Stand Density in Relation to Biological Functions in Young Western Larch Forests

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Introduction

Dynamic change—that is what we see in the establishment and development of western larch (*Larix occidentalis*) forests. Spawned by traumatic events such as fire, harvesting, or post- harvest treatments that prepare receptive seedbeds, larch regenerates promptly and more often than not, excessively over much of its natural range (Schmidt and others 1976).

Excessive stocking eventually proves to be a forest management problem for this seral species because it impedes tree development in the competition for light, water, and nutrients (Seidel 1986). The effects of this intertree competition are already apparent in stands less than 10 years old, and if left unattended, the dynamic juvenile growth gradually diminishes and the long slow process of natural selection and perturbation of biological and physical factors predominate. Forest managers seldom have the luxury of waiting for this natural process and as a result seek treatments that extend the dynamic juvenile growth of larch, capitalizing on its inherent potential.

The need for information about the natural and regulated stand development of young larch forests spawned the long-term spacing study described in this paper. Results presented here are brief summaries of tree growth and a wide variety of related phenomena that occurred during the 30-year period of this study in western Montana, U.S.A.

Methods

Information in this paper comes from the first 30 years of a long-term study installed in 7- and 9-year-old western larch at four locations in western Montana (Schmidt 1961, 1978). Two sets of plots were installed at Coram Experimental Forest, one set at Cottonwood Lakes about 150 km south of Coram, and another set at Pinkham Creek near the U.S./Canada border about 150 km northwest of Coram.

Ecological habitat type (Pfister and others 1977) was the same at all four locations—*Abies lasiocarpa / Clintonia uniflora*. Elevation at Coram 1 and 2 averaged 1,165 m, Cottonwood 1,615 m, and Pinkham 1,485 m. Site indices at 50 years were about 18 m at Coram 1 and 2, 16 m at Cottonwood, and 21 m at Pinkham.

Initially, these young stands were thinned to densities ranging from 272 to 6,718 trees/ha. The core study design was the same at the four locations. A subset of that design included paired plots to evaluate effects of shrub removal on tree development. In addition to the core design, unthinned and more widely spaced plots were established at the two Coram locations.

Individually tagged trees were measured at 5-year intervals on all the 0.04 hectare measure plots located within a buffer area of about 0.4 ha thinned to the same density. Height, diameter, and crown dimensions were measured, and tree conditions affected by biological and physical factors were recorded. During the 30-year period discussed in this paper, additional studies were superimposed to capitalize on this basic factorial design, as were adjunct studies related to this basic design.

Results

This paper reports some of the normal growth dimensions such as height and diameter. Greater emphasis, however, is being placed on describing those factors that were associated with stand development in these regulated young larch forests, information not often recorded in long-term studies such as this.

Crown Development

Crowns are the production factory for the tree, and they reflect western larch's sensitivity to shading at different levels of stand density. This sensitivity results in relatively consistent crown shapes—the upper portion a long-tapered cone and the lower portion an inverted but short-tapered cone. Crown dimensions related closely to stand density in length, width, and height to the widest part of the crown (Schmidt and Seidel 1988). Coram 1 vividly illustrated this (Figure 1).

Absolute crown lengths, even on the 494 largest trees per hectare , responded to stand densities. Crowns at 39 years on Coram 1 were longest on the least dense stands, disproportionately so on the 494 largest trees per hectare (hereafter referred to as crop trees). On these comparable crop trees, crown lengths varied from about 5.8 m on those in the unthinned plot to 11.6 m where the stand density was 494/ha. As shown, crown lengths were proportional to stand density but higher crown ratios (crown length/total height) were skewed toward the stands 494 trees/ha or less (Table 1).

In open-grown stands with 272 trees/ha on Coram 1, crown ratios declined relatively slowly during the age period 9 to 39 (Figure 2). For example, at age 9 immediately after thinning

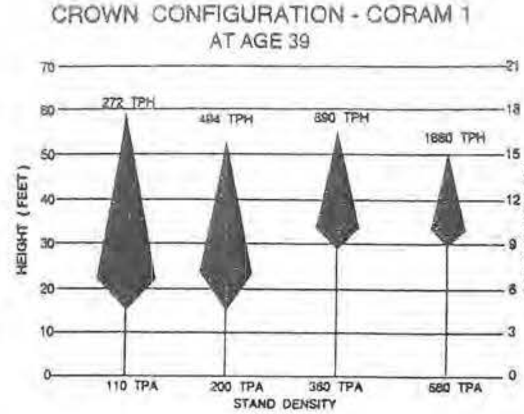

Figure 1.
Effect of stand density on crown configuration, Coram 1.

