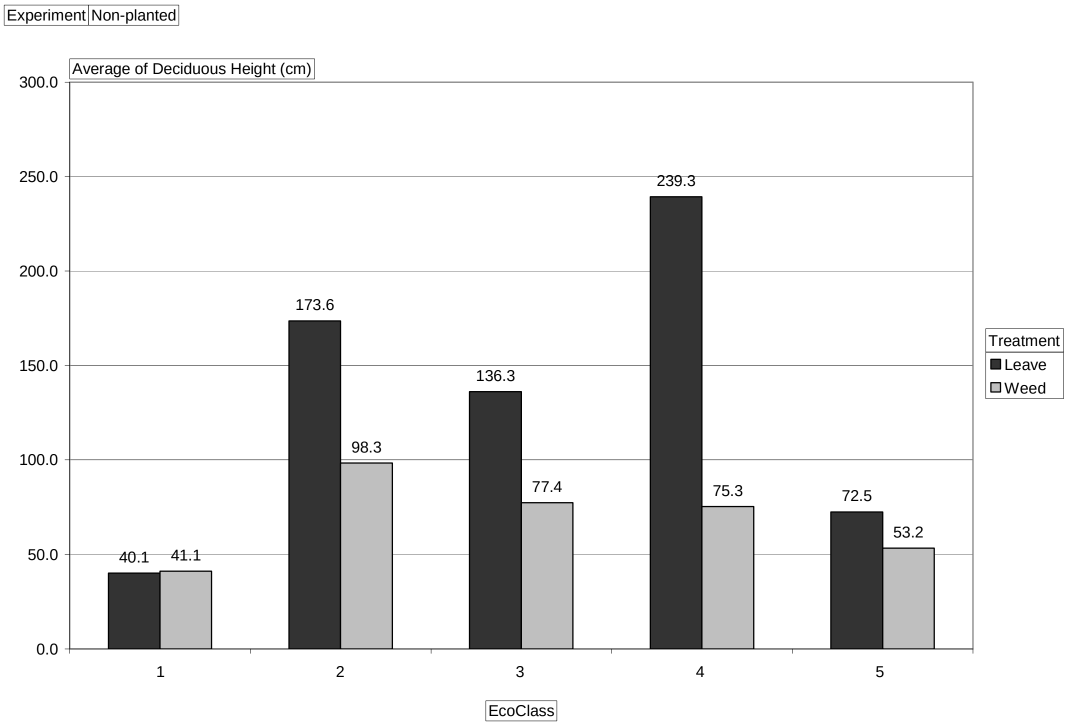


Figure 7. Average deciduous ground-line diameter in planted plots

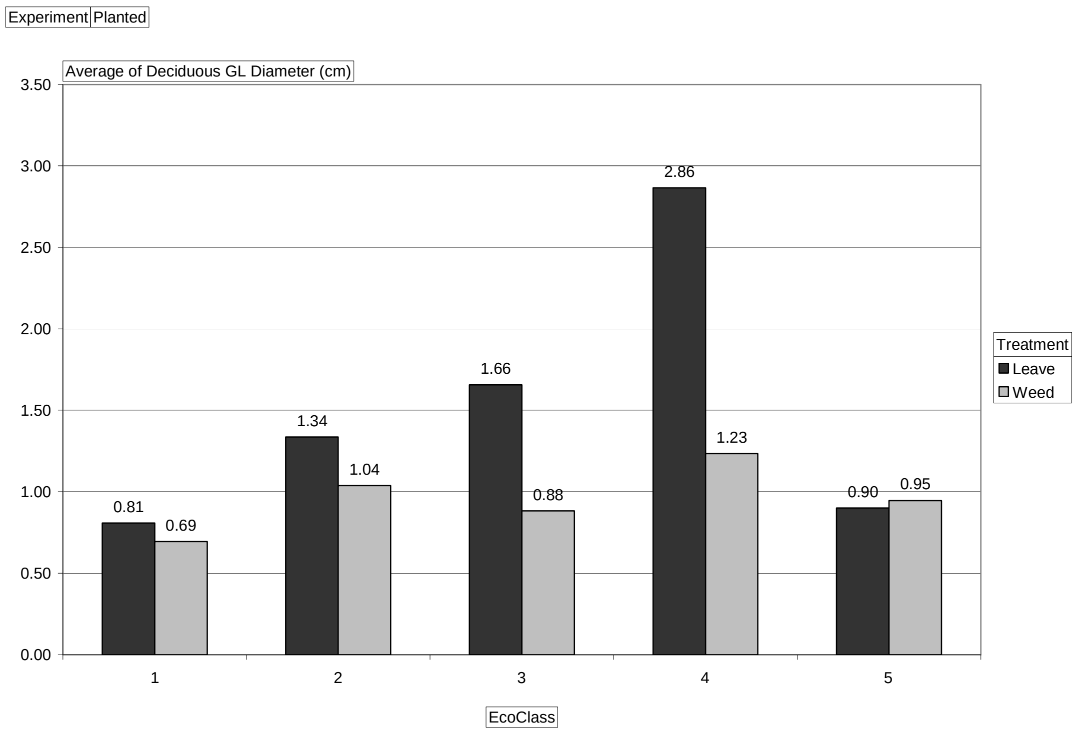


Figure 8. Average deciduous ground-line diameter in non-planted plots

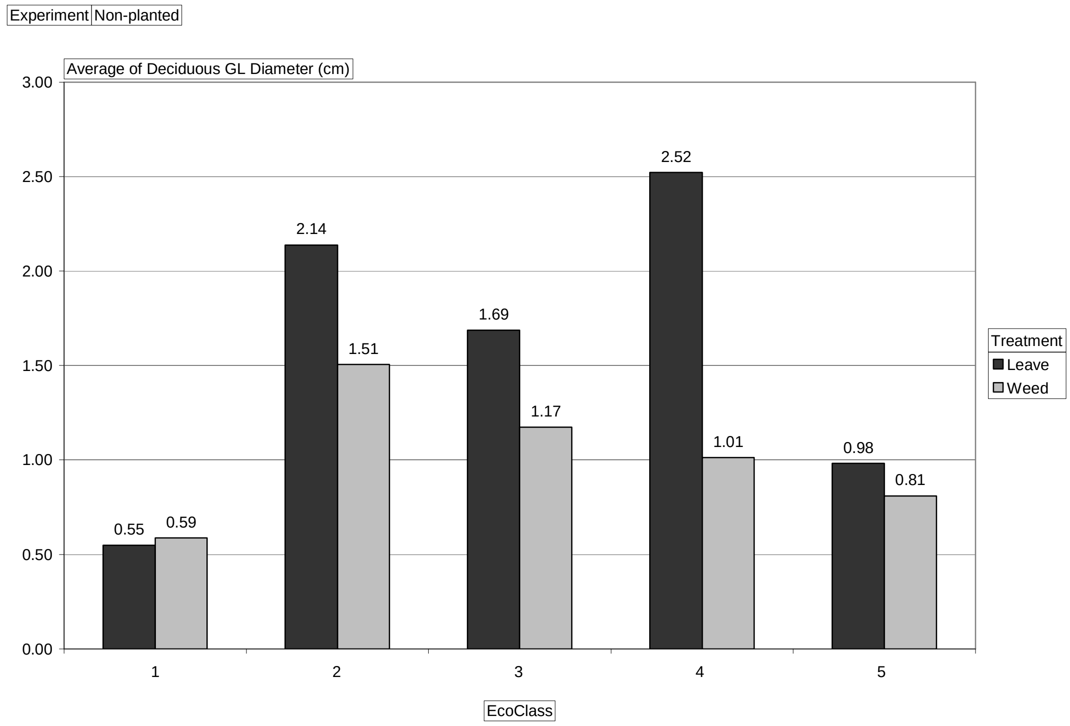


Figure 9. Percent cover of willow and alder

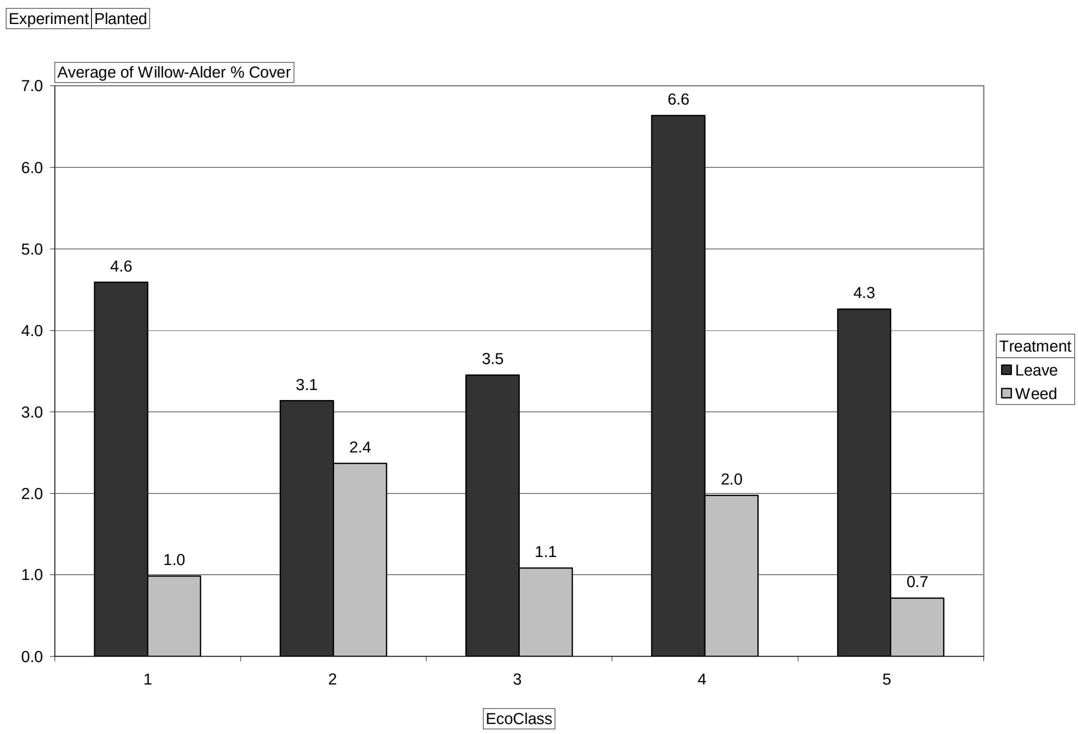


Figure 10. Height of willow and alder

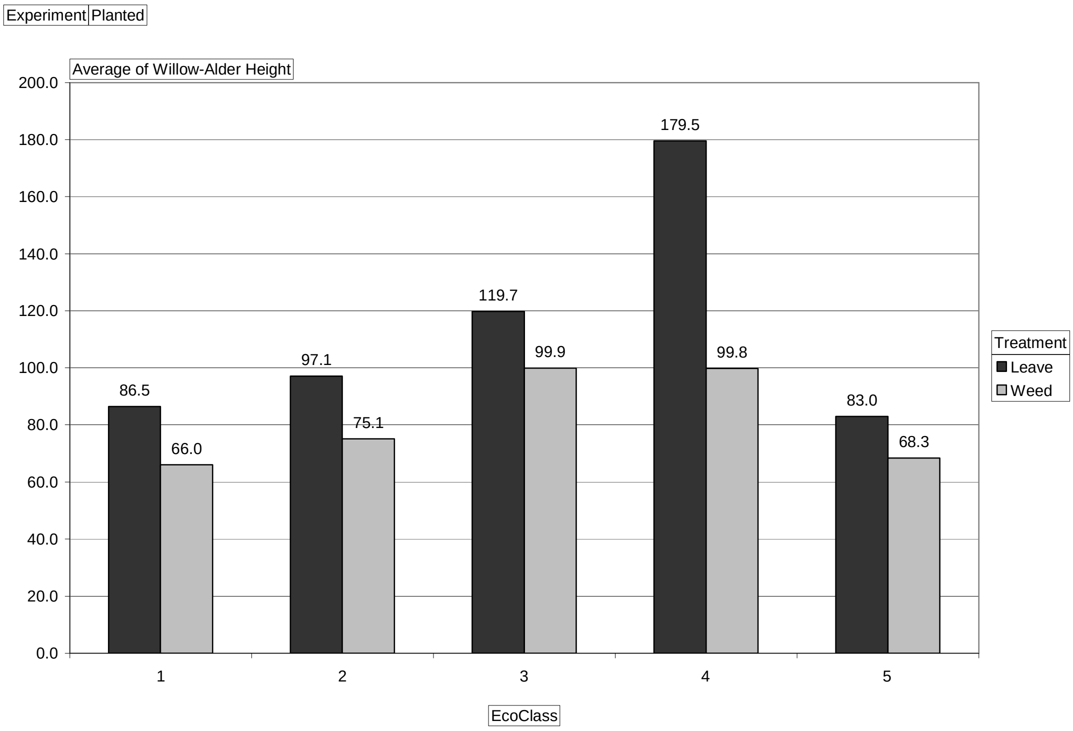


Figure 11. Percent cover of other tall shrubs

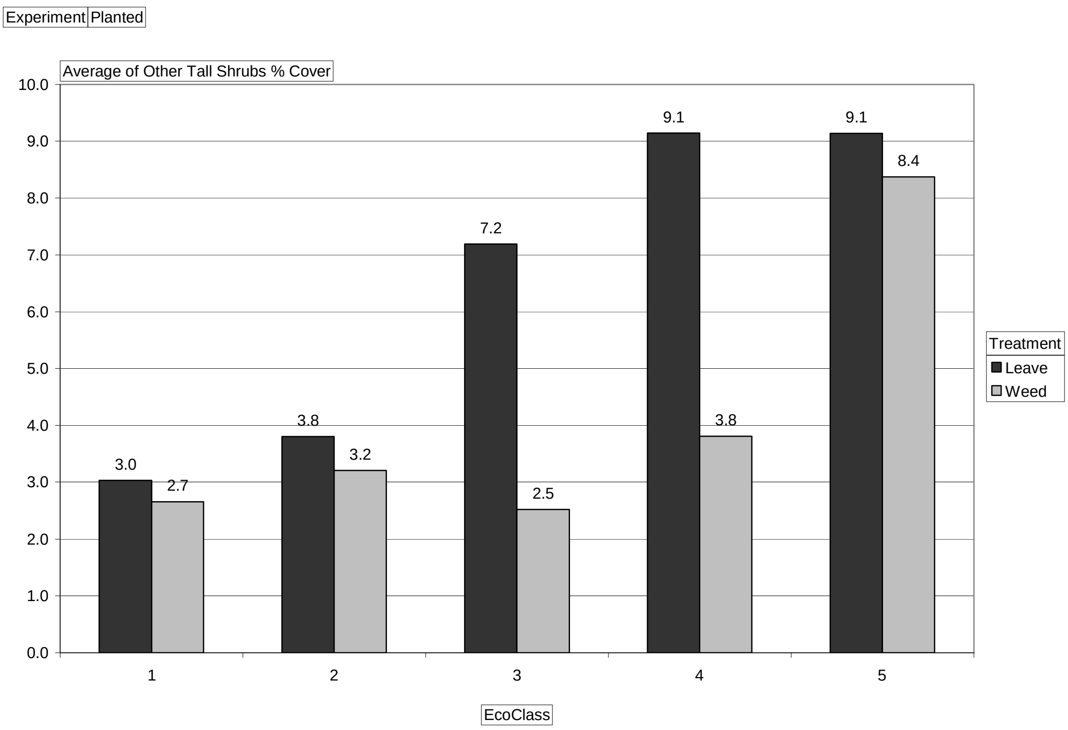


Figure 12. Percent cover of short shrubs

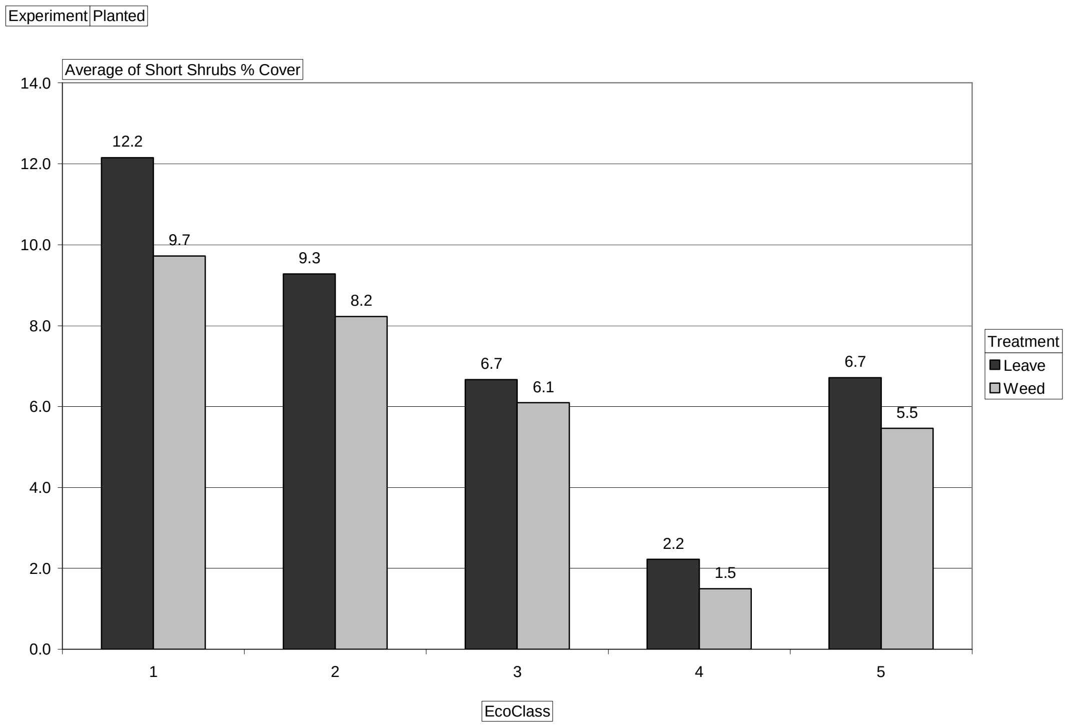


Figure 13. Percent cover of forbs

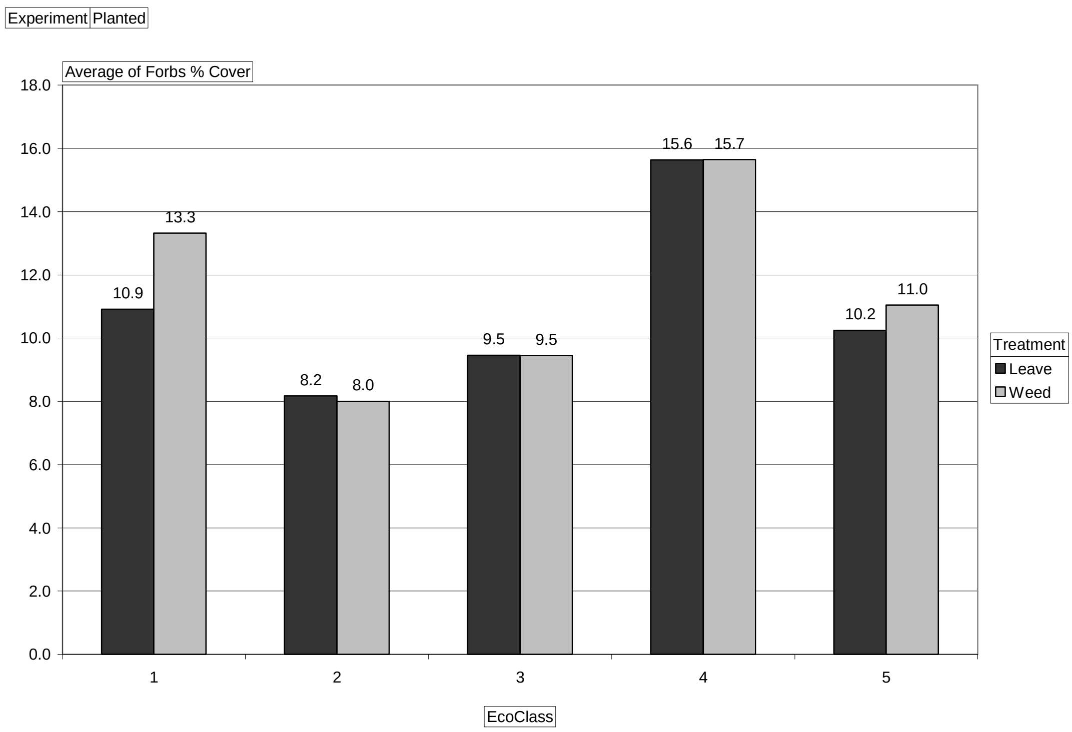


Figure 14. Height of forbs

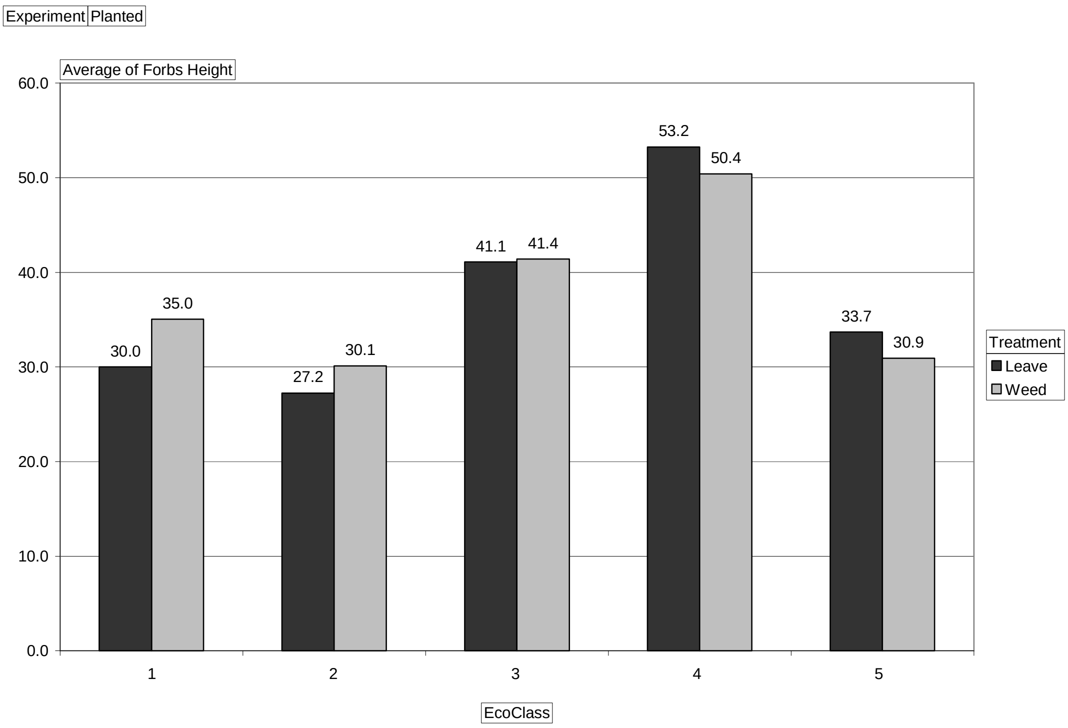


