Foothills Growth and Yield Association

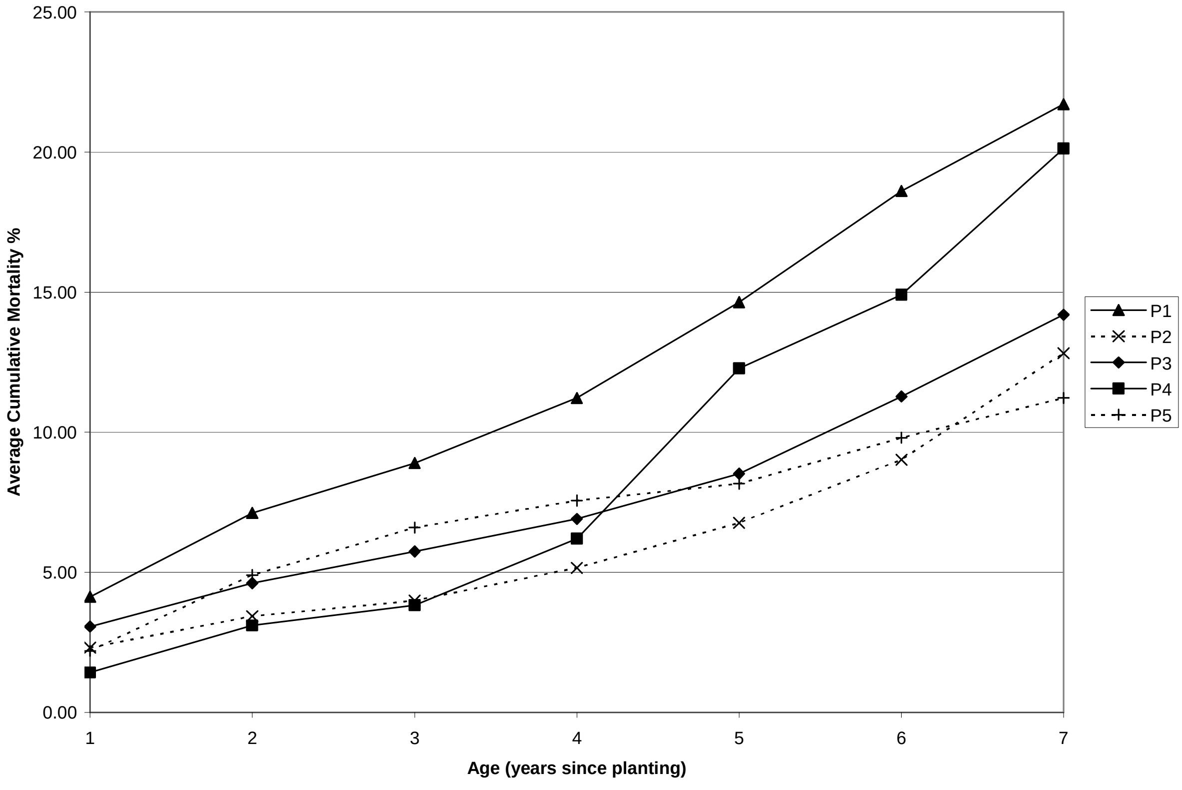
Technical Note 2010-3

Effects of Climate on Mortality of Immature Planted and Naturally Regenerated Lodgepole Pine

Introduction

An examination of tree mortality and its relationship to climate during the first 5 growing seasons of the Foothills Growth and Yield Association's (FGYA) Regenerated Lodgepole Pine (RLP) research trial was conducted based on climate data for the period 2001 to 2006. Results were preliminarily reported in 2009[1]. Concerns raised by the preliminary report over levels of early mortality in planted stock have been reinforced by continued mortality since 2006. Figure 1 shows cumulative mortality over 7 growing seasons. The average periodic mean annual mortality rate of planted stock in the RLP trial during growing seasons 6 – 8 increased relative to that during the first 5 growing seasons, and increasing mortality in natural regeneration was also observed in the latest measurements.[2] Previous published reports suggest that persistent mortality in juvenile lodgepole pine stands is not a new phenomenon.[3]

Figure 1. Mortality of planted stock in the regenerated lodgepole pine (RLP) trial
(see Table 1 for explanation of legend)



[1] Foothills Growth and Yield Association. Effects of Climate on Mortality of Young Planted Lodgepole Pine.. *Interim Technical Note*, February 2009.
[2] Dempster, W.R. 2010. Regenerated lodgepole pine trial, 2009 crop performance report. *Foothills Growth and Yield Association Technical Report*.
[3] 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*.

The RLP trial is not yet sufficiently advanced to fully assess relationships of climate to mortality in naturally regenerated stock, because the regeneration is still becoming established. Documentation and data were therefore examined from an earlier study by Ives and Rentz in west-central Alberta of survival in immature, predominantly naturally regenerated, lodgepole pine.[3] This also provided an opportunity to determine the extent to which the trends observed in the RLP trial could be replicated with independent data collected over a different time period, and over an extended range of stand age.

The analysis described below involved extension of the preliminary RLP analysis using data from the Ives and Rentz study, and re-examination of the RLP planted-stock data following field and data checks conducted during 2008 and 2009 to verify mortality levels and factors.