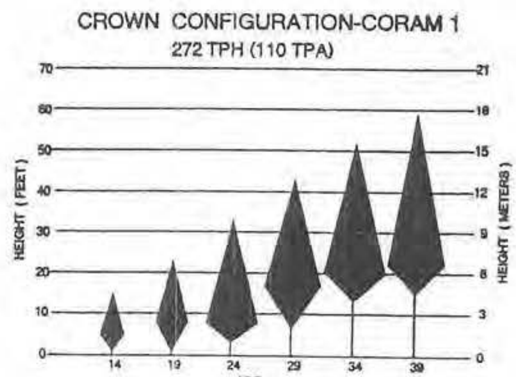

Figure 2.
Crown development of larch in open-grown stands up to age 39, Coram 1.

Table 1.
Effects of stand density on crown length and ratios at age 39, Coram 1

Stand Density (trees/ha)	**Crown Length** (m)	**Crown Ratio**
Unthinned	5.8	44
1,680	7.9	46
890	9.1	49
494	11.6	71

crown length to height ratio was 88. At age 19, 29, and 39, the ratios were 95, 88, and 68, respectively. Crown size, even of the preselected crop trees, deteriorated steadily on the unthinned plots (Figure 3).

Crown widths were also sensitive to stand density. Lateral shading limited the outward extension of the crowns in proportion to stand densities and stand age. As indicated in Figure 4 , none of the crowns occupied the full spacing allotted to them at age 19, but by age 29 and even more so at age 39, nearly all the crown space allotted was occupied in stands where densities averaged 890 trees /ha or more.

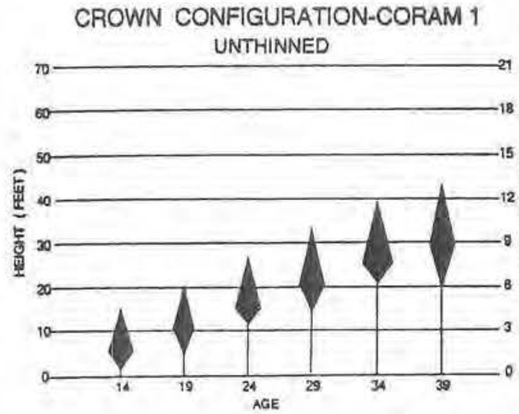

Figure 3.
Crown configuration of pre-selected crop trees in the unthinned stands, Coram 1.

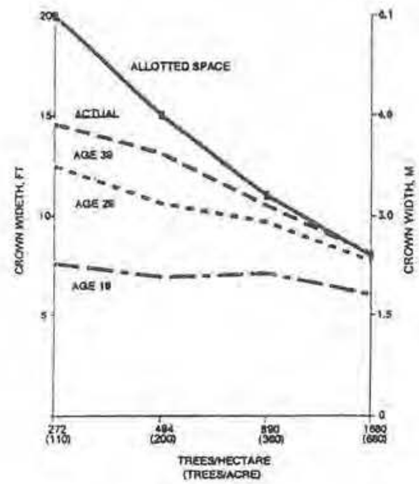

Figure 4.
Relationship of actual crown width development over time to spaces allotted for different stand densities.

Diameters

Diameter is characteristically the dimension most sensitive to stand density, and that certainly has been consistent in this larch study (Schmidt 1989). Using the Coram 1 location as an example, low stand densities of 272 trees/ha produced 25 cm trees and stands with 494 trees/ha produced trees of nearly 20 cm by age 39. Meanwhile, their pre-selected crop-tree counterparts on the unthinned plots reached only about 11 cm (Figure 5). Intermediate densities of 890 and 1,680 trees/ha produced intermediate size trees.

A comparison of diameter growth at the four locations but at the same stand density showed only modest differences between Coram 1, Coram 2, and Pinkham. Only the Cottonwood plots reflect substantial differences (Figure 6). Trees on the plots with 494 trees/ha at the three locations of Coram 1, Coram 2, and Pinkham have essentially paralleled each other during the 30-year period. Cottonwood is a lower quality site on an alluvial fan and has consistently grown at a slower rate.