Figure 15. Percent cover of grasses

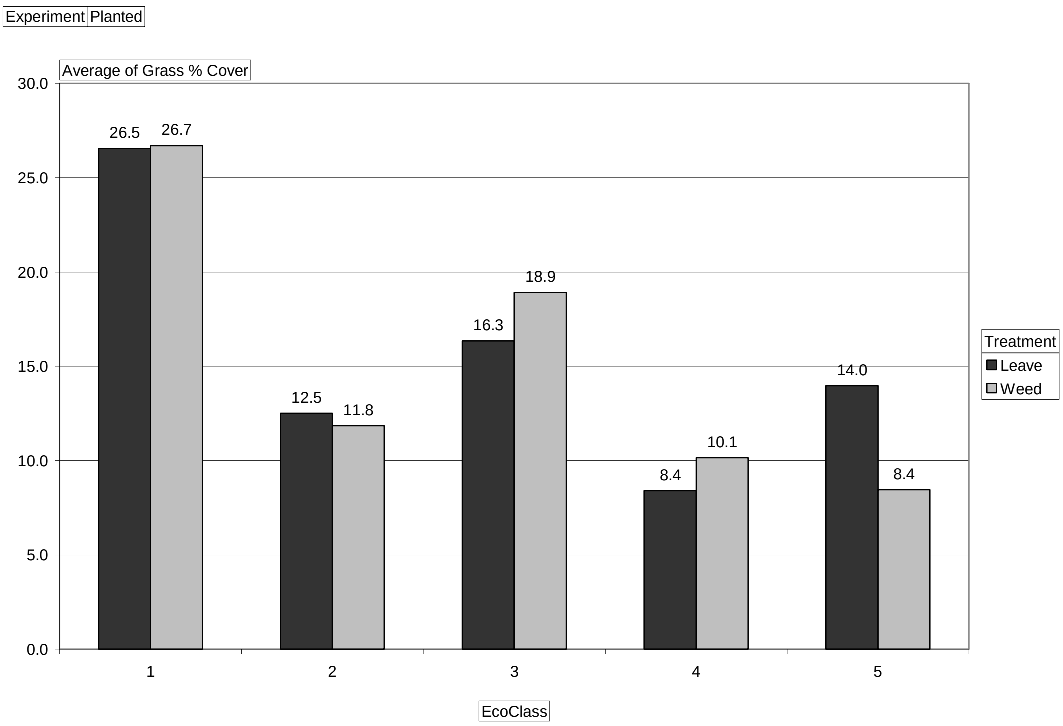
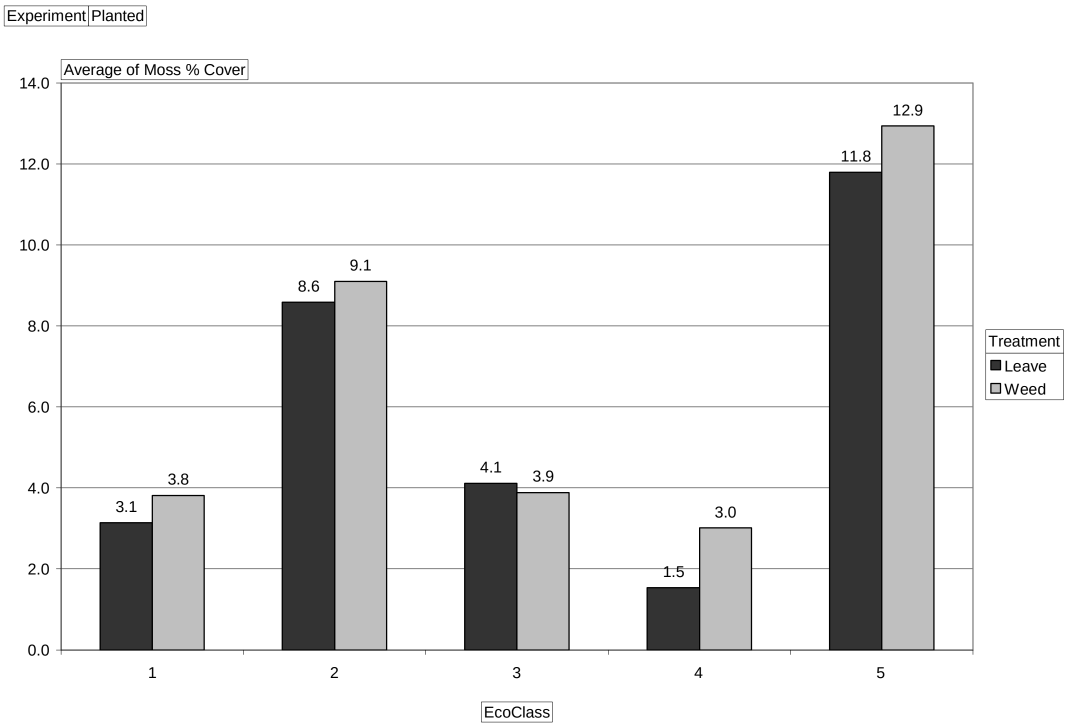


Figure 16. Percent cover of mosses



2.2. Height and Diameter Growth

Figures 17 to 22 summarize height and diameter achievement on planted stock after 7 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.

The height of planted stock is strongly influenced by site, but the slight apparent effects of weeding (Figure 17) are not statistically significant. Diameter of planted stock is significantly increased by both site and weeding (Figure 18).

Height and diameter of natural regeneration are also influenced by site. Differences between vegetation treatments are not statistically significant, though average height and diameters are consistently higher for weeded plots in all site classes except EcoClass 5 (Figures 19 and 20).

Height and diameter of planted stock are substantially higher for planted stock versus natural regeneration on all sites (Figures 21 and 22). The differences are greatest on EcoClasses 4 and 5, where ingress of natural regeneration has been slowest.

Planting density is the only other factor experimentally controlled in the trial in addition to site (eco-class) and vegetation management (weeding). No consistent and statistically significant effects of planting density have yet been observed, but this is expected to change in later measurements as crowns close and available rooting space is utilized.