Methods

Table 1 describes the scheme used for grouping sample plot data from the two trials into common, or at least comparable, strata.

Table 1. Stratification scheme applied to sample plot data

Trial	EcoClass	Ecosite[4]		Regime		Vegetation	Stratum
		WC	SW	Moisture	Nutrient		
Ives and Rentz (**N**atural regeneration)	1	b, c	-	submesic	medium - poor	non-*Ledum*	N1
	2	d	-	mesic	poor	*Ledum*	N2
	3	e	-	mesic	medium	non-*Ledum*	N3
	4	f	-	subhygric	rich	non-*Ledum*	N4
RLP (**P**lanted stock)	1	b, c	b	submesic	medium - poor	non-*Ledum*	P1
	2	d	c	mesic	poor	*Ledum*	P2
	3	e	d	mesic	medium	non-*Ledum*	P3
	4	f	e	subhygric	rich	non-*Ledum*	P4
	5	h	f	hygric	poor	*Ledum*	P5

The RLP plots were planted between the summer of 2000 and the spring of 2002, as part of the installation of a large replicated trial to monitor harvest-origin stand development over much of the geographic range of lodgepole pine throughout Alberta, in relation to site (5 "eco-classes" – see Table 1), initial density of planted stock (5 classes from 816 to 4444 trees per ha), and vegetation control (2 classes: "weed" and "leave"). Periodic mean annual mortality percent for each sample plot was calculated and reported as the total number of trees that died during the 5-year period, divided by the number of elapsed growing seasons and expressed as a percentage of the initial density. No significant differences in mortality could yet be attributed to density and vegetation control. For the purposes of evaluating climate effects on mortality, vegetation treatment sub-plots were therefore merged at each plot cluster (vegetation treatments had been applied to split "clusters" or whole plots), and whole plots (clusters) planted at different densities were treated as replicates.

[4] WC = 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.
SW = Field guide to ecosites of southwestern Alberta, J.D. Beckingham, G.D. Klappstein, and I.G.W. Corns, *Can. For. Serv.*

ClimateAB, an Alberta version of the program ClimatePP [5] was used to generate climate data localized to each of 85 planted plot clusters over the 5 growing seasons from 2001 to 2006, based on input values for longitude, latitude and elevation. During the preliminary analyses described in the interim report[1] the correlations between mortality and 35 temperature and precipitation related variables, most of which were highly inter-correlated, were explored. Attention in the present study was confined to a single climatic variable, mean annual temperature (MAT), which had consistently demonstrated a good relationship with mortality in the preliminary study. For each plot cluster in the RLP trial, MAT was averaged for the period 2001 to 2006.

Mortality continues to be measured annually on the RLP trial, but analysis of its relationship to climate past the first 5 growing seasons is not yet possible because the ClimateAB has not been updated since 2006.

The Ives and Rentz plots were established to monitor survival of immature lodgepole pine in over 70 cutover areas in west-central Alberta. Three-year survival rates spanning a 9-year period from 1981 to 1990 were reported for most of the sampling areas. For the present study, these were combined to produce estimates of periodic mean annual mortality percent for the entire 9 year period. Locations (longitudes and latitudes) of sample areas were obtained from maps in the study report[3]. This provided spatially located mortality data for each sample area, which were distributed throughout regenerated stand ages ranging from 6 to over 30 years since harvest. The data could thus be assigned MAT values by application of the ClimateAB program, and analyzed and compared with the RLP data. Elevations (required for climate value estimation) were computed by the PRISM algorithm within the program. (Use of elevations recorded in the Ives data, based on altimeter or topographic map data, gave poorer results.)

The following points are noted regarding the Ives data and published information report:

- Ecosite data were provided for 28 of the 71 study areas used in our analysis during a re-examination of the data by J. Beckingham.[6] For areas where ecosite information was not available, strata were inferred from Ives' records of site productivity and drainage. Therefore the stratification may not be reliable.
- Mortality was calculated over the full 9-year period for most study areas, though a few are based on 6 or less years.
- Establishment of natural regeneration was assumed by Ives to have occurred 6 years after harvest.
- The data demonstrated no relationship between stand age and rate of mortality. Although the average rate of mortality was low, Ives expressed concern at the sustained level of mortality resulting from biotic damage.
- The average rate of mortality in the Ives study was about half that observed in the first 5 years of the RLP planted trial. Prior to the analysis reported below, it was variously speculated that the difference was attributable to sample tree selection (RLP tree selection was random whereas Ives confined monitoring to "crop" trees), drought conditions shortly after RLP planting, stress resulting from out-planting, poor planting practices, or inappropriate seed-lot allocation for planting stock.

Data for periodic mean annual mortality percent were not normally distributed. The arcsine transformation (which converts a binomial random variable into one that is nearly normal and whose variance depends little on the parameter p[7]) substantially removed the significant levels of non-normality,

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[5] Wang, T., Hamann, A., Spittlehouse, D., and Aitken, S. N. 2006. Development of scale-free climate data for western Canada for use in resource management. *International Journal of Climatology*, 26(3):383-397.