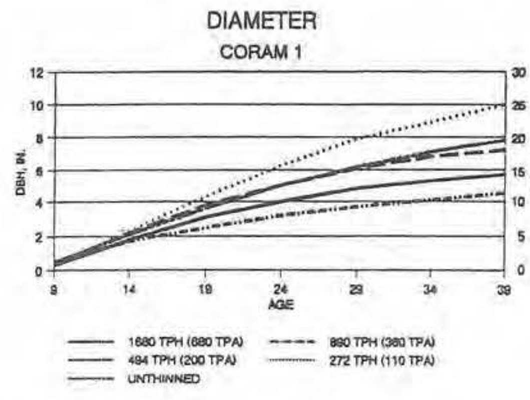

Figure 5.
Diameter growth of larch under a range of stand densities to age 39, Coram 1. Pre-selected crop trees are used for the unthinned plot.

Height

Height relationships are essentially the same as those illustrated for diameter, but the differences between stand densities are less pronounced (Figure 7). Again, using Coram 1 as an example, height growth differences under the various densities have been relatively modest, except for those pre-selected crop trees in the unthinned plots. Trees in the thinned plots average about 16 m at age 39 while their counterparts in the unthinned areas are about 13 m—about a 20 percent difference.

There was little difference in height growth of trees in plots with 494 trees/ha on the three locations of Coram 1, Coram 2, and Pinkham, averaging about 16 m at age 37-39 (Figure 8). The lower site quality at the Cottonwood location is readily apparent in the height growth differences, growing about three-quarters as fast as those on the other three locations. However, as discussed later, budworm damage at Cottonwood may account for some of these height growth differences.

Volume

Age, stand density, and location strongly influenced cubic volume produced on the larch spacing study plots. Stands with the most trees produced the most cubic volume. Using Coram 1 as an example, cubic volume in the stand with 1,680 trees/ha reached 175 m³/ha by age 39, with growth distributed on more but smaller trees (Figure 9). This relates closely back to crown occupancy shown in Figure 4. Trees in this stand density had near-complete crown closure. Stands with 494 trees/ha produced about 90 m³ on fewer but larger trees.

Locations, with their different site qualities produced different cubic volumes (Figure 10). Comparing growth of trees growing in the same stand density of 1,680 trees/ha at all four locations vividly demonstrates the different growth potentials as affected by site quality. Pinkham led the parade in volume production followed by Coram 1, Coram 2, and Cottonwood.

Shrub Removal

To evaluate the effects of major shrub species competition on the early development of larch, paired plots with shrubs removed and shrubs

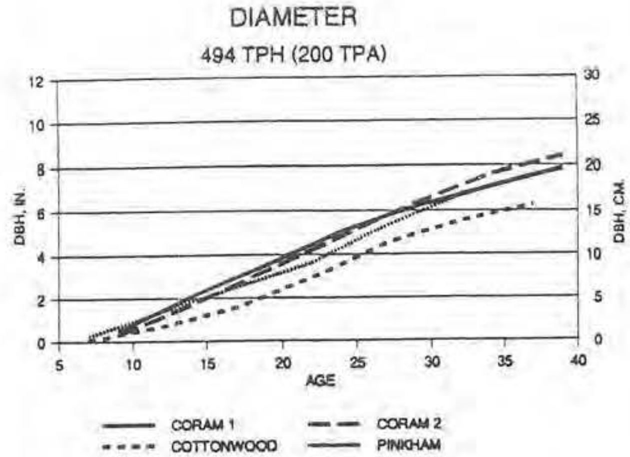

Figure 6.
A comparison of diameter growth at the four study locations, holding stand density constant.

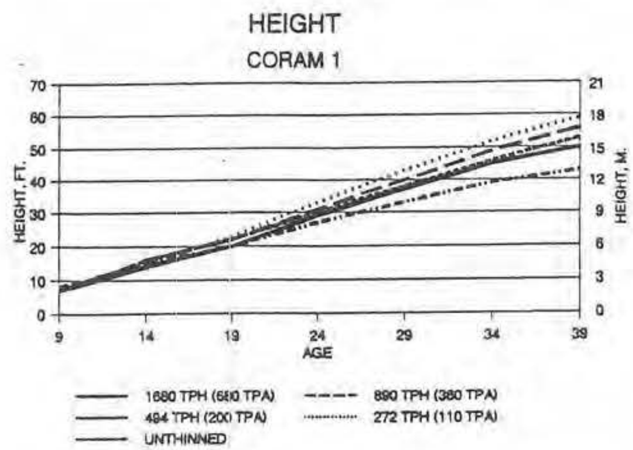

Figure 7.
Height growth of larch under a range of stand densities to age 39, Coram 1. Pre-selected crop trees are used for unthinned plot.

