Prince George Forest Region

Forest Resources & Practices Team

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Note #PG-12-3

The influence of planting density on the early performance of three sub-boreal tree species in the Prince George Forest Region

FOREST RESEARCH NOTE

EXPERIMENTAL PROJECT 660 - **31 Year Progress Report for the Chilco Creek Installation, Vanderhoof Forest District**

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Introduction

The choice of which tree species to plant following harvest and the density of planting are fundamental choices by foresters at the beginning of a rotation. These choices will influence not only the future options available to foresters, but also many of the final outcomes at subsequent harvest. They are also the two factors most easily controlled by the forester (Daniel *et al.* 1979).

Plantation density is know to have the greatest initial effect on mean tree size (quadratic mean diameter, also known as average stand diameters) and subsequently, if densities are high enough, on final yield at rotation (Daniel *et al.* 1979). However, density also strongly affects the height of the live crown. Stands grown at high density have live crowns concentrated in their upper boles. This results in trees with less taper and greater proportions of mature wood to juvenile wood when compared to trees grown at lower densities. It is rare in the Prince George Region for target stocking densities to go above 1200 stems per hectare (sph) (Anonymous 1993). Stands that are grown at such densities usually have very large live crowns, maintain live branches for long periods of time on the lower bole and have very large branch diameters. These characteristics can result in lower wood quality at final harvest.

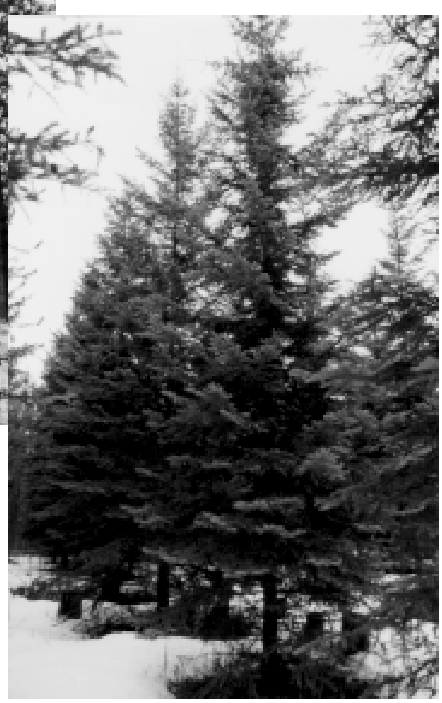

Photo 1: 3m x 3m lodgepole pine.
Photo 2: 3m x 3m white spruce.

The growth of both spruce and pine at Chilco Cr. was some of the best observed of the 3 EP660 installations.

Relative to other areas of British Columbia (BC) with more southern or coastal climates, foresters working in boreal and sub-boreal forests of north-central BC have relatively few species of conifers to choose from. More than 97.4 per cent of all the planting within the Prince George Region is accomplished with only two species; interior white spruce (*Picea glauca* [Moench] Voss) and lodgepole pine (*Pinus contorta* Doug. *ex.* Loud.) (Anonymous 1997). Together, these two species represent only 74.2 per cent of the volume of billed stumpage within the Region. Other species such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), sub-alpine fir (*Abies lasiocarpa* [Hook.] Nutt.), western red cedar (*Thuja plicata* Donn *ex* D. Don in Lamb.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) are under-represented in the numbers of seedlings replanted versus their billed volumes. We can interpret these data as indicative of a bias towards species which are know to have very fast initial growth following out-planting. Tree species that lack fast initial growth, those that have real or perceived problems at establishment with frost and other abiotic site factors, or those species which are utilised so seldom that little operational experience in growing or planting them exists have traditionally been avoided in the Prince George Region.

The bias towards fast initial height growth is understandable. In BC silviculture prescriptions must specify time lines for stands to reach a "free growing" condition following harvesting. A free growing stand is defined as "a stand of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees" (Anonymous 1995). Species with slower initial height growth will take longer to reach the minimum heights necessary to be declared free growing, or may require additional silvicultural treatments to reach free growing.

This bias may however have many unforeseen consequences. While tree species such as lodgepole pine do display very good initial growth, these species differences in growth rate often decrease dramatically the older the stands get (Bella and De Franceschi 1974). Species which display very fast initial growth also tend to be highly susceptible to pest and pathogen problems (e.g. red squirrel [Sullivan *et al. 1996]* and western gall rust [Van der Kamp 1981] damage to young lodgepole pine stands). Very often these agents damage trees well past the age that free growing is declared. Other species may indeed have slower initial growth, but offer much greater resistance to pests and pathogens. Over the course of a rotation it may be that resistance to a wide range of pests, pathogens and abiotic damage is much more important for the achievement of management objects than is initial growth rate

Experimental Project (EP) 660 is a long-term plantation study examining the influence of planting density (espacement) on the growth performance of white spruce, Douglas-fir and lodgepole pine. Established in 1967, this study is one of the oldest plantation studies in northern BC.

The Chilco Creek study area is one of three EP 660 installations surrounding Prince George. These three study installations were created at the same time using the same experimental methodology and planting stocks. Details on the EP 660 study rationale and methodology are reported in Research Note PG-12 (Coopersmith *et al.* 1997a). Results from the Buckhorn Ridge trial are summarized in Research Note PG-12-1