[6] Geographic Dynamics Corp. 1999. Juvenile lodgepole pine mortality – Re-examination of the Ives and Rentz mortality data. *Final Report* (commissioned by Weldwood of Canada)

[7] http://demonstrations.wolfram.com/TheArcsineTransformationOfABinomialRandomVariable/

kurtosis and skewness observed in the non-transformed data. Its use permitted application of standard least-squares statistical tests and methods, such as analyses of variance and co-variance, in assessing the response of mortality to climate and other factors.

Results

Figure 2 shows the relationship between MAT and mortality of natural regeneration in the Ives trial. The 3 extreme outlier circled, with periodic annual mortality rates exceeding 3.5%, were all recorded as having endured sustained mammal damage throughout the 9 year study period. They were excluded from significance tests and calculation of the trend line. Both the average rate of mortality and non-transformed mortality variation increased with temperature. The relationship between arcsine mortality and MAT was highly significant (prob>F <0.001), and MAT explained about 50% (unadjusted R-square 0.50) of the variation in arcsine mortality across all strata. The effect of stratum, which was statistically significant when MAT was ignored, was only marginally significant after MAT was accounted for by analysis of covariance.

Figure 2. Mortality and mean annual temperature – Ives and Rentz trial

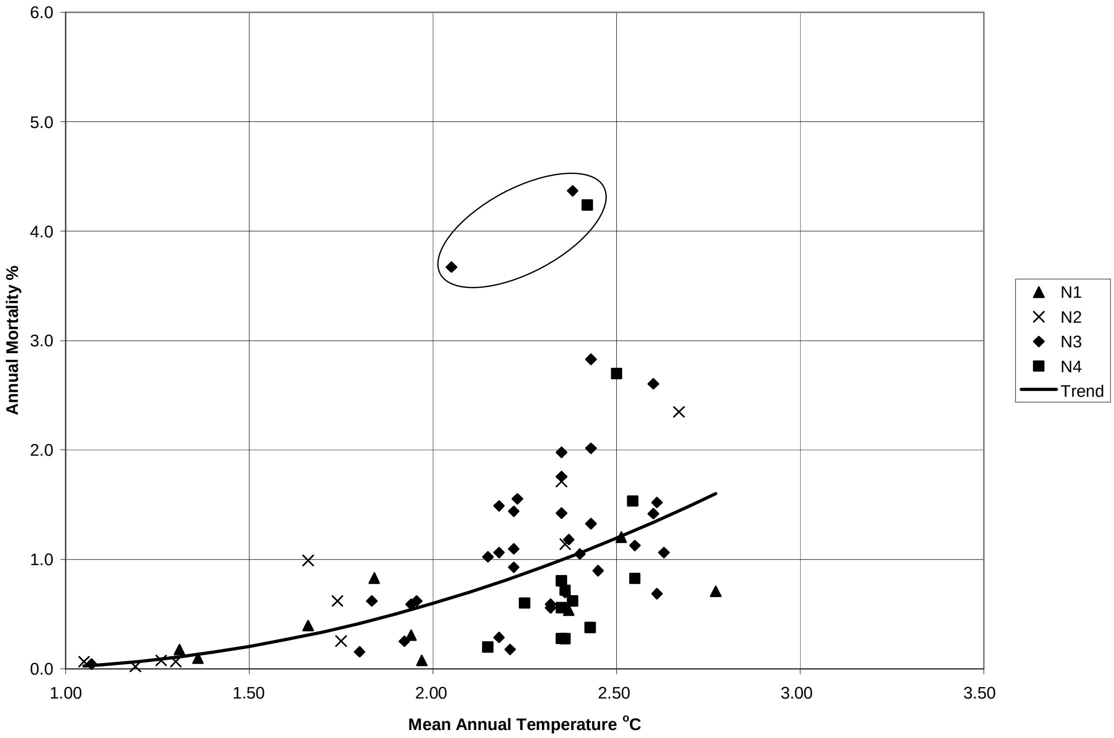
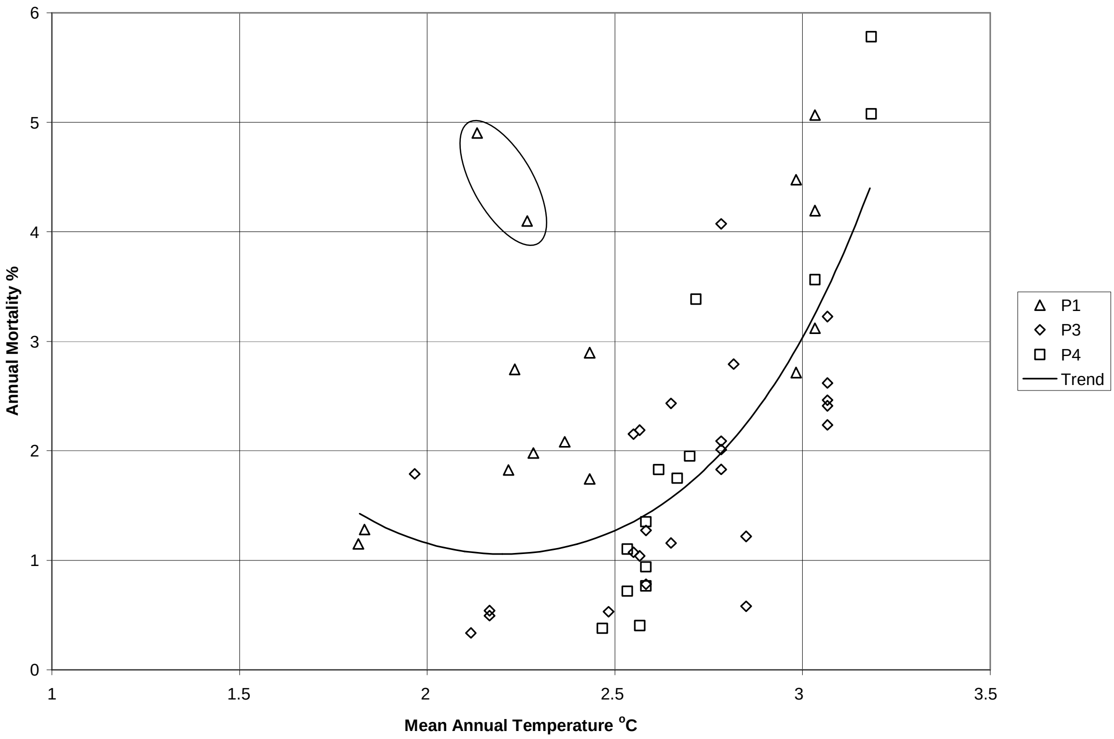