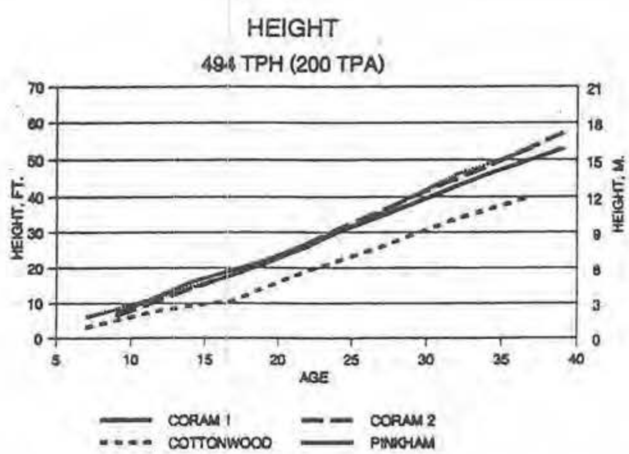

Figure 8.
A comparison of height growth at the four study locations, holding stand density constant.

retained were established at three different stand densities and at all four locations at the outset of this study. Shrub development is usually robust on this habitat type (Pfister and others 1977) and it was felt at the time this study was started in 1961 that shrub competition limited early growth of larch. Using Coram 1 and a stand density of 1,334 trees/ha as an example, there is little difference in either diameter or height growth of larch, with or without major shrub competition (Figures 11, 12). Effects on larch growth were reasonably consistent throughout combinations of density and location.

Phenology

The larch spacing study provided conditions for determining phenological characteristics of western larch. Quantitative measurements of needle, diameter, and height at weekly intervals during several growing seasons told much about "when" and "how much" larch grows. Although the original intent was only to relate tree phenology to insect development, the basic information has proved of interest to other disciplines.

Western larch very effectively partitions various components of overall larch growth during the growing season (Figure 13). This may partially account for its success as a major species of the Northern Rockies. For example, average daily needle growth of this deciduous conifer peaks and starts to decline about the time diameter growth begins in mid-May. Average daily diameter growth accelerates rapidly and reaches its greatest average daily growth in mid- to late June—the time needle growth ceases. Coincident with this is the time trees begin to grow in height. Seasonal height growth peaks about mid-July and is complete by mid-August. All three components of growth accelerate, peak, and decline rapidly with needle and height ending abruptly. Diameter can respond to late summer rains but apparently this additional water only replenishes water in cells desiccated by summer drought.

Location differences appeared minimal on tree growth phenology, even though locations were geographically separated about 300 km and there were modest elevation differences. As

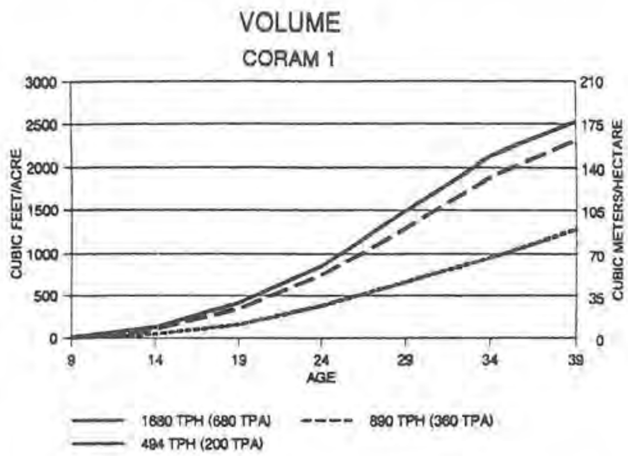

Figure 9.
Cubic volume production of larch as related to stand density to age 39, Coram 1.

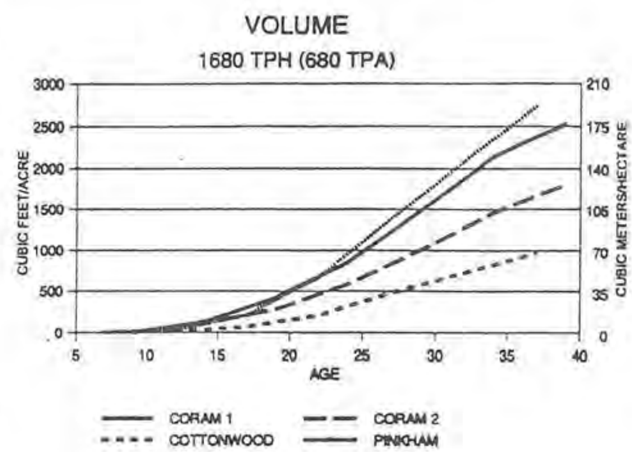

Figure 10.
Cubic volume at four locations , each with the same density, to ages 37-39.