Figure 17. Height of planted stock

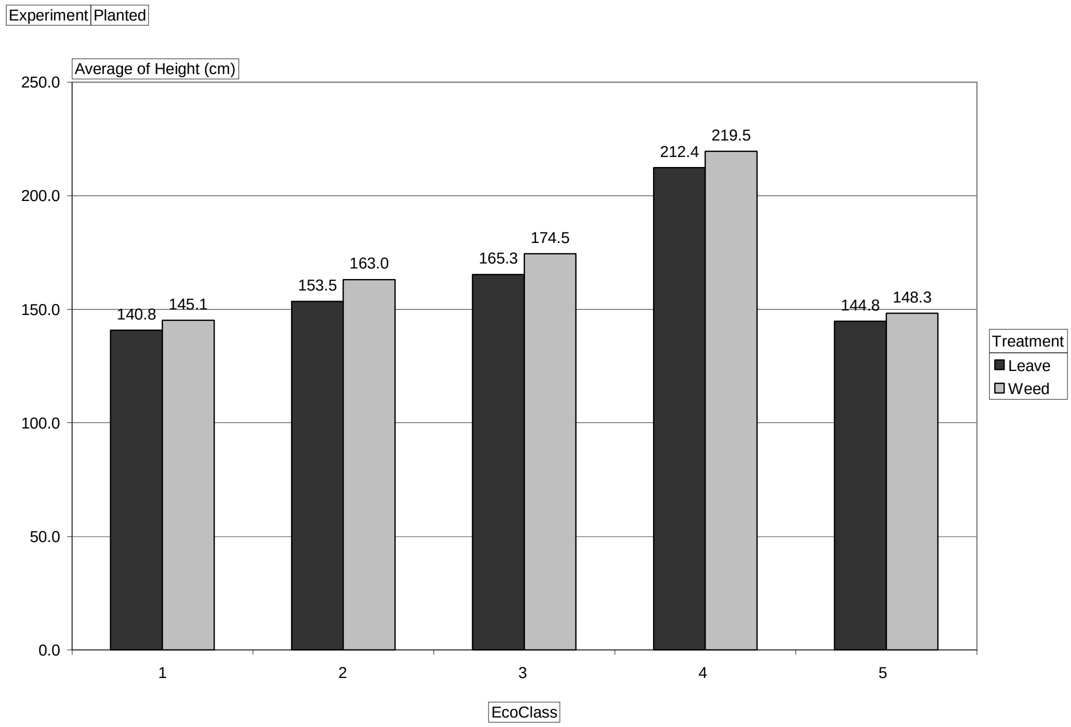


Figure 18. Ground-line diameter of planted stock

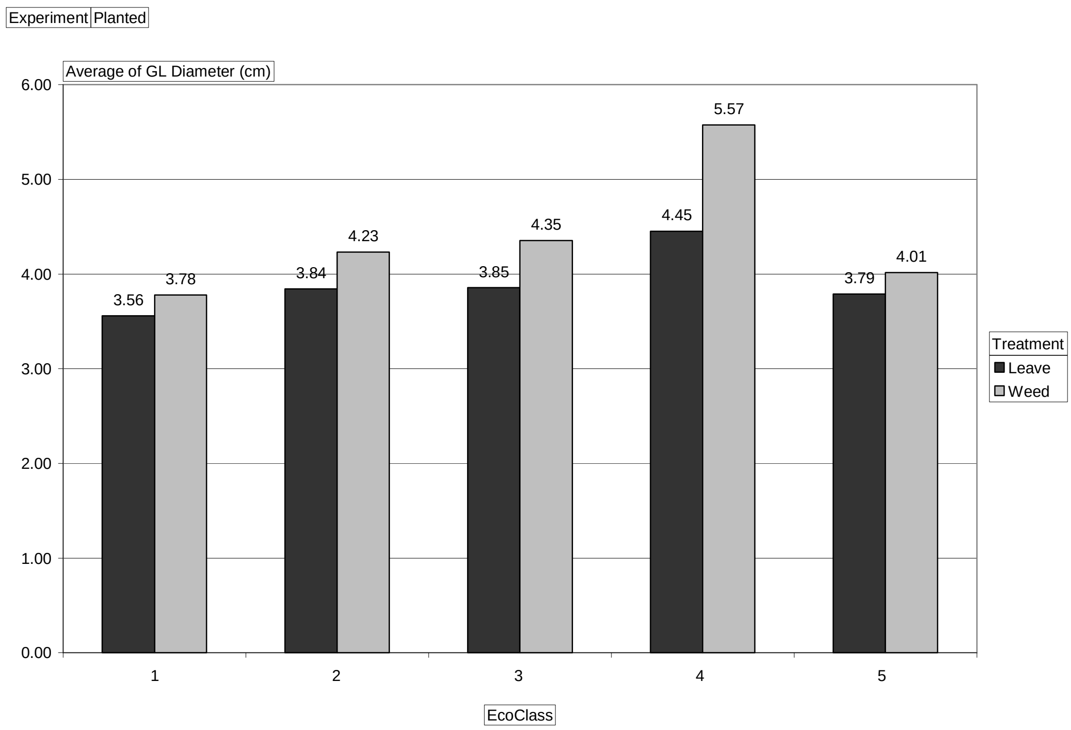


Figure 19. Height of natural regeneration

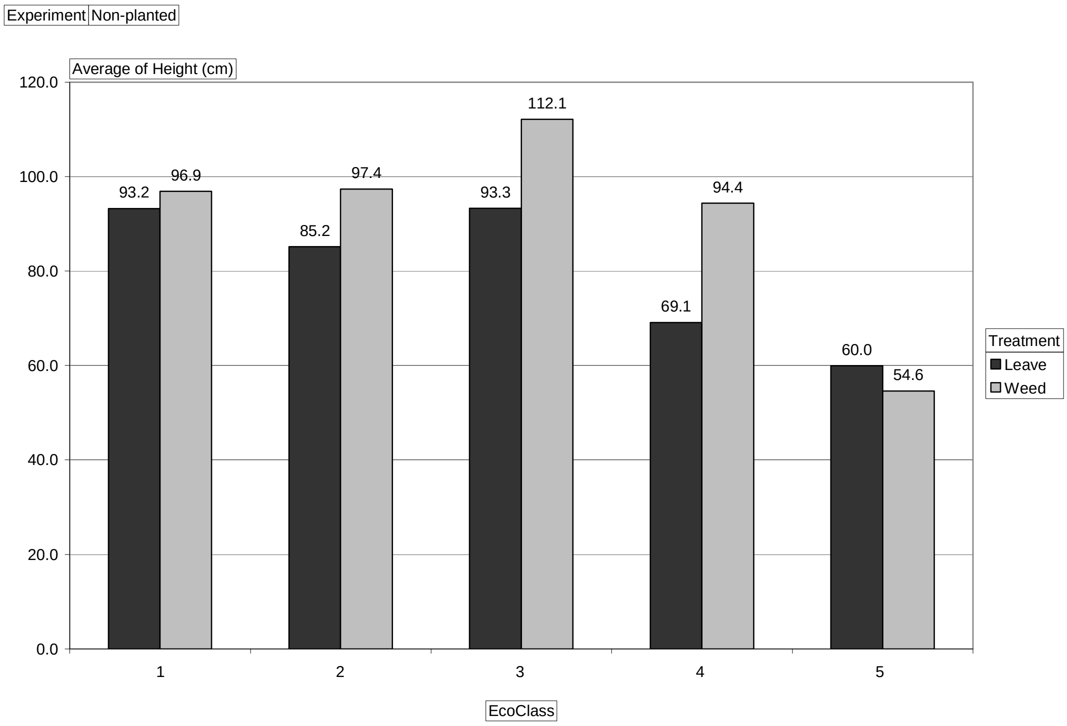


Figure 20. Ground-line diameter of natural regeneration

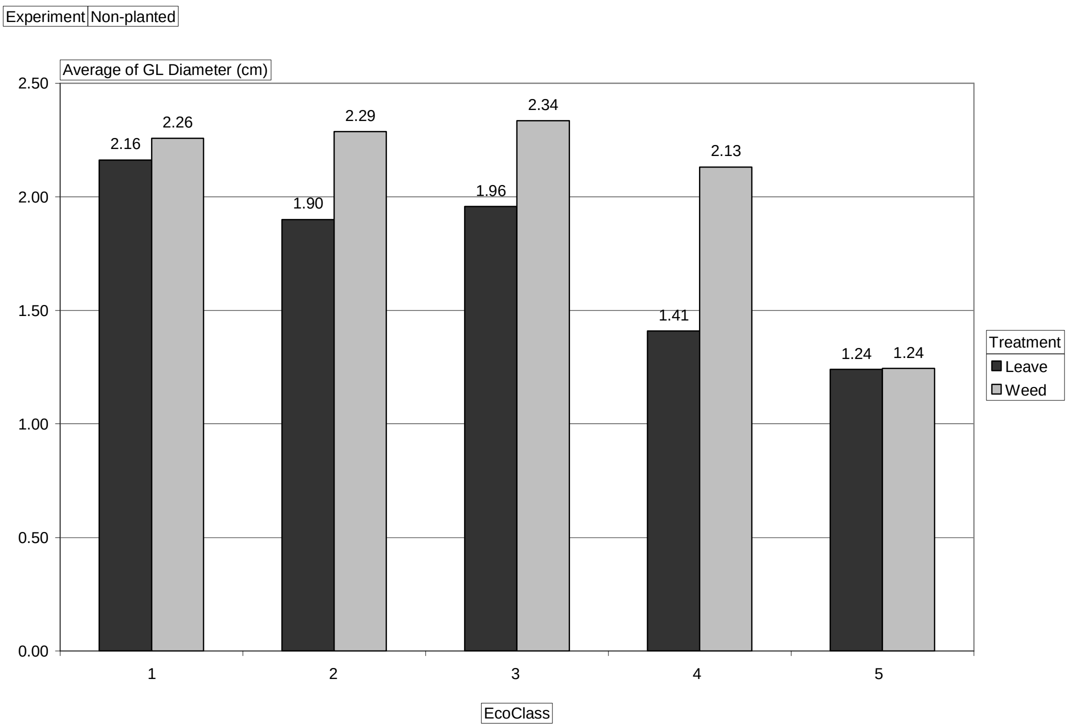


Figure 21. Height comparison between planted stock and natural regeneration

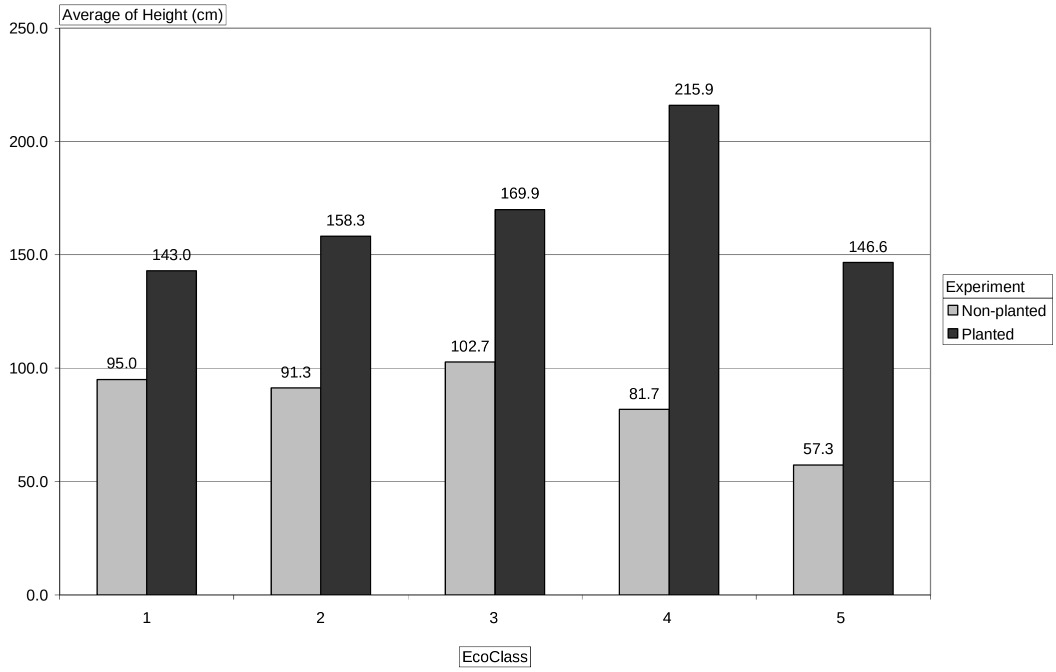
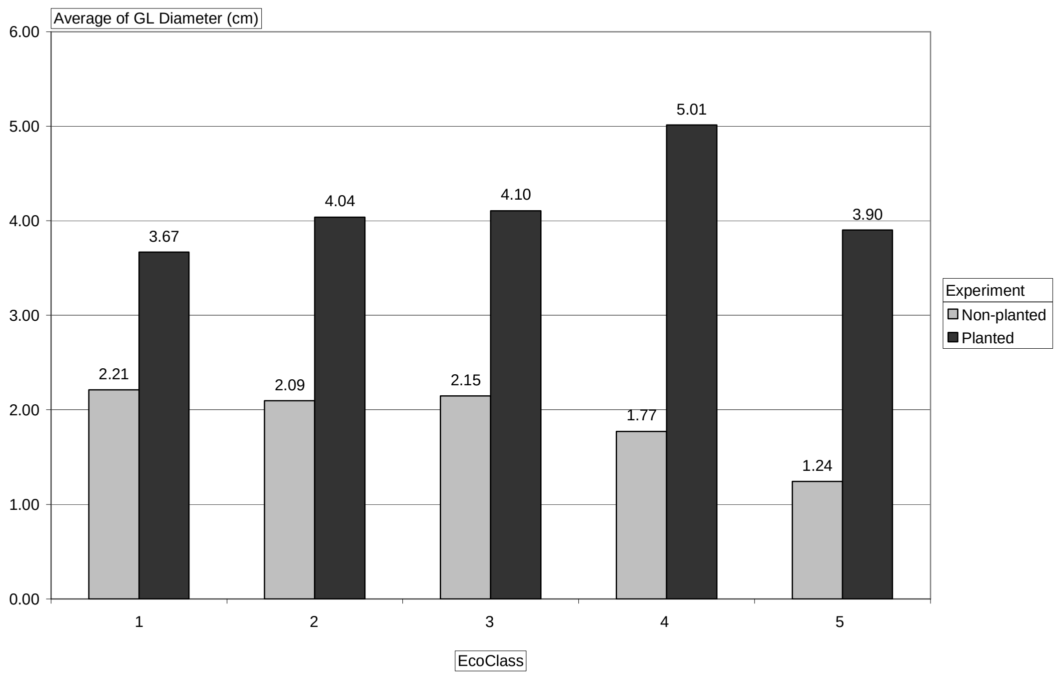


Figure 22. Ground-line diameter comparison between planted stock and natural regeneration



2.3. Ingress of Natural Regeneration

Figures 23 to 26 summarize ingress of natural regeneration. Results are based on detailed measurements taken at the same time as those reported in Figures 17 to 22 for planted stock and conducted 7 growing seasons after planting of installations. The measurements were taken between 7 and 9 years following site preparation and 7 to 10 years following harvest.