Figure 3 shows the relationship between mortality and MAT observed for non-*Ledum* sites in the RLP trial (i.e. strata P1, P3 and P4 in Table 1). The circled two most extreme upper outliers were omitted from statistical tests and computation of the trend line. (One had severe horse browsing; the other may have suffered from poor planting, as “J” rooting was noted.) The relationship between arcsine mortality and MAT was again highly significant (prob>F <0.001), and MAT again explained about 50% (unadjusted R-square 0.49) of the variation in arcsine mortality across all 3strata, and across all density and vegetation management treatments. It was noted that the level of mortality at a given temperature tended to be higher on the dry (P1) versus other sites. The majority of upper outliers belong to this stratum.

Figure 3. Mortality and mean annual temperature – RLP non-*Ledum* strata



An opposing trend was shown by planted stock on *Ledum* (Labrador Tea) sites, where mortality decreased with increasing MAT (see Figure 4 trend "P"). Such sites can be difficult to successfully plant with pine because of their cold wet soils. The effect was most noticeable in stratum P5 (hygric-poor ecosites), which is not represented in the Ives trial and may be marginal for natural regeneration of lodgepole pine.

Natural regeneration on the P2 (mesic-poor) *Ledum* sites in the Ives trial shows a clear upward trend with MAT (see Figure 4 trend "N"), in common with all other natural regeneration and all RLP planted non-*Ledum* strata. Because the anomalous decrease in mortality with MAT was observed only in the RLP (planted stock) data, and not in the later-age Ives data, it cannot be predicted whether the trend will persist over time, or will decline with years since planting. The negative trend was somewhat weaker (unadjusted R-square 0.43) than the positive trend shown by natural regeneration and planted stock on other sites, and examination of the latest RLP measurements suggests that it might be diminishing with age. The negative trend is represented by the equation:

Arcsine PMAM = 0.9836 - 0.660393*MAT^2
where:
PMAM = periodic mean annual mortality percent[8]
MAT = mean annual temperature in degrees C
(Equations for the positive trends in other strata are given below.)

Figure 5 illustrates trend lines, and the data from which they were calculated, based on analysis of covariance of combined data from both the Ives ("N") and the RLP ("P") trials. It includes all strata referenced in Table 1, except the anomalous planted *Ledum* sites (P2 and P5).

[8] Arcsine PMAM can be converted to PMAM by the formulae: PMAM = $(\text{sine}(\text{arcsinePMAM}/(180/\text{Pi})))^2*100$.

Figure 4. Opposing trends shown by Ives ("N") and RLP ("P") data on *Ledum* Sites