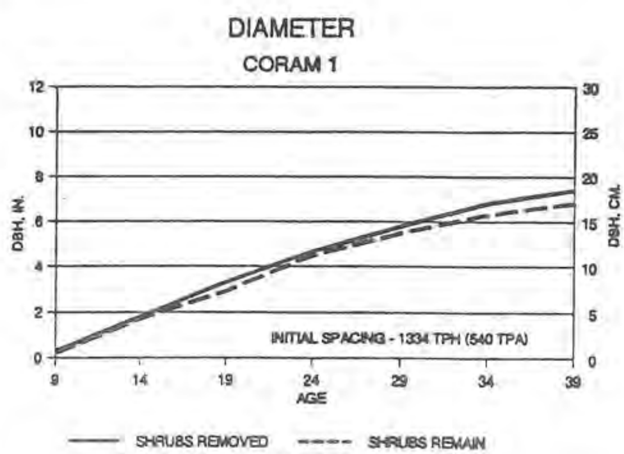

Figure 11.
Effects of shrub competition on larch diameter growth, Coram 1.

pointed out earlier, there were some location differences in absolute height growth, particularly at Cottonwood, but when evaluated in terms of relative seasonal growth, there are essentially no differences in phenological development between study locations (Figure 14). Although height growth started about a week apart at the study locations, average relative growth was essentially the same.

Water Use

Western larch grows in the upper montane to lower subalpine zone and water is usually regarded as a major limitation to larch growth. To evaluate the effects of stand density on water use in the larch spacing study plots, we superimposed a study that utilized neutron probe methods to determine soil water status throughout the growing season. From this we determined periodicity and total water used in the various stand densities of the study (Figure 15).

As an example, the Coram study area receives about 80 cm of precipitation annually and the soil profiles are nearly always fully charged at the beginning of the growing season. At age 19, ten years after the initial treatments, unthinned stands used about 55 cm of water and those with 494 trees/ha used about 45 cm with intermediate amounts used by stands with densities in between those extremes. Ten years later at age 29, water use differences between stand densities mostly disappeared—reflecting increasing occupancy of the site by the fewer but larger trees in the lower density plots.

Cone Production

A 12-year study of cone development on dominant trees in the larch spacing study plots showed stand density played a major role in how many seed and pollen cones were produced—trees in the lowest stand density plots produced disproportionately more seed and pollen cones than trees in the dense plots (Figure 16, 17). Trees 30 and 32 years old at the start of the cone study on the least dense plots of 272 trees/ha accumulated an average 12-year total of 42 seed cones and 340+ pollen cones

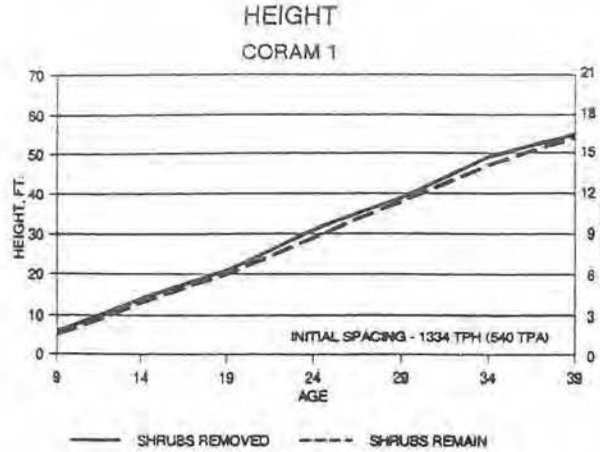

Figure 12.
Effects of shrub competition on larch height growth, Coram 1.

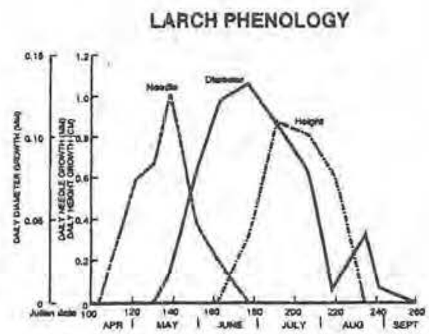

Figure 13.
Phenology of three major components of larch growth.