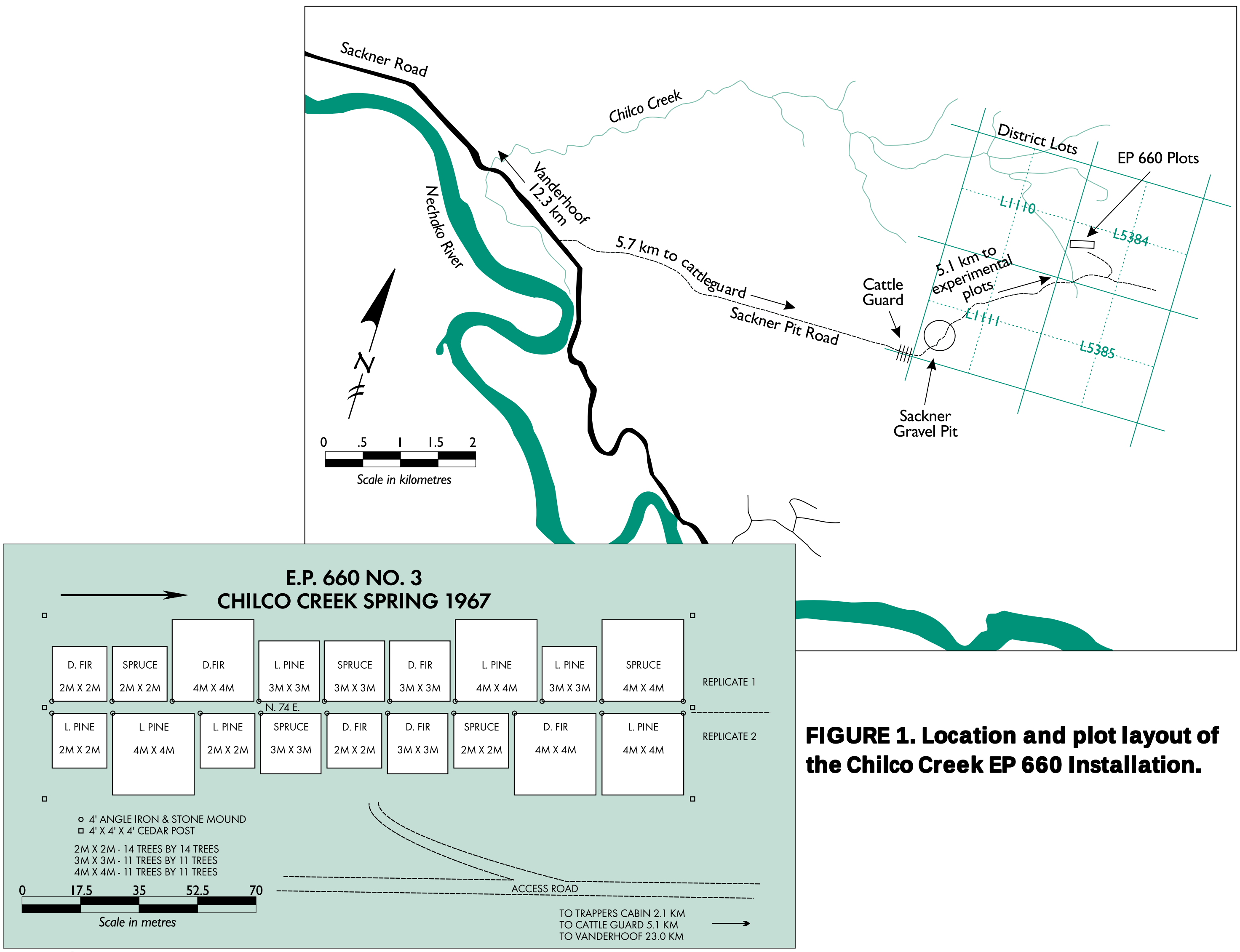

FIGURE 1. Location and plot layout of the Chilco Creek EP 660 Installation.

(Coopersmith *et al.* 1997b), while those for the Bobtail Road installation are summarized in Research Note PG-12-2 (Coopersmith *et al.* 1998) in this same series.

The Chilco Creek Study Area

The Chilco Creek study area is located approximately 65 km northwest of Prince George and 30 km northeast of Vanderhoof along the Sackener Road (figure 1). The study plots are located within district lot 5384 (123° 43' W, 54° 41' N, NTS grid map 093J-002). Mean elevation of the study area is approximately 760 m. Like the Bobtail Road study area, the Chilco Creek installation is located in the Stuart dry warm Sub-Boreal Spruce biogeoclimatic sub-zone. However, the Vanderhoof installation is moister than the Bobtail installation, and is located in the mesic to sub-hygric spruce - Pink spirea - Prickly rose site series ($SBS_{dw3/06}$, DeLong *et al.* 1993). Prickly rose (*Rosa gymnocarpa* Nutt.) Sitka mountain alder (*Alnus viridis* [Chaix] DC. spp. *sinuata* [Regel] Love and Love) and various willow species (*Salix* spp.) are the dominant shrubby vegetation on site.

Soils underlying the study area consist of complexes of fine-textured Orthic Grey Luvisols belonging to the Vanderhoof-Pineview-Barrett map complex (Dawson 1989). The fine-textured Vanderhoof and Pineview Soil Associations of this complex are formed from the clayey glaciolacusrine plain that was formed beneath the Vanderhoof glacial lake. At the old glacial lake margins, these glaciolacustrine deposits take on the gently rolling topography of the underlying drumlinized basal till. This basal till forms the stonier glacial till of the Barret Soil Association.

The rolling topography of this land form is evident at the Chilco Creek study site. The rooting depth of the soils here is shallow, generally less than 50 cm. Plot slop is negligible, although the drainage off the study area is to the north-west via Chilco Creek.

The original stands of white spruce were clearcut logged in the early Winter of 1964-65 and the site was broadcast burned in 1966. The area outside the research plots was left for natural regeneration, presumably for lodgepole pine. An interesting mix of pine and trembling aspen (*Populus tremuloides* Michx.) now occupies much of the area surrounding the trial. In fact, some of the best young pure stands of trembling aspen in the Vanderhoof district can be found in the stands adjacent to the study area. The study plots were laid out and planted in 1967.

Study Design and Measurement Schedule

The EP 660 trial uses a factorial design. Three planting espacements (factor 1; 2m x 2m or 2197 sph, 3m x 3m or 1076 sph, and 4m x 4m or 637 sph) were used for each of the three species (factor 2; lodgepole pine, white spruce and Douglas-fir). This 3 x 3 design results in 9 treatment combinations per replicate. Two replicates of 9 plots were used at each installation, resulting in 18 plots per installation (Figure 1). Treatments were assigned to plots randomly within replicates.