While there are significant differences between site classes, no statistically significant differences in stocking or density of natural regeneration could be found between weeded versus non-weeded plots (Figures 23 and 24). The species composition of natural regeneration varies by site class (Figure 25).

Substantial differences are apparent between site preparation treatments in eco-classes 1, 2 and 3. Figure 26 shows the differences in trees per stocked plot apparently resulting from manual (or no) scarification versus mechanical scarification on planted plots. Similar, though not so pronounced, trends were observed in stocking differences. It should be noted that, unlike weeding and ecological site, site preparation was not experimentally controlled in the trial.

For regeneration modeling purposes, trends of ingress over time (years since last disturbance) were explored by logistic regression. These will be reported elsewhere and analyzed further following collection of more ingress data in 2009.

Figure 23. Percent stocking of coniferous natural regeneration (trees >10cm tall)

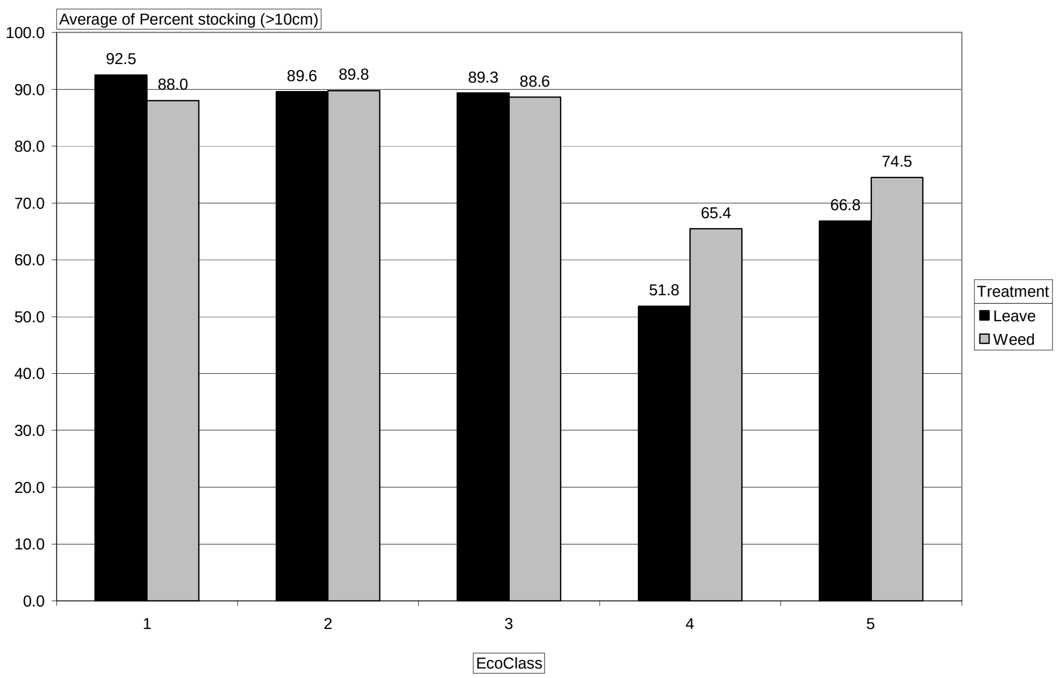


Figure 24. Percent stocking of coniferous natural regeneration (trees 30cm+ tall)

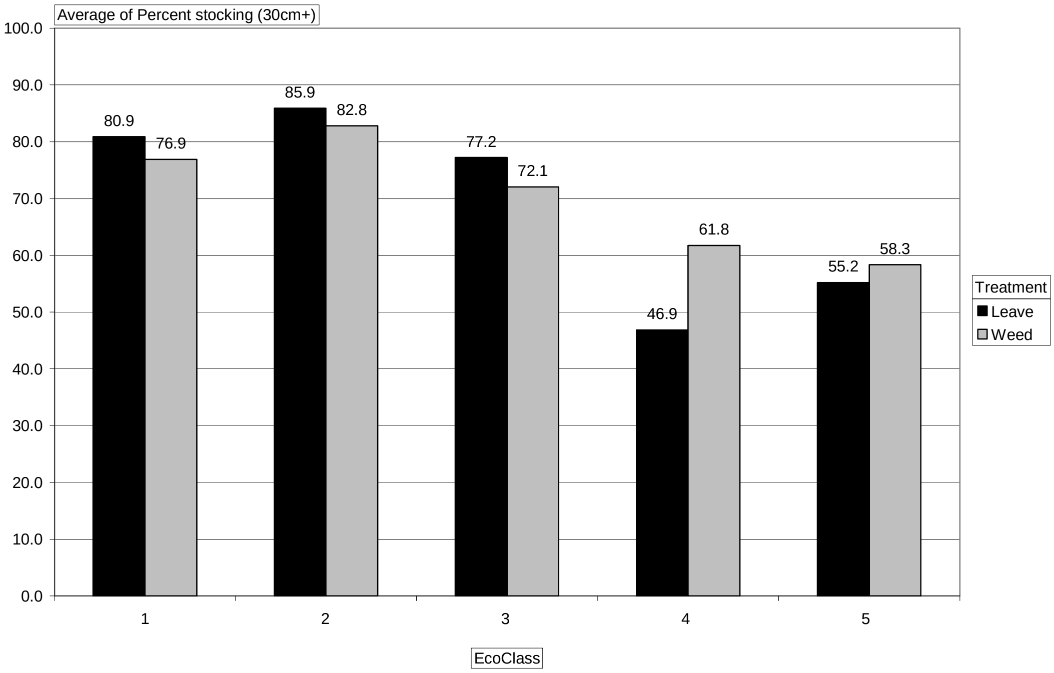
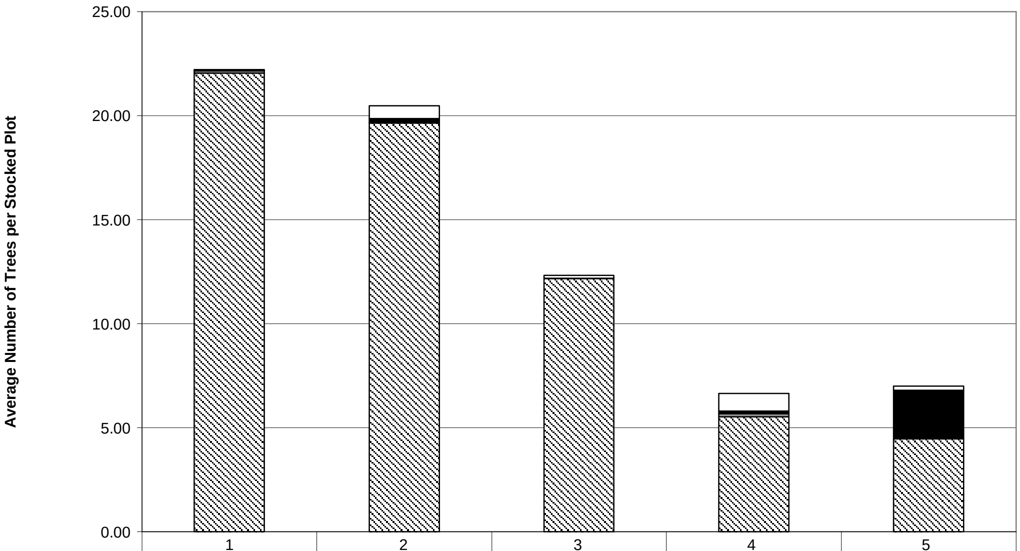