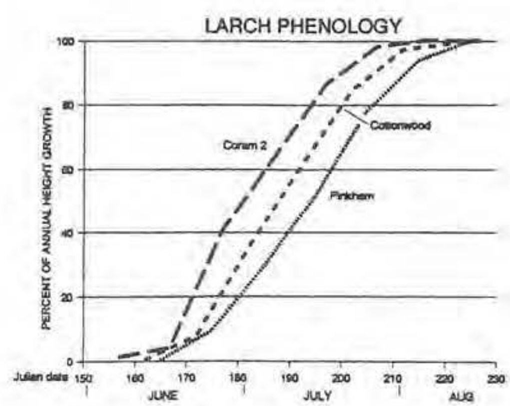

Figure 14.
Effects of location on the relative height growth phenology of larch.

per tree. Cone averages per tree are deceptive here because some trees produced few or no cones while two trees, both partially girdled by bear, produced about 1,000 seed cones in one season. Trees on stand densities with over 890 trees/ha produced very few seed or pollen cones in this 12-year period. Yearly cone production varied widely between years and locations. For example, a bumper seed cone crop in 1991 at Coram 1 and 2 was totally absent at Cottonwood and only nominal at Pinkham. Conversely, 1995 was a good cone year at all four locations. Bear stripped bark at the base of some of the larger trees and appeared to stimulate cone production on those trees at Coram 1 and 2, but were not a factor at Cottonwood or Pinkham. About 95 percent of the seed cones were found in the upper two-thirds of the crown and nearly all of the pollen cones were found on the lower two-thirds of the crowns (Shearer and Schmidt 1987).

Wood Density

Larch wood is a species highly valued for its strength. Strength is closely related to wood density. Nearly all the information on wood properties of larch have been developed from old-growth samples. The larch spacing study provided an opportunity to evaluate wood density of young larch under a variety of stand density and site conditions. A cooperative study currently underway with FORINTEK is beginning to provide information indicating that high wood densities of larch occur in young larch as well as in the older trees. Average densities are varying from about 0.53 to 0.64 with a mean of 0.56. Latewood densities of 0.74 far surpass those of earlywood at 0.38. Stand density and location effects, if any, have not yet been analyzed.

Mortality and Damage

Natural mortality is persistent and substantial in unthinned stands of western larch (Figure 18). Only about one-quarter of the trees alive at age 9 were still alive at age 39, declining from an average of about 55,000 to about 14,000 per hectare in that 30-year period. Most of this loss

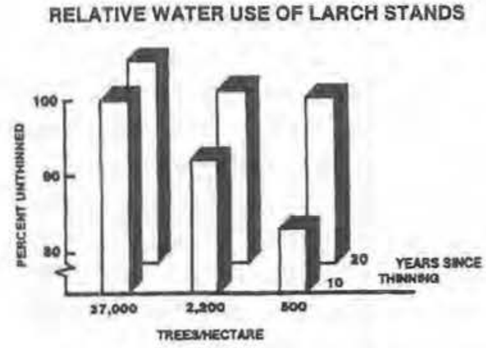

Figure 15.
Relative soil water use by larch stands of different densities 10 and 20 years after thinning.

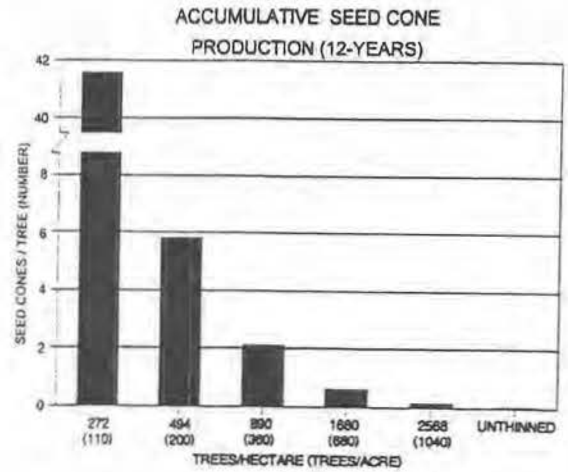

Figure 16.
Accumulative number of seed cones produced over a 12-year period as related to larch stand density at four locations.