Treatments were planted as either 11 rows by 11 row or 14 rows by 14 rows depending upon available space. However assessments were confined to the middle 7 rows by 7 rows of trees, or 49 trees per species-x-spacing-x-replicate combination. This meant that all measurement plots were surrounded by a minimum of two buffer rows and a maximum of four buffer rows planted at similar espacements. The plantation was measured in 1977 (year 10), 1982 (year 16), 1986 (year 20), 1991 (year 25) and 1997 (year 31). However, growth measurements were adjusted by 2 years (for lodgepole pine and Douglas-fir) or by 3 years (for white spruce) to account for time since germination in the nursery. Analysis of height and diameter growth for the trial was performed using a repeated measures analysis of variance (ANOVA) procedure. Basal areas (outside bark) were calculated from measured diameters using standard formula (Wenger 1984). Total tree volumes were calculated using the equations for juvenile trees from Kovats (1977).

Complete brushing and weeding of the plots and boundaries took place in 1979, 1986 and 1997. During the first measurement in 1977 the trees were not numbered. In 1982, the study trees were tagged, but many of these original tags were lost. All trees in the plots were re-tagged in 1986. However, the pattern of live and dead trees within the plots dating back to 1982 has allowed us to positively match trees between measurement years regardless of tag number.

In the fall of 1997, the Douglas-fir at the Chilco Road installation were pruned to a height of 3 m, or to 50% of their live crown height where total height was less than 6 m. Both pruning saws and pruning shears were used, although the shears proved ineffective for the very large branch diameters in most of the stand and were soon discarded. The pruning saws, although slower than the shears, could reach much easier to the desired 3 m height and produced a much cleaner cut and smaller branch nub. Pruning was done to allow tag numbers to be attached at breast height to tree boles with 3 inch zinc-coated box nails, and to facilitate easier site visits and measurements which were becoming difficult because of the thick tangle of branches in most plots. Prior to the pruning, the tags on the Douglas-fir were strung from the lower branches with wire. Where these lower branches have died and broken off, some tags have been lost. The lodgepole pine on site were pruned in 1986. A similar pruning operation is currently planned for the white spruce plots in 1998.

Results

Table 1 and Figures 2 through 5 summarise the changes in heights and diameters and calculated volumes and basal areas that have been observed at Chilco Creek since establishment in 1967. Table 2 summarises the findings of the repeated measures ANOVA for changes in height and diameter with species and spacing at Chico Creek.

Effects of Species and Spacing on Top Height and Quadratic Mean Diameters

The most startling difference in tree growth between the Chilco Creek installation and the other two EP 660 installations (Bobtail Road and Buckhorn Ridge, Coopersmith 1997b, 1998) has been the very poor performance of Douglas-fir at Chilco Creek. Top heights and quadratic mean diameters (QMD) for this species are well below those at the latter two installations regardless of initial spacing (Top height is defined as the average height of the 10 tallest trees per hectare, quadratic mean diameter is the diameter of the tree of average basal area, Daniel *et al.* 1979). Even more dramatic than these growth differences, the rate of Douglas-fir mortality has been substantially higher at Chilco Creek than anywhere else in the EP 660 trial. Of the original 294 Douglas-fir planted at each site (49 trees/replicate x 2 replicate/spacing x 3 spacings) only 59.5% remain after 31 years at Chilco compared with 91.2% at Buckhorn and 93.9% at Bobtail after 30 years. The rate of loss observed in the Douglas-fir plots have also been steady since 1977 and are not the result of a single mortality event. All three espacements have lost substantial numbers of trees between the 1991 and 1997 evaluations (10 trees from 60 in the 2m x 2m espacement, 8 trees out of 76 in the 3m x 3m espacement and 4 trees out of 61 in the 4m x 4m espacement, Table 1). Patterns of mortality for the other two species were not significantly different at Chilco than they were at either Bobtail or Buckhorn.

Photos 3, 4, & 5: Although many individual Douglas-fir grew well at Chilco Creek, most of the trees of this species have been damaged by repeated frost events, resulting in short, stunted trees with multi-leadered tops.

From these data we can conclude that the Chilco installation is substantially different from Bobtail and Buckhorn with regards to Douglas-fir growth and survival. Why should this be so? The most likely answer to this dilemma is recurrent frost. Most of the remaining Douglas-fir at Chilco Creek show symptoms of repeated frost damage (photos 3 and 5). Some are so severely damaged that they resembled 2 m tall cabbages. Although both Chilco Creek and Bobtail Road are in the same biogeoclimatic sub-zone (SBS_{dw3}), they differ in several important ways. The Chilco Creek study area is located in the Nechako Plain physiographic area (Dawson 1989). At 760 m mean elevation, this is an extremely flat area with little topographic relief which was formed from the bottom of the Vanderhoof glacial lake. The areas' fine-textured soils and flat topography make them very suitable for agriculture, but also highly prone to frosts. In fact the management field guide for this site series recommends the avoidance of Douglas-fir in areas such as these because of the likelihood of frost damage (DeLong *et al.* 1993).

By comparison Bobtail Road is located within the Fraser Basin physiographic area (Dawson 1989). At 840 m a.m.s.l., this area has greater topographic relief and coarser soils. Cold air pooling is less likely on sites like these and frost events probably occur less frequently and with less severity than they do at Chilco. Summer drought and not frost is noted to be a particular hazard for regeneration on site series such as those for the Bobtail Road installation (DeLong *et al.* 1993).

The stands at Chilco Creek are well stratified by species in terms of both top height (P›.000, Table 2) and quadratic mean diameter (P›.001, Table 2). Not surprisingly, lodgepole pine contains on average both the tallest and the largest diameter trees in the plantation, followed by Douglas-fir and white spruce. The latter two species do not differ significantly in size from each other. The tallest individual lodgepole pine are now more than 15.8 m tall, with top heights between 13.9 m and 14.5 m depending upon espacement (Figure 2a). By comparison the tallest Douglas-fir at Chilco Creek are now only 12.6 m tall as compared with individuals as tall as 26 m at Bobtail Road. Top heights for Douglas-fir are now between 10.3 m to 9.0 m (Figure 2b). The tallest white spruce were measured at 12.7 m height with approximate top heights between 11.4 m and 9.4 m (Figure 2c). As for both lodgepole pine and Douglas-fir, the observed height growth for white spruce was less at Chilco than it was at Bobtail.