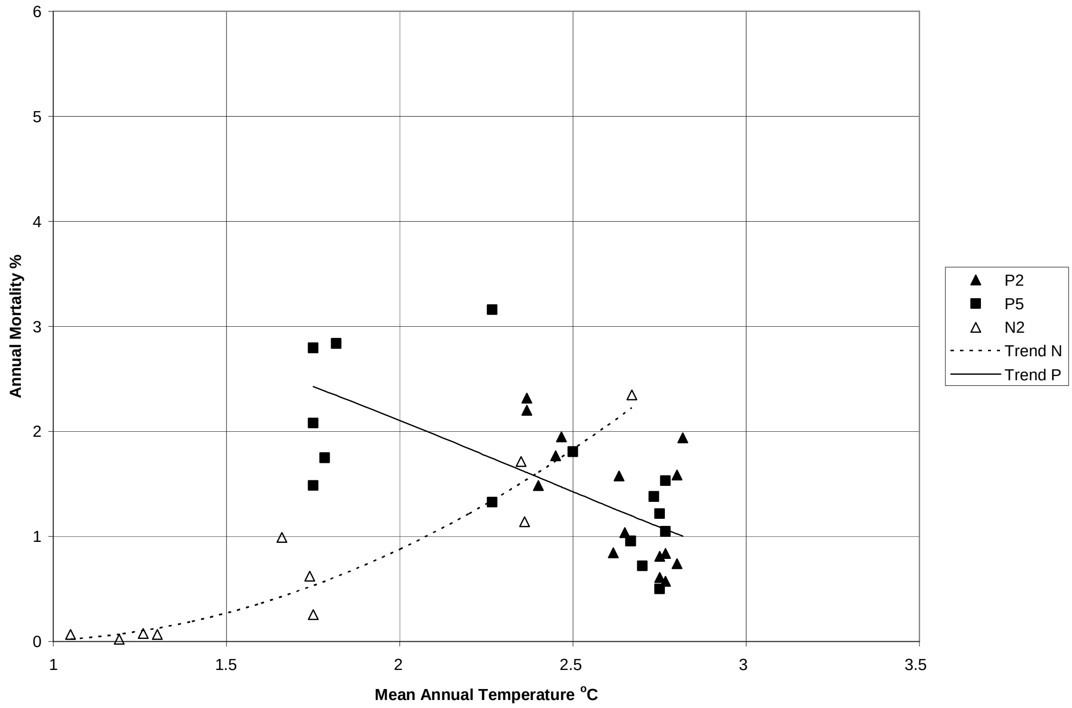
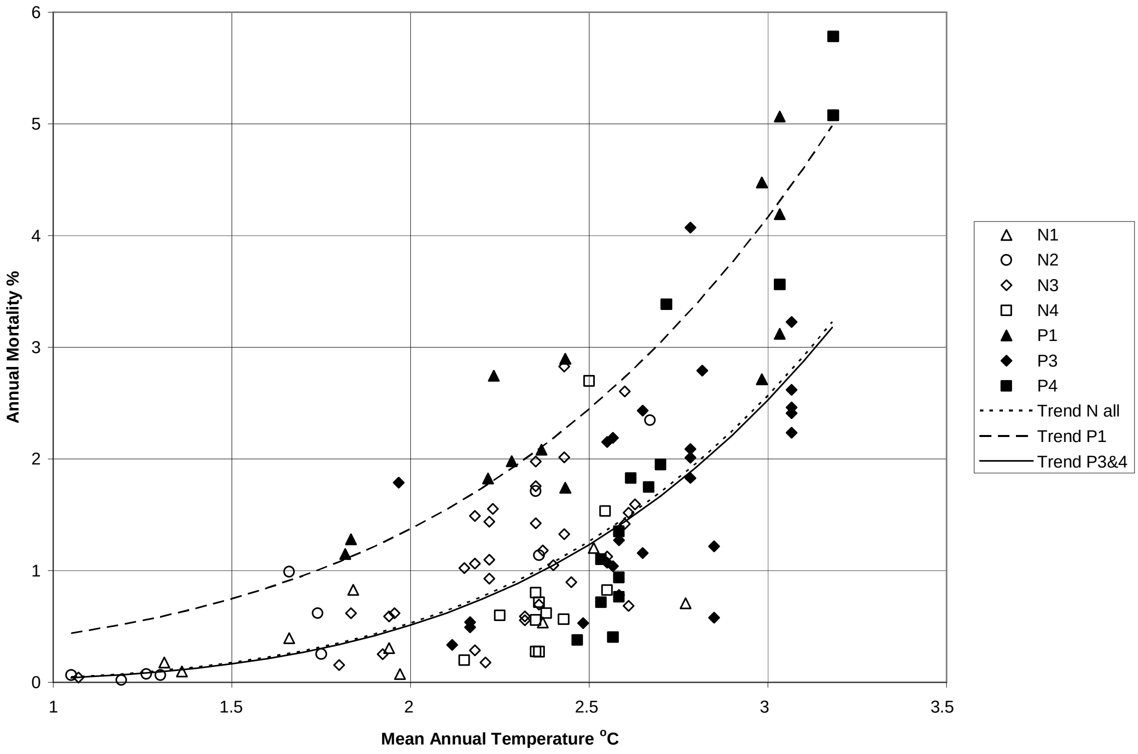


Figure 5. Mortality and mean annual temperature – Ives and RLP trials
(excluding planted *Ledum* sites)



One-way analysis of variance demonstrated a significant difference in mortality rates (normalized by arcsine transformation) between the two trials. However, the addition of MAT^2 (mean annual temperature squared) as a covariate partially substituted for the trial effect (difference between trials). When stratum P1 was removed from the analysis of covariance, the trial effect was totally substituted by temperature and was no longer significant.

Analyses of covariance, and testing of least squares means after adding MAT^2 as a covariate, showed stratum P1 to be significantly different from other strata, with higher levels of mortality at a given temperature. The resulting model explained about two-thirds of the overall variation in arcsine annual mortality percent (unadjusted R-square 0.66). It indicated almost identical trends on Ives naturally regenerated sites (all "N" strata) and RLP planted medium-to-rich sites (strata P3 and P4). The generally higher level of mortality in stock planted on dry sites (P1) was not shown by naturally regenerated stock on apparently similar (N1) sites. The trends shown in Figure 5 are represented by the following series of equations:

For all N strata: Arcsine $PMAM_N = 0.9693 - 0.8255*(1) + 1.7263*(0) + 1.008925*MAT^2$
For stratum P1: Arcsine $PMAM_{P1} = 0.9693 - 0.8255*(0) + 1.7263*(1) + 1.008925*MAT^2$
For strata P3 and P4: Arcsine $PMAM_{P3\&4} = 0.9693 - 0.8255*(-1) + 1.7263*(-1) + 1.008925*MAT^2$

In spite of the strong correlation between mortality and temperature observed in both the Ives and the RLP trials, probable causes of seedling death identified in the field were usually not directly attributable to climatic injury (e.g. drought, frost, wind, red belt), and more often were the result of biological pathogens. Ives attributed mortality primarily to mammals, gall and blister rusts, *Armillaria* root rot, and root collar weevils (*Hylobius*). Accurate observations of initial mortality causes in the RLP trial verified by forest health experts are not available; but in response to persisting high levels of mortality 5 years after planting, forest health specialists from the Alberta Department of Sustainable Resource Development inspected a number of the sites and provided comprehensive training in the recognition of health and mortality factors to field crews engaged in plot measurement. Figure 6 compares causes of mortality identified from the latest measurements of the RLP study during 2008 and 2009 (7 to 8 years after planting) with those from a subset of the Ives sample areas in which the natural regeneration was aged 10 years or less since establishment.

Both studies attributed high levels of mortality to *Armillaria* and *Hylobius*. The incidence of these two factors is higher in the RLP trial. Rusts and mammals were identified as additional causes of mortality in the Ives trial, but have not yet emerged as major factors in the RLP trial.

Figure 7 shows the main mortality causes observed in recent assessments of the RLP trial broken down by ecological stratum. The highest proportion of mortality attributed to *Armillaria* root disease was on the dry P1 sites and the lowest proportions were in the moist-wet P4 and P5 sites. This would appear to be consistent with the findings of Mallet and Maynard[9] who reported that *Armillaria* incidence increased significantly with increasing sand content of the soil surface mineral horizon and decreasing NH_4^+ concentration of the surface organic horizon. The highest proportion of mortality attributed to *Hylobius* was on the rich-moist P4 sites.

[9] Mallett, K.I. and D. G. Maynard. 1998. *Armillaria* root disease, stand characteristics, and soil properties in young lodgepole pine. *Forest Ecology and Management, Volume 105, Issues 1-3, Pages 37-44*

Figure 6. Mortality causes during the first 10 years after establishment – comparison between the Ives and RLP Trials

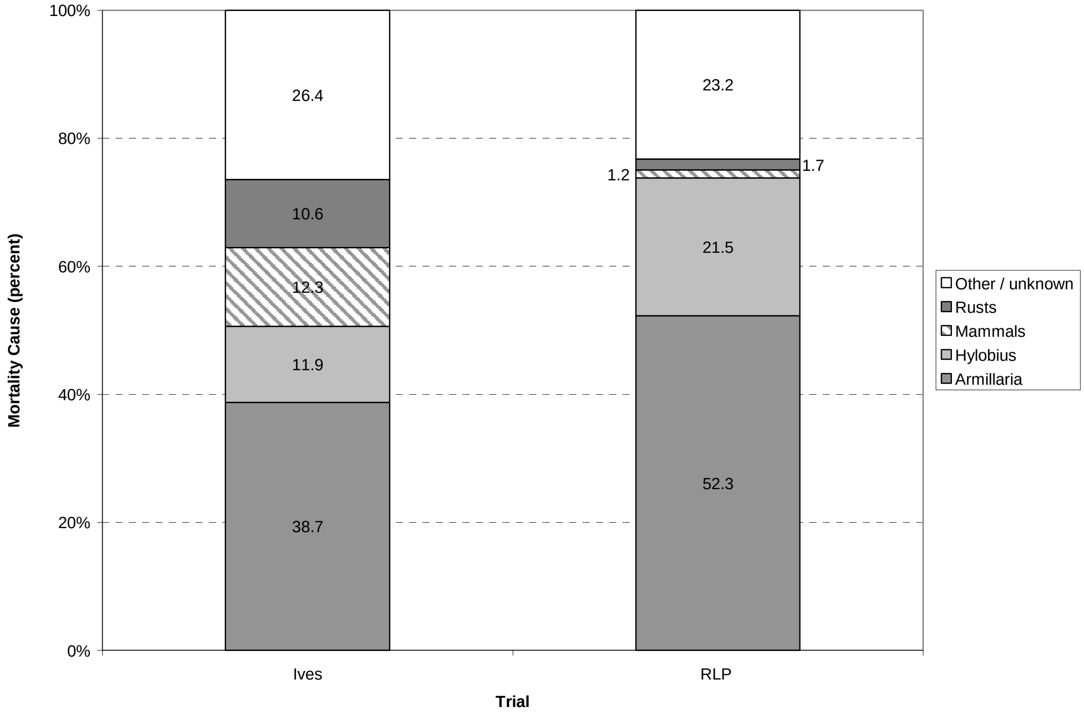
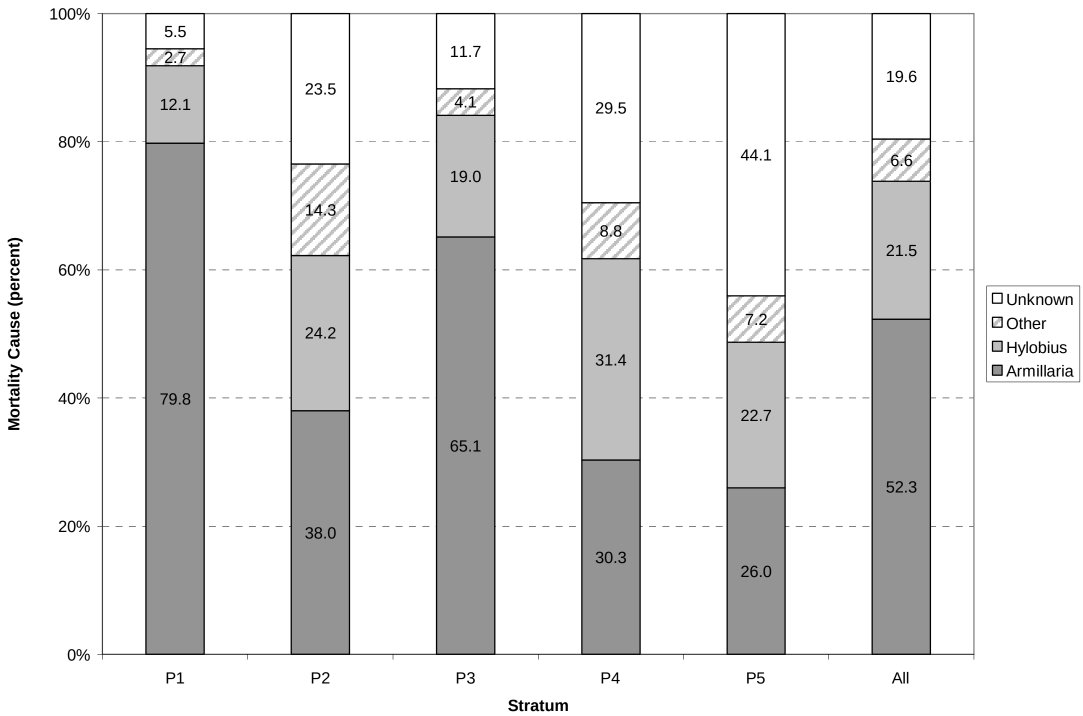