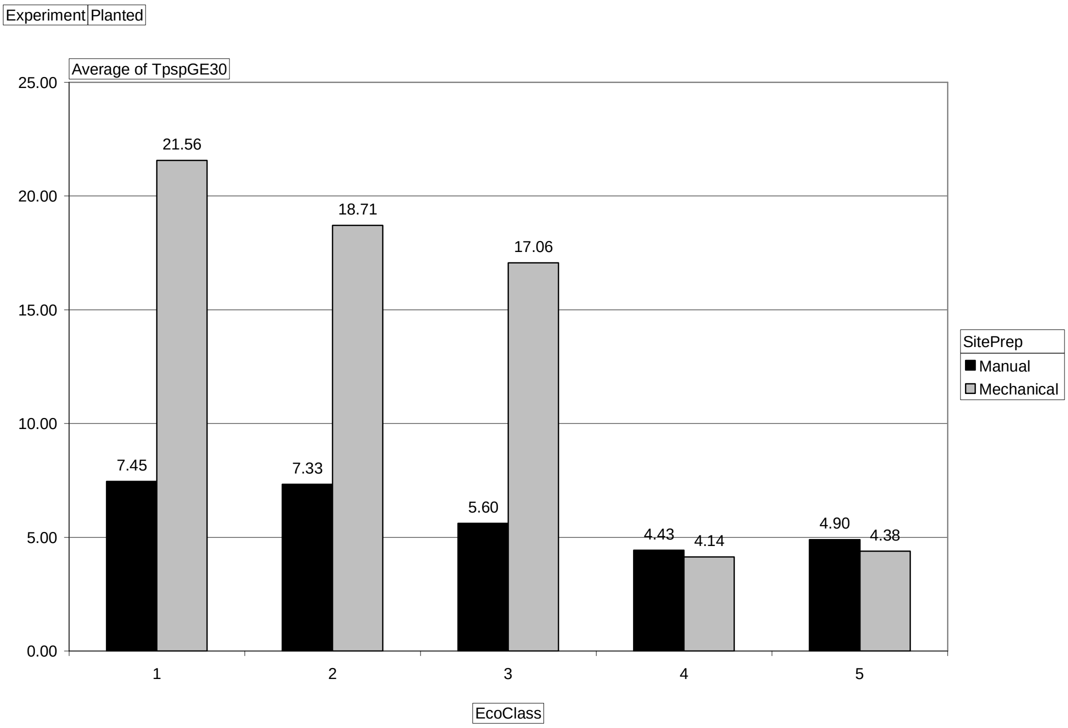
Figure 25. Density and species composition of coniferous ingress ((trees >10cm tall)



	1	2	3	4	5
White Spruce	0.06	0.61	0.13	0.85	0.21
Black Spruce	0.01	0.21	0.02	0.11	2.32
Fir	0.11	0.01	0.01	0.16	0.01
Pine	22.04	19.64	12.17	5.52	4.47

EcoClass

Figure 26. Effect of site preparation on density (trees 30cm+ per stocked plot)



2.4. Mortality

Figure 27 shows periodic mean annual mortality for planted stock after 8 growing seasons. While there are significant differences between sites, vegetation management has not had any significant effect. Missing trees have previously created uncertainty over actual mortality levels. While missing sample trees are most likely to have died, this cannot be assumed with absolute certainty. During 2009 a major effort was made to locate missing trees and confirm their status. This removed some of the previous uncertainty for planted stock. Remaining levels of uncertainty are shown to be quite small in Figure 28, which illustrates the proportion of missing and dead trees that have never been confirmed dead. A small number of plots with unusually high numbers of missing trees were excluded from mortality calculations.

Concerns over levels of early mortality in planted stock raised by the 2006 crop performance report and related analyses have been reinforced by continued mortality since 2006. Figure 29 shows cumulative mortality trends over 8 growing seasons. It might appear to the optimist that there is some evidence of a decline in the last year, but this could simply reflect the incidence of sample trees previously assumed dead that were found alive as a result of the previously mentioned special field effort in 2009. The average periodic mean annual mortality of planted stock during growing seasons 6 to 8, when expressed as the percentage of trees alive after 5 growing seasons, increased substantially relative to that during the first 5 growing seasons on all sites except eco-class 5 (Figure 30).

Mortality in natural regeneration has also increased dramatically since 2006 (Figure 32). However, ingress has not been established long enough to ascertain trends reliably, and this uncertainty is exacerbated by a high proportion of missing trees that have not yet been confirmed dead (Figure 32).

Figure 27. Periodic mean annual mortality of planted stock after 8 growing seasons

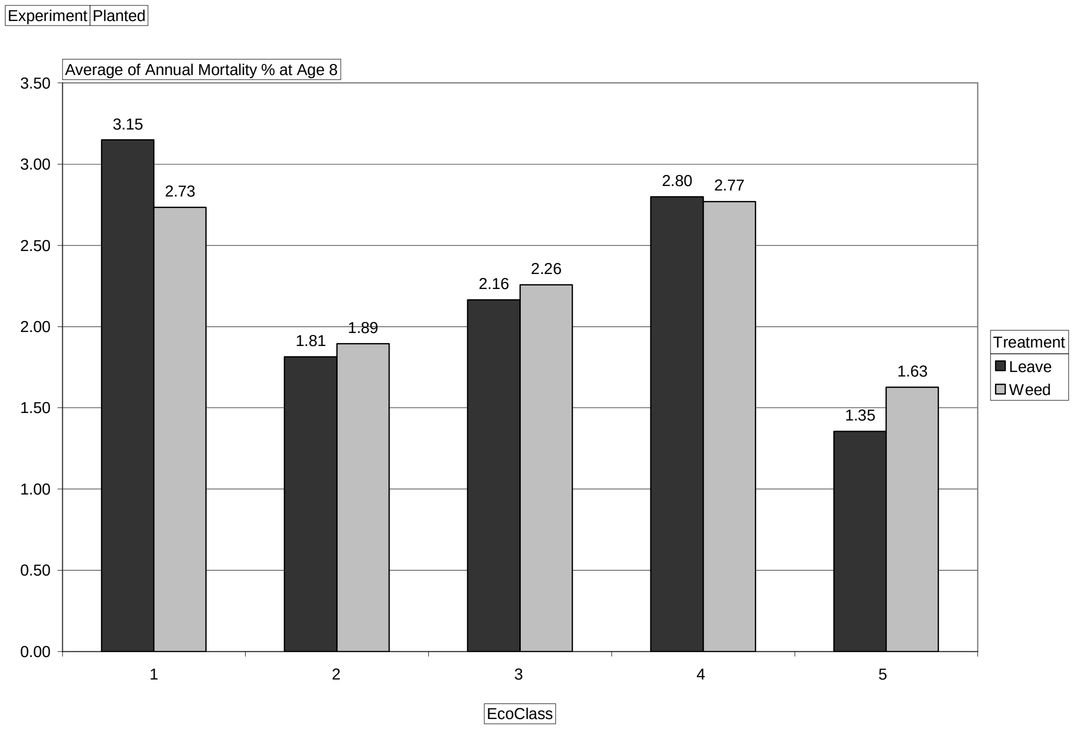


Figure 28. Uncertainty in mortality resulting from missing planted trees never confirmed dead