In comparison to top heights, there were smaller differences between species for quadratic mean diameters. Lodgepole pine again had the largest quadratic mean diameters, varying from approximately 13.2 cm and 18.7 cm respectively depending upon espacement (Figure 3a). Douglas-fir and white spruce were both substantially smaller than lodgepole pine. The quadratic mean diameters of Douglas-fir ranged between 12.7 cm and 14.3 cm (Figure 3b) while those for white spruce varied between 9.2 cm and 14.2 cm respectively (Figure 3c).

In contrast to the more obvious species effect observed at the Chilco Road installation, initial spacing did not have a significant effect on average height (p›.052, Table 2). After 31 years, there is virtually no difference in the top heights between espacements for any of the three species at the Chilco Creek installation. This reinforces the common silvicultural observation that height growth is set more by climate and soil than it is by plantation density, except at the extremes (both high and low) of stand density (Daniel *et al.* 1979).

Spacing did however have a very strong influence on diameter growth (DBH, p›.003, Table 2). All three species exhibited a strong inverse relationship between diameter growth and espacement. The largest quadratic mean diameter trees for all three species were found in the lowest density 4m x 4m espacements, followed respectively by the 3m x 3m and the 2m x 2m plot quadratic means. This same relationship has been shown for all commercial forest species in North America (Daniel *et al.* 1979).

Basal Area and Volume Changes over Time

Since basal area is directly related to diameter, it is not surprising that the basal area development of lodgepole pine is far ahead of that of both Douglas-fir and white spruce at Chilco Creek (Figure 3). It is similarly not surprising that the highest density plots have the greatest calculated basal areas. In the highest density 2m x 2m plots, lodgepole pine basal area (25.74 m^2/ha) is nearly double the basal area of white spruce (13.48 m^2/ha) and two and a half times the basal area of Douglas-fir (10.09 m^2/ha).

As was observed for lodgepole pine at Bobtail Road, the rate at which new basal area is being added to the lodgepole pine plots appear to have peaked, perhaps as early as the 15 year evaluation in 1981 for the 2m x 2m plots (Figure 4a). This shows that the highest density lodgepole pine have fully occupied the site (probably since 1981) and are now experiencing strong inter-tree competition. The graph for basal area for these plots is curvilinear downwards whereas all other graphs for the Chilco plots are either linear or are still trending upwards For both Douglas-fir and white-spruce, there is no sign yet that their rates of basal area increment have slowed (Figures 4b and 4c). The growth of individual trees on these plots is not yet limited by inter-tree competition.

Lodgepole pine plots contain substantially greater total volumes compared with both Douglas-fir and white spruce. Average total volumes in the 2m x 2m lodgepole pine are now more than 98.1 m^3/ha compared with approximately 18.7 m^3/ha for Douglas-fir and 21.2 m^3/ha for white spruce (Figure 5, Table 1). Mean annual increments for the highest density lodgepole pine plot are now more than 3 m^3/ha/yr, more than five times that of Douglas-fir (0.6 m^3/ha/yr) and nearly four times that of white spruce (0.8 m^3/ha/yr). Since volume calculations utilise both height and diameter components, the greater height of lodgepole pine would on average account for the greater observed amounts of volume for this species.

Periodic annual increments (PAI's) peak before MAI's do, and it would appear that the highest density lodgepole pine stands reached their maximum PAI's in the 1986-91 period. The PAI for these plots is now approximately 4.40 m^3/ha/yr, down from the maximum PAI values of 6.32 m^3/ha/yr recorded in the 1986-91 time period. The drop in PAI values signifies the point at which stands enter the stem exclusion phase of stand development. (Oliver and Larson 1990). Inter-tree competition is increasing to the point that we can expect to see additional mortality. The PAI values for all other stands at Chilco Creek are still increasing. Inter-tree competition in these stands is not yet severe enough for us to expect to see density-related mortality.

Comparison of Stand Density Indexes at Bobtail

It is often times difficult to compare the growth rates of stands of different species grown at different initial densities. This problem is often tackled by using various relative density measures or stand density indexes which are independent of site and age (Larson and Cameron 1986). Two of the most useful indexes are Reineke's Stand-Density Index (SDI) (Reineke 1933, [in Daniel *et al.* 1979]) and Curtis's relative density (RD) (Curtis 1982).

SDI is the oldest of the indexes and is probably the most commonly used in growth and yield literature. Reineke observed that all single-species, even-aged, fully stocked stands of the same quadratic mean diameter will have approximately the same number of stems/ha regardless of site quality or stand age (Daniel *et al.* 1979). Stands will differ in the amount of time necessary to reach a given quadratic mean diameter. Better quality sites will produce trees of larger diameter faster than will poorer sites. However, when they reach the same quadratic mean diameter, they will all have the same approximate density. The relationship of the natural log of density to the natural log of quadratic mean diameter has a near constant slope of -1.605 for many forest species (Larson and Cameron 1986) and can be used to compare stands at various stages of development. SDI for a given stand is the number of trees at equivalent relative density when the average dbh is 25 cm. For coastal Douglas-fir, the maximum observed SDI is 1510 trees/ha while several species of pine ranged in SDI values from a low of 1015 trees/ha (longleaf pine [*Pinus palustris* Mill.]) to a high of 2106 trees/ha (Ponderosa Pine [*Pinus ponderosa* Doug. ex Lawson & Lawson]) (Larson and Cameron 1986).

SDI has increased steadily in all plots at Chilco Creek since the first measurements in 1977. The maximum SDI observed at the Bobtail Road site was 675 sph for the 2m x 2m lodgepole pine plots. This is close to the maximum SDI observed at the Bobtail Road installation (722 sph, again for the 2m x 2m lodgepole pine plots, Coopersmith 1998) No other SDI at Chilco is close to the values observed for lodgepole pine. The greatest SDI for Douglas-fir also occurred in the 2m x 2m plots (287 sph) however these values were less than half the comparable values for lodgepole pine. Similarly, the greatest calculated SDI for white spruce (402 sph, 2m x 2m plots, Table 1) was also well below the SDI values for lodgepole pine.