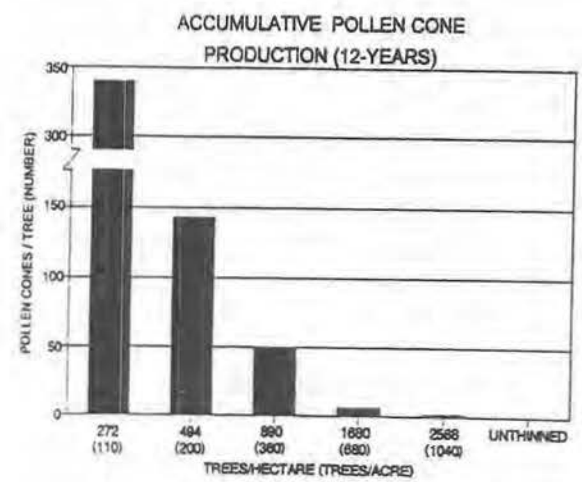

Figure 17.
Accumulative number of pollen cones produced over a 12-year period as related to larch stand density at four locations.

was directly or indirectly related to intertree competition. Snow damage, when large numbers of spindly trees are bent over en masse, accounted for the indirect effect of overstocking on mortality.

Relatively little mortality occurred in the thinned plots during the 30-year period. Annual mortality averaged only about 0.3 percent (Schmidt and Seidel 1988). Mortality that could be reasonably well identified (about half) tended to be location oriented, with heavy snowpacks of Pinkham very early in the study, insect and diseases at Cottonwood, and bear at Coram 1 and 2 the predominant causes.

Snow and Frost

Snow not only causes tree mortality—it can damage trees and result in deformation. At Coram 1 and 2, the 13-year-old larch stand was flattened by a heavy-wet snow in June. We evaluated the recovery pattern the following 11 years and found a remarkable recovery with little or no mortality (Figure 19). A few crooked boles have persisted for nearly 30 years, but most trees returned to vertical—slightly snowbent trees returned in two years, moderately and heavily snowbent in four, and severely snowbent in six (Schmidt and Schmidt 1979). All of these trees were in thinned stands and had the advantage of youth and vigor. Older and less vigorous trees would not likely recover as well as these.

Unseasonal spring frosts have caught larch with a full complement of new succulent needles. Several times during the 30-year period we observed this, but there was no mortality or apparent after-effects except some short-term needle tufting afterwards.

Budworm

Western larch is an atypical host of western spruce budworm (*Choristoneura occidentalis*), a common defoliator in our Douglas-fir (*Pseudotsuga menziesii*) and spruce-fir (*Picea-Abies*) forests in the Rocky Mountain area (Fellin and Schmidt 1967). Although larch is a common associate in these forest types, budworm feeding is usually limited to budworm host forests in late successional stages, usually Douglas-fir and the true firs. However, an unusual budworm feeding habit occurs in some young larch forests. Instead of feeding on the foliage of larch, budworm feed on the terminal and upper lateral shoots, reducing both the annual height growth and jeopardizing the excellent form of larch. Height growth was reduced about one-third for every terminal severance, and were it not for the apical dominance characteristic of larch, it would be more severe.

Budworm severances were found to be related to stand density, with crop trees in the least dense plots most heavily attacked (Schmidt and Fellin 1973). Apparently the random distribution of budworm in both the larvae and adult stages concentrated them on the fewer num-

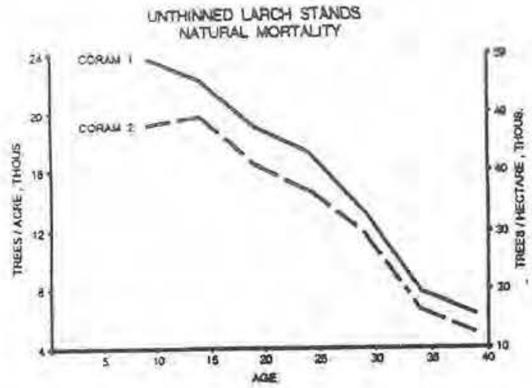

Figure 18.
Natural mortality in unthinned stands up to age 39, Coram 1 and 2.

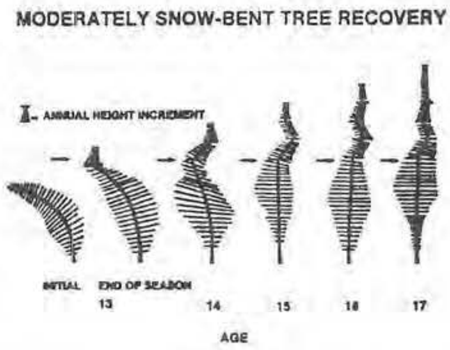

Figure 19.
Recovery pattern of moderately snowbent larch through five growing seasons.

ber of trees in the least dense plots. However, once the budworm population declined, crop trees in the least dense plots recuperated at a much faster rate than those subjected to heavier stocking levels. There was no mortality from budworm.