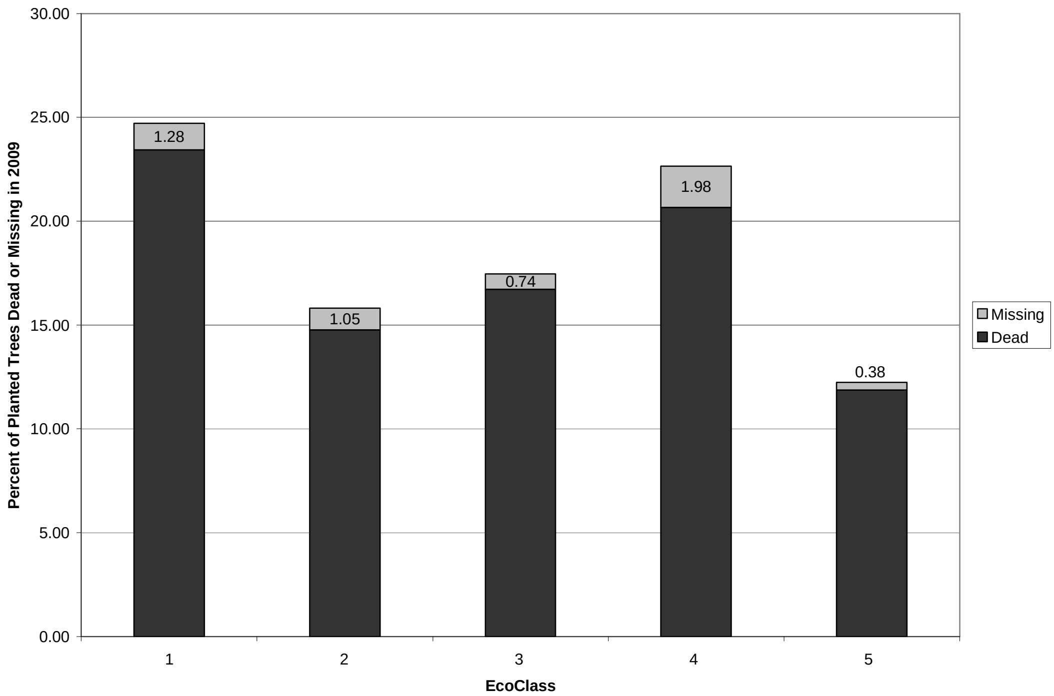


Figure 29. Cumulative mortality of planted stock

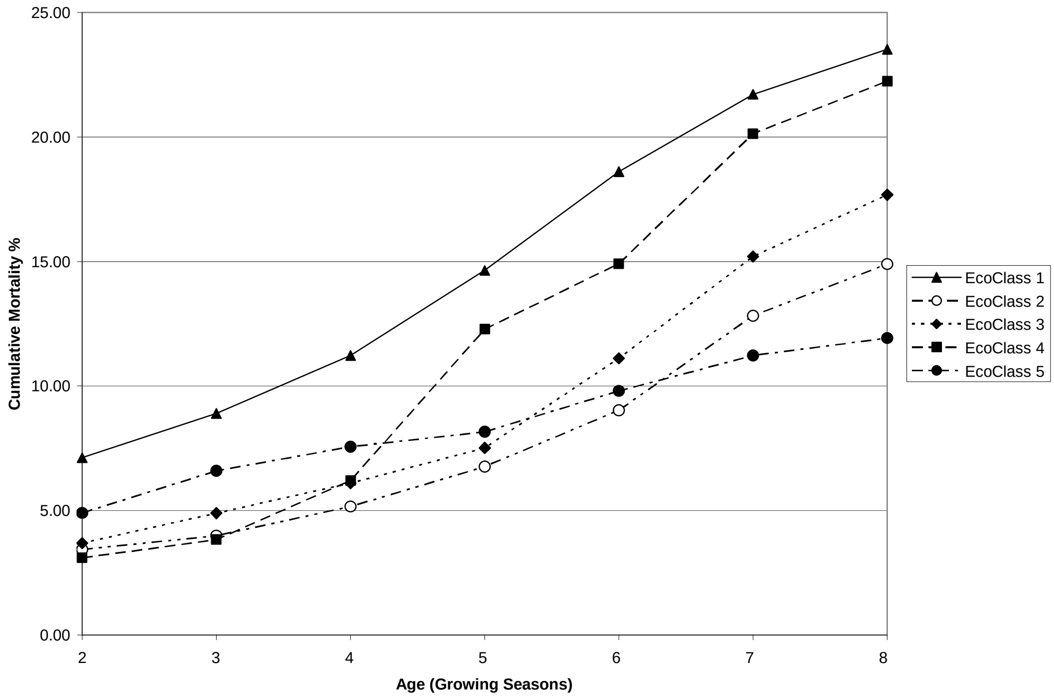


Figure 30. Comparison of mortality between growing seasons 1-5 and 6-8

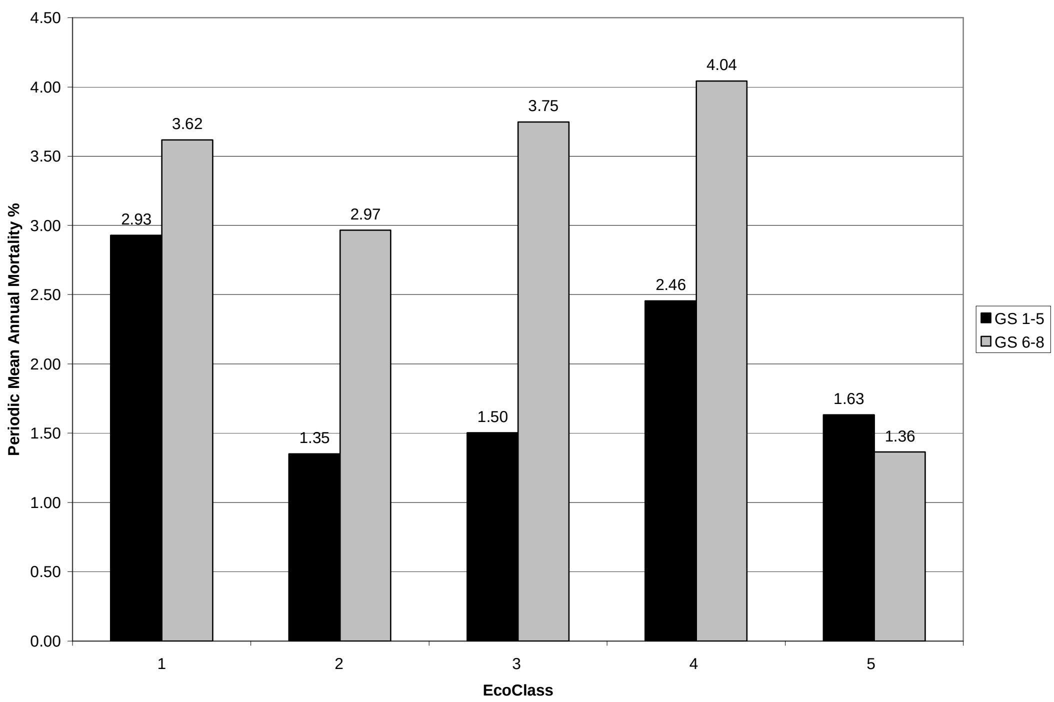


Figure 31. Periodic mean annual mortality of natural regeneration since ingress[2]

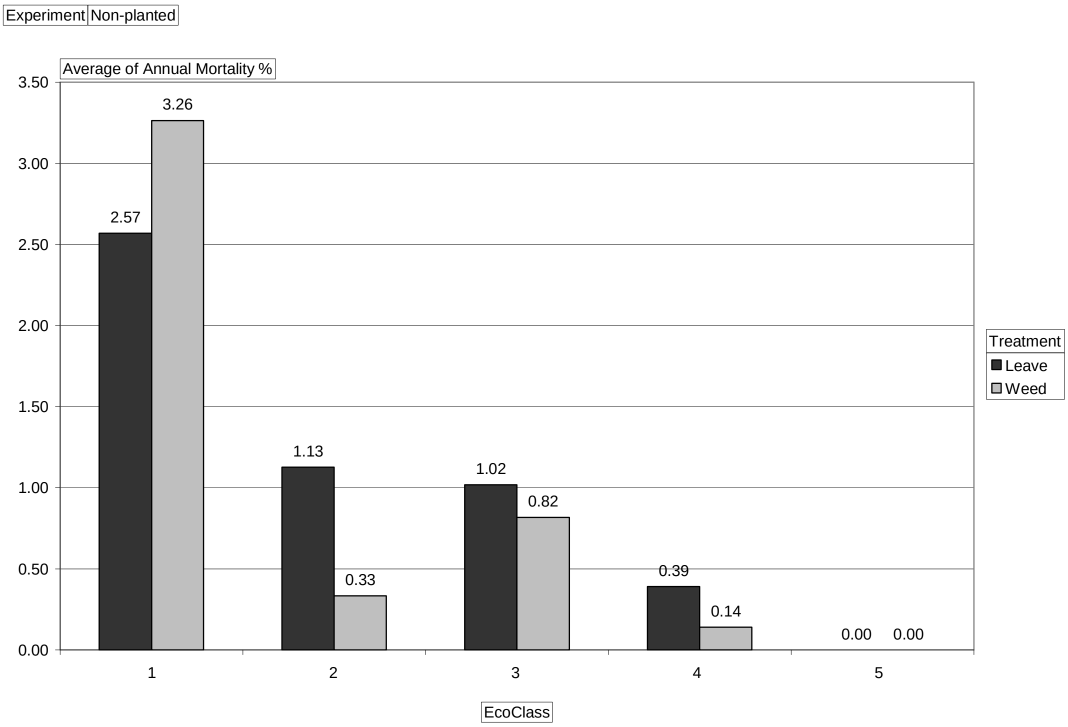
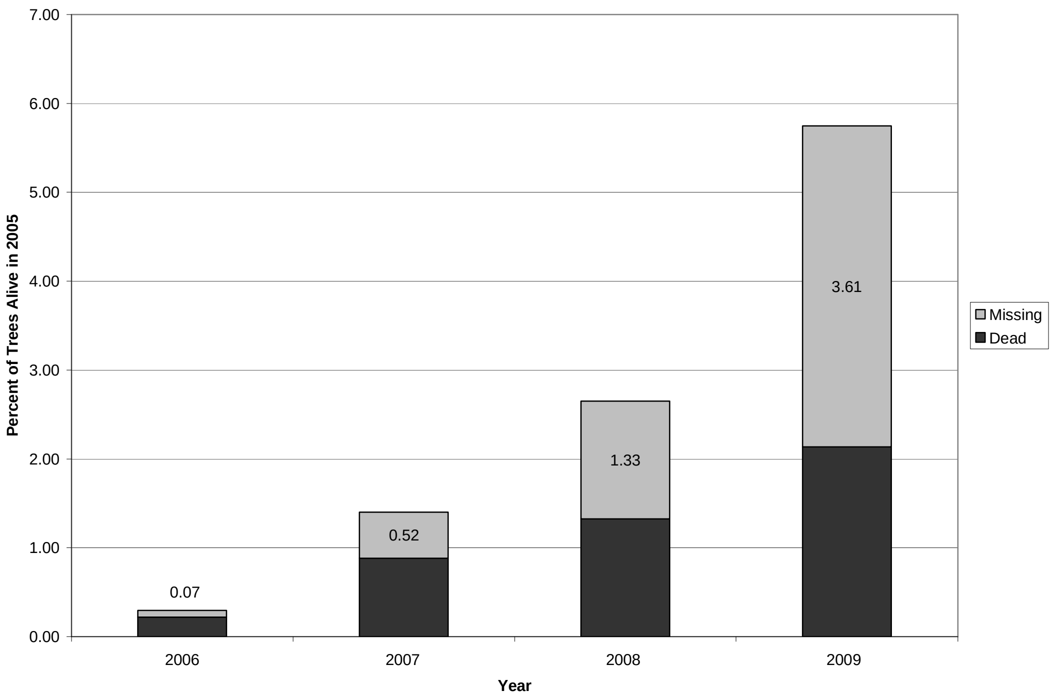


Figure 32. Trees missing or confirmed dead in sampled natural regeneration



[2] Includes missing trees.