The SDI's observed at Chilco are still well below the listed maximums found in the literature for Ponderosa pine, the pine species most similar to lodgepole pine. This should mean that the stands at Chilco will continue to grow with little additional mortality due to inter-tree competition.

Curtis's relative density measurement is similar to SDI except that it uses basal area and quadratic mean diameter in its' calculation. Values of RD range from 0 to 14 for coastal Douglas-fir. Like SDI, values of RD tend to increase over time, but can fluctuate widely as trees self-thin. Because very small trees can remain alive for long periods of time, they can drastically affect RD calculations. Events such as a heavy wind storms or dry summers, which tend to remove the smallest and most moribund individuals within stands, can cause very marked jumps in SDI (Larson and Cameron 1986).

The lodgepole pine 2m x 2m plots had the greatest RD at 7.09. For white spruce, the greatest RD was also found in the 2m x 2m plots at 4.44. The 2m x 2m Douglas-fir plots had the lowest relative density of any of the species at Chilco, with a calculated value of 3.08 (Table 1).

As for SDI, the observed RD values are still well below the values where we would expect to see self-thinning losses due to inter-tree competition. Larson and Cameron (1986) ran a simulated thinning experiment through the Tree and Stand Simulator model (TASS, Mitchell 1975). Starting with a plot of Douglas-fir planted to 1110 sph (3m square spacing) they thinned (by low thinning) to 361 sph at age 32 and 158 sph at age 47. At the time of the first thinning RD was 7.2. The first thinning reduced RD to 3.3. It subsequently recovered to 5.5 at the time of the second thinning, and was again reduced, this time to 2.7 by the second thinning operation.

Future Wood Values

One of the advantages of utilising higher plantation densities is that the live crowns of closely-planted stands lift faster than the live crowns in widely-spaced stands. The lower boles of densely planted stands will have smaller branch diameters and subsequently smaller knots when these branches die. The smaller live crown of very dense stands produce lower percentages of juvenile wood which normally translates to higher wood quality (Cannell 1985).

The crowns of lodgepole pine have lifted dramatically in the 2m x 2m plots at Chilco. In these plots, live crowns are now confined to crown positions between 5 m and 9 m above root collar. However, as density decreases, the live crown for this species increases dramatically. In both the 3m x 3m and the 4m x 4m plots there are live lower branches that start at the first branch (at approximately 2 m above root collar, the height limit of the 1986 pruning), Many of these branches now extend more than 3.5 m from the bole of the tree. Many branch diameters are now as large as 8 cm.

The crowns in the white spruce stands have not lifted appreciably in the first 31 years of the trial. Most trees have live crowns that extend to the ground. However, unlike lodgepole pine, most of the lowest live branches in spruce are quite small, the crowns are very columnar, and the branch diameters are not exceedingly large.

Little can be said about the effects of density on the live crowns of Douglas-fir at Chilco. Mortality has been so extensive in these plots and damage from frost to the remaining trees so widespread that little normal growth is now occurring in these plots. None of the Douglas-fir plots at Chilco have escaped this phenomenon. Very few of the individual live trees left in the installation have enough neighbouring trees surrounding them to cause the crowns to lift.

Despite the crown lift observed for lodgepole pine at higher densities, there has been little natural pruning of branches in these stands. Dead branches had to be manually pruned in order to produce clear boles.

Conclusions

- The overriding observation that one must take away from Chilco Creek is that this site is an exceptionally poor one for Douglas-fir when compared to either the Buckhorn installation or the geographically similar Bobtail installation. Substantial losses have occurred and continue to occur to the Douglas-fir at Chilco. Frost is the most likely candidate for this damage. Virtually every Douglas-fir on site shows recurrent damage from frost.

- There are clear differences between the 3 species in terms of height growth over the first 31 years of the trial. Lodgepole pine has performed the best of the three species, followed by white spruce and Douglas-fir, although the difference between the overall average top heights for the latter two species is negligible. The 1997 top heights of all three espacements of both white spruce and lodgepole pine were substantially taller than the equivalent 1996 top height estimates at either Bobtail or Buckhorn. It would appear that Chilco is a very good site for height growth of both lodgepole pine and white spruce. Interestingly, the largest quadratic mean diameters for these species were found at either Bobtail or Buckhorn, not Chilco Creek.

- Lodgepole pine is also the largest tree on site in terms of quadratic mean diameter. White spruce and Douglas-fir continue to lag far behind the former species in terms of diameter growth.

- The densities of trees tested at the Bobtail Road installation were not high enough to induce natural pruning in any of the three species tested. Given the target and minimum stocking standards of current planting in the Prince George Region (generally between 700 and 1600 stems/ha, Anonymous 1993) manual pruning will be necessary in most plantations if clear wood is the objective.

Photo 6: Most of the trees at the 3m x 3m and 4m x 4m espacements had live crowns which extended to the ground This Douglas-fir was pruned following the Fall 1997 evaluation.

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Table 1: Summary of the 30 year measurements for all 3 species at the Chilco Creek Installation of EP 660.