Larch Casebearer

Larch casebearer (*Coleophora laricella*) is an introduced insect that threatened the feasibility of managing larch (Denton 1979). Until the highly successful introduction of biological controls of casebearer, casebearer populations throughout the range of larch were skyrocketing and approaching this study area. To study this population buildup from Day 1 and determine its effects on young larches, we established an adjunct, parallel study in 1970 that could evaluate stand density effects on casebearer population development and subsequent tree response to these populations. This adjunct study showed that casebearer populations per tree increased at different rates under different stand densities. Stands with the fewest trees/ha supported larger numbers of casebearer per tree than comparable trees in the more densely stocked stands. This was likely due to fewer targets for an apparently evenly dispersed casebearer population throughout the area. The casebearer population built rapidly to where 20 percent of the fascicles had casebearer by year five in the plots with 494 trees/ha. But in year six the population started to collapse, never rebuilt, and did not reach levels that measurably impacted the trees.

Diseases

Only three diseases have been identified on the larch spacing study and none have been of any significant consequence or appear related to stand density—shoot blight (*Encoelipsis laricina*) and needle blight (*Hypodermella laricis*) and needlecast (*Meria laricis*). Needle blight and needlecast are associated with cool-wet springs and have occurred in about seven or eight years of this 30-year study. No mortality or significant growth loss could be attributed to these needle diseases.

An adjunct study of the same age and stand densities as the larch spacing study was established to determine rate of spread of dwarf mistletoe (*Arceuthobium laricis*). This study demonstrated young larch could be successfully inoculated artificially. It demonstrated that even wide spacings of 272 trees/ha did not significantly inhibit lateral dispersal of dwarf mistletoe during the 14 year period after the trees were inoculated at age 16 (Wicker and Wells 1983).

Bear

Black bears (*Ursus americana*) have a distinct liking for young vigorous larch (Mason and Adams 1989). Bear have been observed at all four larch spacing study locations, but bear damage is a learned process from sow to cub and is location oriented. Two of the larch spacing study locations—Cottonwood and Pinkham—showed no bear damage, whereas Coram 1 and 2 were significantly impacted. In May and June, bear feed on the innerbark and cambium of the lower bole when wood sugar arabinogalactan content is high. Bears consistently damage or kill the largest trees in the least dense plots. Although bears damaged larch as early as about 10 years old, the most damage occurred when trees were about 25 years or older (Figure 20) and 15 cm and larger

Figure 20.
Bear damage on larch by age and stand density.

(Schmidt and Gourley 1992). This was all related to stand density—the most damage occurred on the plots with fewer than 890 trees/ha. Given an option within a given stand density, bears chose the largest trees (Figure 21). No bear damage occurred in the unthinned plots.

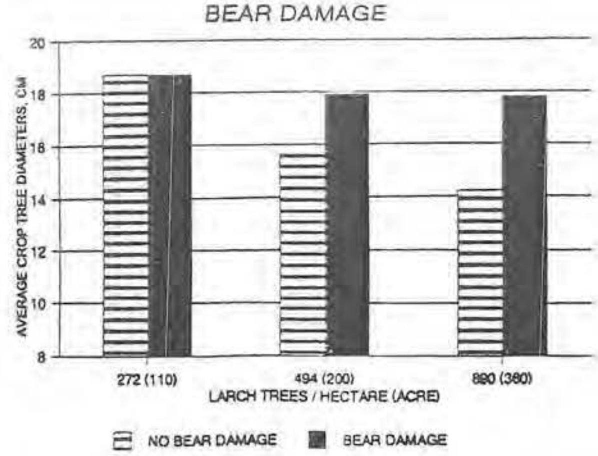

Figure 21.
Bear damage by average diameter and stand density—bear preferred the larger trees on all densities.

Summary

Western larch is a versatile and valuable species in the U.S. and Canadian West. Like most other seral species, it is a good seed producer that claims receptive sites soon after fires, harvesting, or other disturbances over much of its natural range. Its rapid juvenile growth provides a competitive edge over most of its associated species, but it normally overstocks to the point that individual tree growth is inhibited by intertree competition early in its life. This paper describes the development of young western larch under a wide range of regulated and natural stand conditions. It demonstrates larch's rapid growth potential, describes its phenology, soil water use, cone production, wood density, mortality and damage factors such as snow and frost, budworm, larch casebearer, diseases, and bear. Dispersed locations of the study provided the opportunity to monitor different growth performances and the various perturbations that occur during a 30-year period at four widely separated study sites.

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