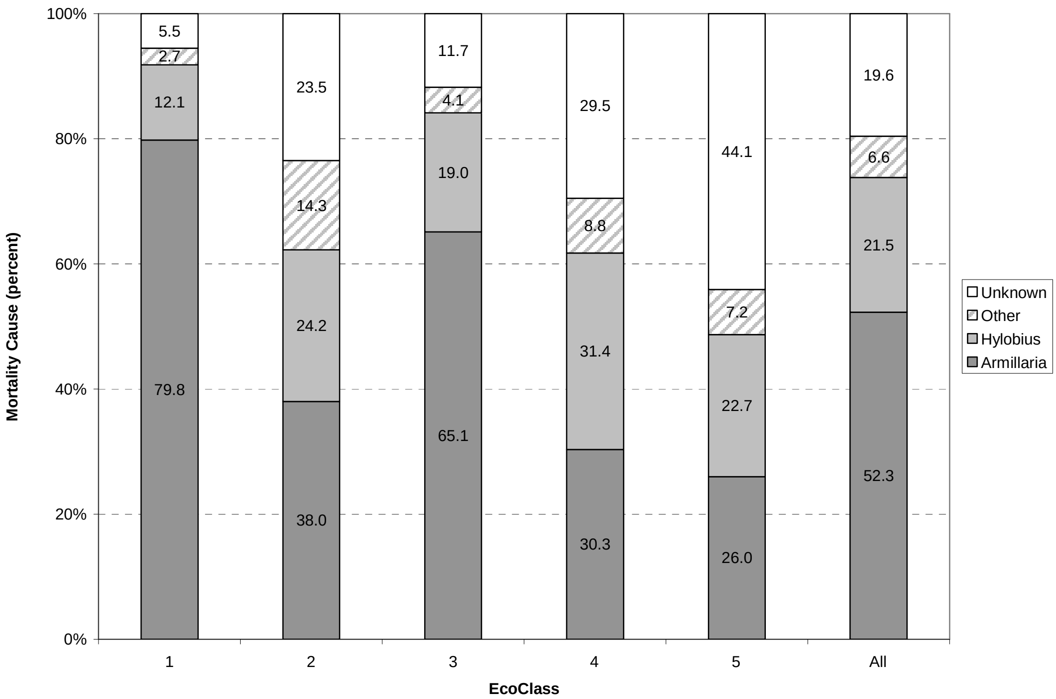
Table 8 and Figure 33 summarize mortality causes observed since 2007, broken down by ecological site class. *Armillaria* root disease and *Hylobius* root collar weevils are by far the most prevalent pathogens identified as causing tree mortality. The highest proportion of mortality attributed to *Armillaria* root disease was on the dry eco-class 1 sites and the lowest proportions were in the moist-wet classes 4 and 5. The highest proportion of mortality attributed to *Hylobius* was on the rich-moist ecosite 4 sites.

Table 8. Apparent causes of recent tree mortality

(percentage distributions in planted trees that have died since 2007)

Mortality Factor	EcoClass 1	2	3	4	5	Trial Average
Armillaria	79.8	38.0	65.1	30.3	26.0	52.3
Climate	0.7	0.3	0.7	0.3	0.0	0.5
Hylobius	12.1	24.2	19.0	31.4	22.7	21.5
Mammals	0.4	0.0	0.0	5.1	0.3	1.2
Rusts	1.1	2.8	1.4	1.3	3.6	1.7
Other	0.5	11.2	2.1	2.1	3.3	3.2
Unknown	5.5	23.5	11.7	29.5	44.1	19.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Figure 33. Distribution of predominant mortality factors by ecological site class



Mortality statistics demonstrate high and increasing levels of variation between installations. Although the difference in averages between ecological sites shown in Figure 27 are statistically significant, site class on its own does not explain a large proportion of the overall variation. However, when it is combined with mean annual temperature at the sample locations, a much higher proportion of the variation is explained. This relationship between mortality and climate has been analyzed and reported elsewhere in detail.[3]

3. Application of Results

Results have been incorporated into two regeneration models (one for planted stock[4] and one for natural regeneration[5]) predicting juvenile stand development up to 12 years following harvest. The models provide users options to adjust "default" projections based empirically on the trial data with their own local knowledge, such as may be obtained from stocking or establishment surveys. Interim projections for height growth, mortality and ingress beyond the current ages of stands in the trial were verified and adjusted against earlier research conducted by Johnstone[6], Ives and Rentz,[7] and Crossley.[8] These extended projections were made with conservative caution pending their replacement over the next few years as experimental data become available from scheduled measurements.

The high and persistent levels of tree mortality observed in the trial, related to pathogens and climate, have potentially important implications for silvicultural risk management. The strong relationship between mortality and mean annual temperature is being incorporated into the regeneration model, and could provide a simple and effective tool for assessing silvicultural investment risks, requiring knowledge only of location (latitude and longitude) and broad ecological site class to map or otherwise identify high risk sites.

Further documentation of trial results and regeneration models, and discussions regarding their development, application and implications, are scheduled for June 2010.

4. Recommendations for Trial Continuation

4.1. Maintenance

An issue has arisen with missing sample trees in natural regeneration (see Figure 32 and pertaining text). The prescribed tree tagging and maintenance protocol involves the use of "pigtails", each located in the ground 20cm north of its assigned tree, until trees are at least 2m tall. Given the high levels of ingress in many installations (see Figures 23 and 25) it is likely that there have been failures to distinguish previously selected sample trees from surrounding ingress.

The current protocol for trees over 2m tall is that they "*should be tagged either by affixing a tag to a lateral branch or, if the tree is less than 4m tall, the tag can be affixed to the main stem by a big-loop-tag that provides a minimum of 4 inches of diameter slack to allow for growth*."[9] It is recommended that in

[3] Effects of climate on mortality of immature planted and naturally regenerated lodgepole pine. *Foothills Growth and Yield Association Technical Note 2010-3.*

[4] RLPp: A Regeneration Model to Predict the Establishment and Performance of Planted Lodgepole Pine. *Foothills Growth and Yield Association Technical Note 2010-1.*

[5] RLPn: A Model to Predict the Establishment and Performance of Natural Regeneration Following Harvest of Lodgepole Pine Stands. *Foothills Growth and Yield Association Technical Note 2010-2.*

[6] Johnstone, W.D. 1976. Juvenile height growth of white spruce and lodgepole pine following logging and scarification in west-central Alberta. *Canadian Forestry Service Information Report NOR-X-171.*

[7] Ives, W.G.B. and C.L. Rentz. 1993. Factors affecting the survival of immature lodgepole pine in the foothills of west-central Alberta. *Forestry Canada Information Report NOR-X-330*.

[8] Crossley, D.I. 1976. The ingress of regeneration following harvest and scarification of lodgepole pine stands. *Forestry Chronicle* February 1976.

[9] Foothills Growth and Yield Association Regenerated Lodgepole Pine Trial: Field manual for measurements and maintenance, Version 3.0, July 2009

the non-planted installations this protocol should be extended to all sample trees as soon as they are robust enough to support a tag or loop.

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 5 years until all installations have reached a stand age of at least 14 years (see Table 4 for current stand ages). This will provide data for modeling the entire regeneration phase to the end of the regeneration survey age range permitted for performance assessment in Alberta. It will facilitate substantial and incremental improvements to the regeneration models every two years, starting with the first enhancement which will be possible after the detailed 2010 field measurements.

While detailed measurements every alternate year are acceptable for most variables, annual checks have proven invaluable for monitoring mortality incidence and cause. Although it is desirable that they be continued, some relaxation of this effort could be tolerated to achieve cost savings, without permanent loss of information.

In the 17 natural regeneration (non-planted) installations it is strongly recommended that annual mortality checks be maintained for the next 5 years. Ingress of natural regeneration has only recently become sufficiently advanced to commence monitoring of mortality. Mortality currently is very dynamic, and its initial assessment made difficult by missing trees. There is a risk of permanent loss of information if this is not addressed by checks in 2010, followed by continuing checks until trends can be identified.

In the 85 planted installations the choice of whether to continue annual checks logically depends on what importance members attach to improving mortality estimates (incorporated into the regeneration models) in one versus two years. Discontinuing the checks would delay feedback on some questions relevant to silvicultural risk management, such as: is mortality in planted stock persisting, increasing or decreasing, and why?

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. However, two additional sub-sampling tasks should be undertaken during the next 5 years and prior to any experimental thinning treatments being applied:

1. Seedlings are currently measured to the base of the terminal bud. A conversion to total height is required for linkage of the regeneration models to conventional growth and yield models, and will ultimately be required for continued inventory monitoring during the growth phase after year 14. The conversion will require a modest sub-sample of trees where both heights are measured. Probably 50 to 100 trees in each of the 5 site classes would suffice.
2. Monitoring of true stand top height requires identification, tagging and measurement of the 10 largest-DBH eligible trees per 0.1 ha plot, regardless of whether they are currently selected as sample trees.

4.3. Treatment

The project design calls for pre-commercial thinning of the designated treatment plots where natural regeneration has resulted in the target density being exceeded. While it is desirable to thin before significant crown-competition occurs, this operation should not be undertaken until ingress of natural regeneration is complete or at least declining, and irregular mortality has stabilized. In most plots both of these conditions has not yet occurred. The trial appears to be generally conforming to ingress trends earlier reported by Crossley[7] which suggest that ingress may continue up to 14 years after peaking at about 7 years.

On many installations mortality of planted stock shows no sign of declining, and trends of mortality in natural regeneration have not yet been confirmed. The experimental design, whilst suitable for assessing growth responses to thinning, may not be so suitable for monitoring responses of pathogens and pathogen-related mortality. This is because, while buffering between plots is adequate for growth responses related to availability of light and nutrients, the distances between measurement plots may not be sufficient to buffer spill-over of pathogen responses.

It is proposed to delay the main thinning treatment until 2013, subject to assessments of mortality, health, ingress and growth in 2010 and 2012. If concerns about suitability of the experimental design remain unresolved, and / or if costs are prohibitive, consideration could be given to applying the treatment to only a sub-sample of the currently scheduled plots. The main treatment could be usefully preceded by a smaller pilot thinning on a few of the most advanced plots in 2011 or 2012, which would allow fine-tuning of the prescription and budget.