A: Lodgepole Pine

Year	**1977**			**1982**			**1986**			**1991**			**1997**		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	18	18	18	21	21	21	26	26	26	32	32	32
sample n	91	87	91	85	83	89	84	79	86	85	77	87	84	76	86
stems/ha	2040	956	592	1906	912	579	1883	868	559	1906	846	566	1883	835	559
average ht. (m) (se)	3.65 (0.24)	2.96 (0.24)	3.33 (0.24)	6.06 (0.38)	4.87 (0.38)	5.58 (0.37	8.09 (0.45)	6.96 (0.46)	7.80 (0.44)	10.66 (0.62)	9.36 (0.65)	10.28 (0.61)	12.16 (0.40)	11.49 (0.42)	12.52 (0.40)
top height[2] (m) (sd)	4.96 (0.15)	4.61 (0.21)	4.32 (0.23)	7.84 (0.41)	7.17 (0.35)	6.86 (0.26)	10.12 (0.53)	9.48 (0.44)	9.19 (0.35)	13.58 (0.55)	12.09 (0.57)	11.95 (0.51)	14.48 (0.33)	13.92 (0.49)	14.51 (0.66)
sample n[1]		60	81							84	76				
arithmetic mean diameter (cm) (se)		5.05 (0.46)	5.01 (0.40)	8.32 (0.51)	8.04 (0.52)	9.29 (0.50)	10.29 (0.65)	11.28 (0.67)	12.78 (0.64)	11.78 (0.87)	14.13 (0.91)	15.55 (0.85)	12.90 (0.90)	16.57 (0.94)	18.52 (0.89)
quadratic mean diameter (qmd) (cm)		5.23	5.16	8.51	8.67	9.58	10.49	11.87	13.00	11.99	14.59	15.83	13.19	16.99	18.71
basal area (m^2/ha)		1.42	1.10	10.85	5.38	4.17	16.28	9.6	7.42	21.26	13.96	11.13	25.74	18.95	15.37
Relative Density (RD) (ba/qm$^{d.5}$)		0.62	0.48	3.72	1.83	1.35	5.03	2.79	2.06	6.14	3.65	2.80	7.09	4.60	3.55
Reineke's SDI		77.62	47.04	338.04	166.66	124.19	467.20	262.61	195.70	586.05	356.44	271.83	674.76	449.21	351.07
Total Volume (m^3/ha)		6.08	4.51	19.71	8.60	6.86	40.14	21.11	16.96	71.73	41.04	34.29	98.14	66.86	57.25
mean annual increment (MAI) (m^3/ha/yr)		0.507	0.376	1.095	0.478	0.381	1.911	1.005	0.808	2.759	1.578	1.319	3.067	2.089	1.789
5-year periodic annual increment (PAI) (m^3/ha/yr)[3]				3.942	0.504	0.470	4.086	2.502	2.020	6.318	3.986	3.466	4.402	4.303	3.827

[1]Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2]Top height calculations are averages of the 100 tallest trees/ha. For the 2m x 2m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3m x 3m plots, the average is based on the tallest 9 trees. For the 4m x 4m plots, this average is based on the tallest 15 trees.

[3]5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth.

Table 1: Continued. **B: White Spruce**

Year	1977			1982			1986			1991			1997		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	13	13	13	19	19	19	22	22	22	27	27	27	33	33	33
sample n	93	97	96	90	92	92	90	90	93	90	88	92	89	86	93
stems/ha	2085	1066	624	2018	1011	598	2018	989	605	2018	967	598	1996	945	605
average ht. (m)	1.34	1.40	1.51	2.31	2.50	3.11	3.50	3.98	4.77	4.62	5.44	6.42	6.45	7.64	8.62
(se)	(0.24)	(0.23)	(0.23)	(0.37)	(0.36)	(0.36)	(0.43)	(1.43)	(1.43)	(0.60)	(0.61)	(0.60)	(0.39)	(0.40)	(0.38)
top height[2] (m)	2.38	2.51	2.44	3.99	4.12	4.82	5.72	6.17	6.95	7.10	7.53	9.07	9.43	10.42	11.35
(sd)	(0.24)	(0.42)	(0.22)	(0.40)	(0.79)	(0.40)	(0.48)	(0.69)	(0.40)	(0.69)	(1.04)	(0.60)	(0.61)	(0.72)	(0.59)
sample n[1]				85	87	90		88							
arithmetic mean diameter (cm)				2.54	2.98	4.03	4.39	5.42	7.22	6.57	8.42	10.36	8.83	11.89	14.22
(se)				(0.51)	(0.50)	(0.50)	(0.63)	(0.64)	(0.62)	(0.84)	(0.85)	(0.83)	(0.87)	(0.89)	(0.85)
quadratic mean diameter (qmd) (cm)				2.84	3.34	4.43	4.74	5.80	7.68	6.95	8.85	10.86	9.22	12.37	14.72
basal area (m^2/ha)				1.19	0.84	0.90	3.57	2.56	2.80	7.65	5.95	5.54	13.48	11.36	10.28
Relative Density (RD) ($ba/qm^{d.5}$)				0.71	0.46	0.43	1.64	1.06	1.01	2.90	2.00	1.68	4.44	3.23	2.68
Reineke's SDI				61.49	39.96	37.20	139.91	94.80	91.01	258.59	182.63	156.86	402.59	305.49	258.56
Total Volume (m^3/ha)				1.01	0.78	0.99	4.22	3.46	4.39	11.55	10.32	11.35	27.89	26.63	27.07
mean annual increment (MAI) ($m^3/ha/yr$)				0.053	0.041	0.052	0.192	0.157	0.200	0.428	0.382	0.420	0.845	0.807	0.820
5-year periodic annual increment(PAI) ($m^3/ha/yr$)[3]				0.202	0.156	0.198	0.642	0.536	0.680	1.466	1.372	1.392	2.723	2.718	3.144

[1] Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2] Top height calculations are averages of the 100 tallest trees/ha. For the 2m x 2m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3m x 3m plots, the average is based on the tallest 9 trees. For the 4m x 4m plots, this average is based on the tallest 15 trees.

[3] 5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth.

Table 2: Summary of the repeated measures analysis of variance (ANOVA) for height and diameter growth differences for the 3 species and 3 spacings at Bobtail Road. The repeated measures ANOVA was given REPxSPECIESxSPACING means as input terms rather than individual tree data in order to get the correct error term in the model. The reported F-values and probability tests are for the Wilkes-Lambda test which is the correct F-test for repeated measures analysis. Because only lodgepole pine has DBH recorded for the 1977 measurement, the repeated measures analysis was done on the 1981-1997 data. This results in reduced degrees of freedom (df) for this portion of the analysis. Analysis for height was done with 1977 to 1997 data for all species. Because the year x species x spacing interactin terms for height and DBH are not significant, the regression lines for species and spacing main effects are not parallel. The linear or quadratic regression lines of best fit are shown in Table 3.