Figure 7. Distribution of predominant mortality factors in the RLP trial by stratum



Implications to Forest Management

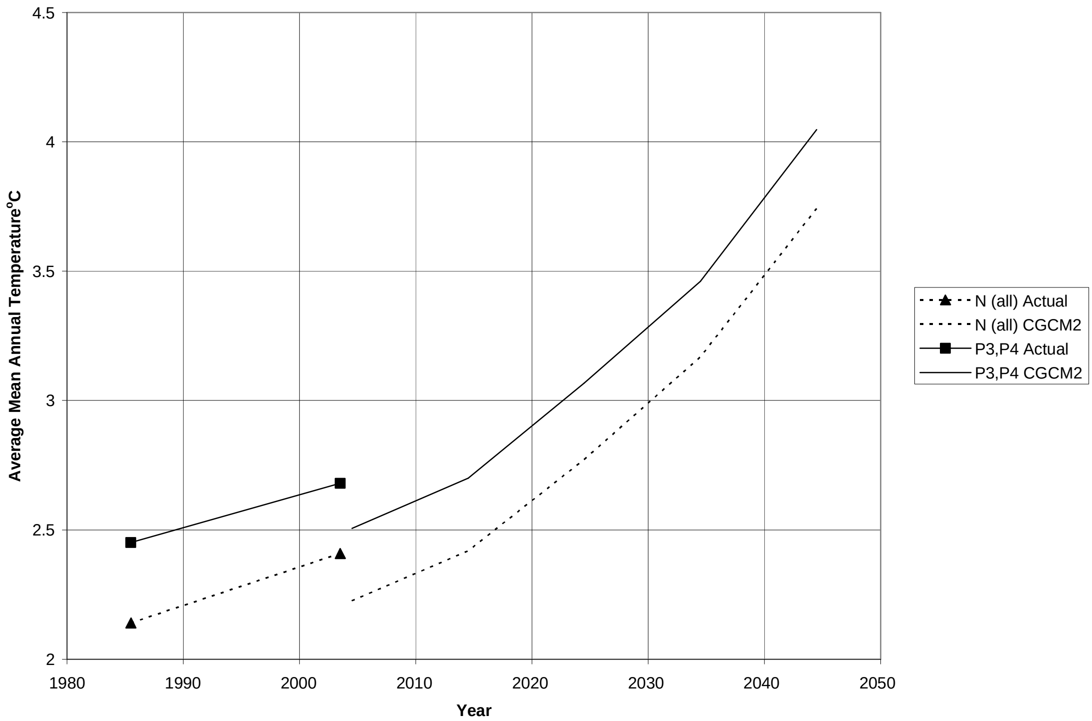
Because seedling death was usually not directly attributable to climatic injury, and more often was the result of biological pathogens, it appears probable that the effect of higher MAT, or more likely related climate conditions for which it is a surrogate, is to increase pathogen activity which in turn results in higher mortality, except (possibly) in planted stock on cold wetter sites.