Source	Sum of Squares	df	MeanSquare	F value	Probability[1]
DBH					
Year	665.018	3	221.673	398.040	0.000
Year*Species	5.786	6	0.964	6.856	0.001
Year*Spacing	21.646	6	3.608	6.010	0.003
Year*Species*Spacing	2.875	12	0.240	0.516	0.879
Error	6.633	27	0.246		
Height					
Year	503.792	4	125.948	939.770	0.000
Year*Species	30.242	8	3.780	11.186	0.000
Year*Spacing	2.390	8	0.299	2.815	0.052
Year*Species*Spacing	1.653	16	0.103	0.660	0.798
Error	3.750	36	0.104		

[1] Probabilities less than 0.05 are considered significant

Table 1: Continued. **C: Douglas-fir**

Year	1977			1982			1986			1991			1997		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	18	18	18	21	21	21	26	26	26	32	32	32
sample n	80	91	74	72	87	67	63	80	62	60	76	61	50	68	57
stems/ha	1794	1000	481	1614	956	436	1413	879	403	1345	835	397	1121	747	371
average ht. (m) (se)	0.88 (0.25)	1.19 (0.24)	1.21 (0.27)	1.61 (0.41)	2.06 (0.37)	2.22 (0.45)	2.55 (0.53)	3.12 (0.46)	3.43 (0.59)	3.68 (0.76)	4.79 (0.66)	4.95 (0.81)	5.73 (0.57)	6.87 (0.45)	6.96 (0.57)
top height[2] (m) (sd)	1.98 (0.19)	2.40 (0.43)	2.29 (0.27)	3.73 (0.27)	4.41 (0.68)	4.10 (0.57)	5.21 (0.23)	5.89 (0.77)	5.87 (0.83)	7.15 (0.60)	8.03 (0.90)	7.78 (0.94)	9.0 (0.88)	10.33 (0.83)	9.93 (0.84)
sample n[1]				39	59	48	43	67	51	49	72	58			
arithmetic mean diameter (cm) (se)				2.69 (0.86)	2.88 (0.62)	3.24 (0.87)	4.72 (1.01)	5.04 (0.73)	6.13 (1.05)	7.37 (1.19)	7.94 (0.94)	9.34 (1.19)	9.98 (1.27)	11.78 (1.00)	13.12 (1.27)
quadratic mean diameter (qmd) (cm)				3.06	3.26	3.75	5.10	5.75	6.88	8.10	8.96	10.47	10.70	12.61	14.25
basal area (m^2/ha)				0.65	0.54	0.34	1.97	1.89	1.23	5.65	4.92	3.24	10.09	9.34	5.91
Relative Density (RD) ($ba/qm^{d.5}$)				0.37	0.30	0.18	0.87	0.79	0.47	1.99	1.64	1.00	3.08	2.63	1.57
Reineke's SDI				55.44	36.35	20.75	110.18	83.09	50.81	220.37	160.86	98.20	287.13	249.04	150.51
Total Volume (m^3/ha)				0.52	0.55	0.36	2.26	2.51	1.81	8.18	8.85	6.06	18.7	21.24	13.94
mean annual increment (MAI) (m^3/ha/yr)				0.029	0.031	0.020	0.108	0.120	0.086	0.315	0.340	0.233	0.584	0.664	0.436
5-year periodic annual Increment (PAI) (m^3/ha/yr)[3]				0.104	0.110	0.072	0.348	0.392	0.290	1.184	1.268	0.850	1.753	2.065	1.313

[1]Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.
[2]Top height calculations are averages of the 100 tallest trees/ha. For the 2m x 2m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3m x 3m plots, the average is based on the tallest 9 trees. For the 4m x 4m plots, this average is based on the tallest 15 trees.
[3]5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth..

Table 3: Summary of regression analysis and equations of best fit for the prediction of average height at Chilco Creek. The equations can be linear or quadratic and were produced using a backward step wise regression procedure. The r^2 values is the proportion of variability observed in the data that is accounted for in the model. These equations lack a constant. This forces the lines through the origin, which is biologically more intuitive than regression lines with constants.

Effect	Level	Equation	r^2
species	lodgepole pine	$ht = 0.01\,(age^2)$	0.97
	white spruce	$ht = 0.04\,(age) + 0.01\,(age^2)$	0.98
	Douglas-fir	$ht = 0.01\,(age) + 0.01\,(age^2)$	0.96
spacing	2m x 2m	$ht = 0.23\,(age)$	0.80
	3m x 3m	$ht = 0.24\,(age)$	0.89
	4m x 4m	$ht = 0.25\,(age)$	0.87

Figure 2. Changes in top height over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

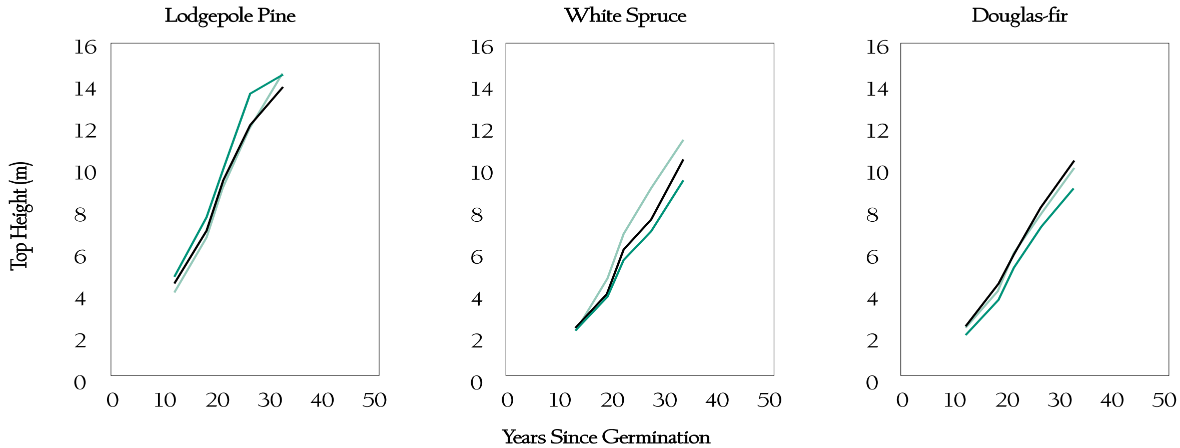


Figure 3. Changes in quadratic mean diameter over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

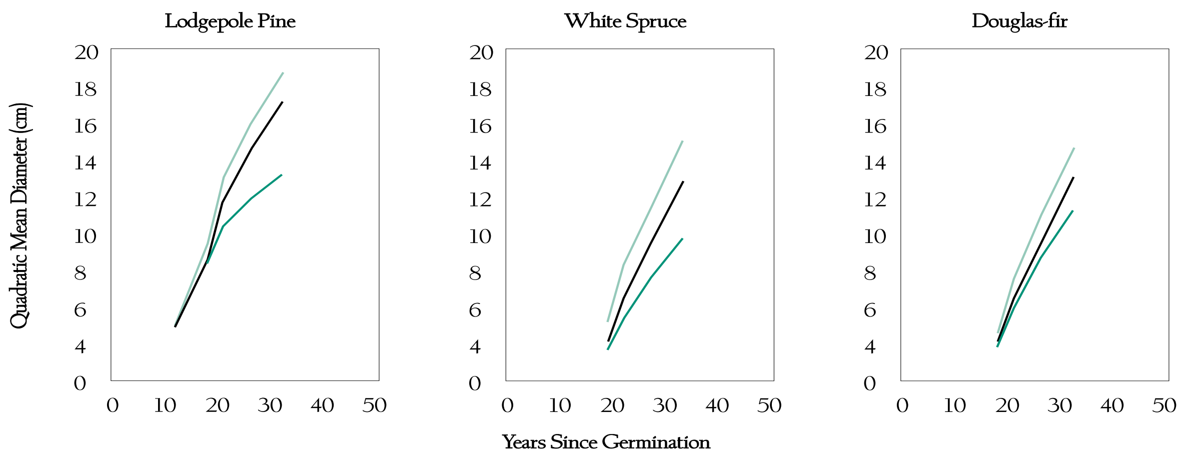


Figure 4. Changes in summed basal area over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

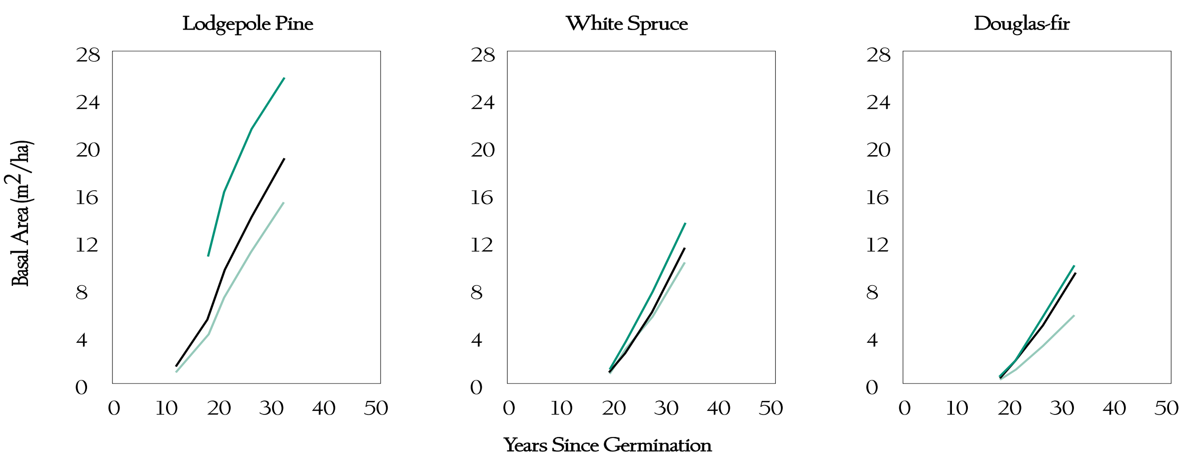
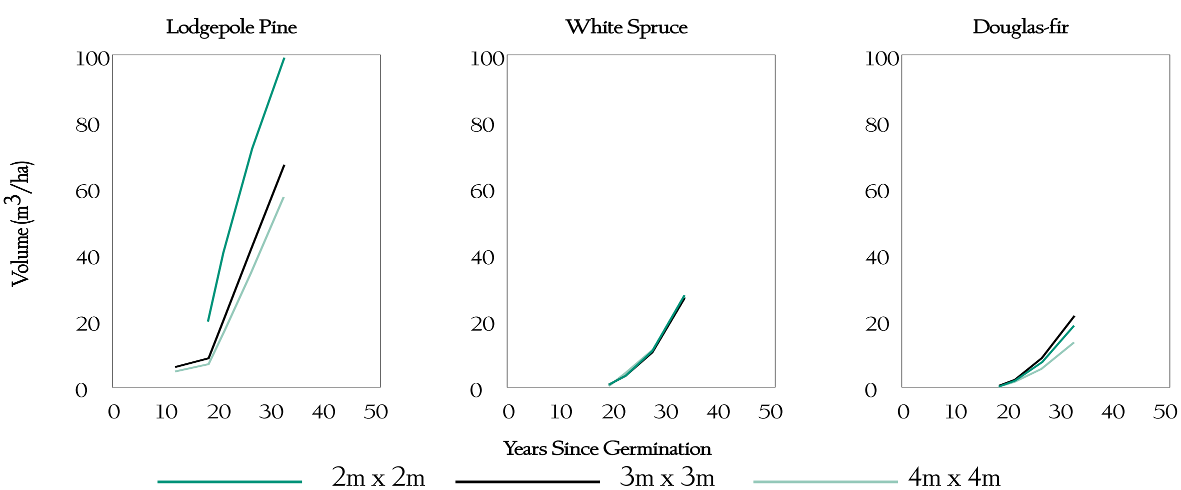


Figure 5. Changes in summed total volume over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.



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