The strong relationship between mortality and MAT 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. This could be supplemented by a decision-support system drawing on knowledge of pathogen behavior to identify appropriate strategies for mitigating potential problems. For example, on high risk sites practices (such as planting, brushing, or thinning) that are conventionally advocated to increase allowable cut, meet legislated regeneration standards, or even mitigate climate change effects, may be ineffective and counterproductive, as well as costly. Lower-risk and lower-cost alternatives on such sites may be (depending on the pathogens involved): delay or avoidance of planting, minimal brushing and thinning, and / or more reliance on natural regeneration.

Implications of Climate Change

The observed trends are potentially more onerous in the context of climate change. The steep increase in mortality associated with only small temperature differences shown in Figure 5 could be a serious threat if the trends observed across the landscape translate into similar trends with climate change over time.

Figure 8. Historic and projected average temperatures for Ives and RLP sites

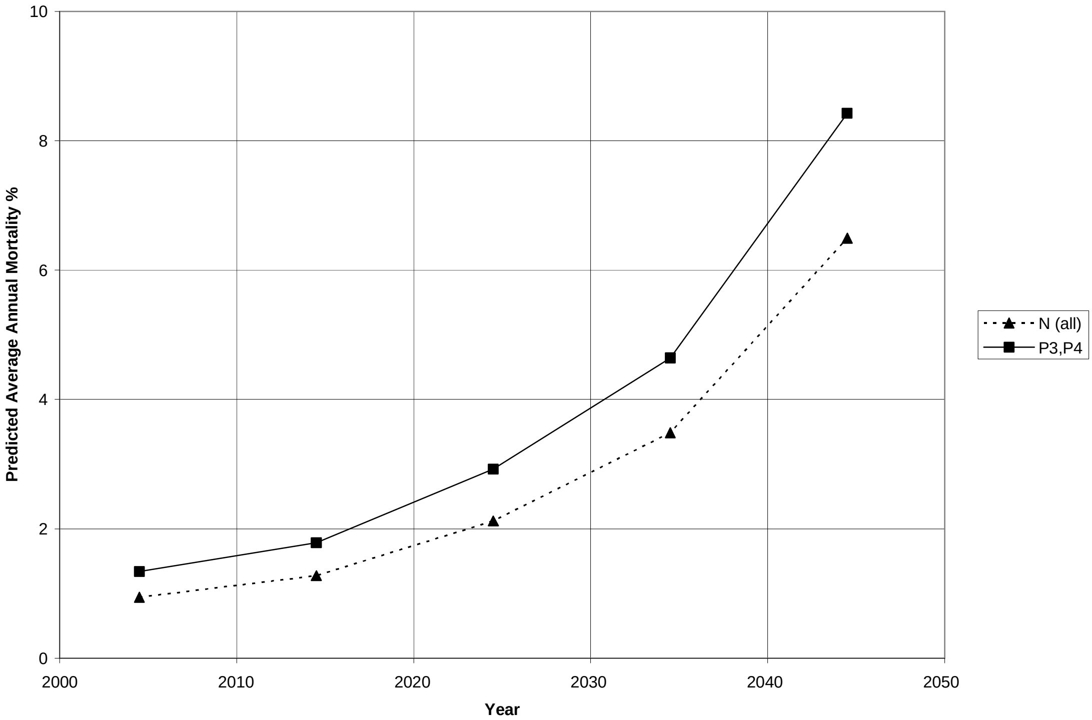


For example, Figure 8 shows historic and predicted temperature trends averaged across all strata in the Ives trial (N) and across the medium-to-rich RLP strata which showed the same (or a very similar) response to temperature. (The anomalous planted *Ledum* strata (P2 and P5), and the planted dry stratum

(P1) with higher levels of mortality, are not included.) "Historic" temperatures are shown for both trials for 2 periods: 1981-1990 (duration of Ives study), and 2001-2006 (the first 5 years of the RLP study). Projections of future temperature were made using CGCM2.[10] The average temperature of the RLP trial sites is higher than that of the Ives trial, primarily because the average elevation is lower in the former.

Figure 9 shows mortality levels for the same sites, predicted from the relationships between mortality and MAT shown by the "N all" and "P3&4" trend-lines in Figure 5, and the temperatures shown in Figure 8. The projections exclude the dry planted P1 sites where mortality rates are currently about twice those on modal RLP sites at a given temperature. (These sites usually incur very high levels of natural regeneration, and would not normally be planted.) Figure 9 also excludes planted Ledum sites, where mortality levels currently tend to be higher at lower temperatures, but could possibly decline with increasing temperature. (These sites, especially the wet P5 stratum, tend to be problematic for successful planting with pine because of their cold wet soils.)

Figure 9. Predicted average mortalities on Ives and RLP sites based on projected MAT increases



Note in Figure 9 that average mortality rates are predicted to double within 20 years, and increase by a factor of about 6 within 40 years. It is not yet known whether and to what extent these trends will be manifested, because the mortality response to temperature was calculated from contemporaneous observations across the landscape rather than actual changes over time. However, they reinforce the importance, already justified by current mortality levels, of paying more attention to forest health risks in the selection of silvicultural practices.

W.R. Dempster
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February 24, 2010

[10] Canada Centre for Climate Modelling and Analysis Coupled Global Climate Model, 2nd version.