United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

Research Note
PNW-RN-455
November 1986

Growth and Yield of Western Larch in Response to Several Density Levels and Two Thinning Methods: 15-Year Results

K.W. Seidel

Abstract

The 15-year growth response from a levels-of-growing-stock study in an even-aged western larch (*Larix occidentalis* Nutt.) stand, first thinned from above and below at age 55, was measured in northeastern Oregon. Basal area and volume growth increased with stand density for both thinning methods, whereas diameter growth decreased. Attacks of the larch casebearer (*Coleophora laricella* (Hübner)) for about 3 years reduced height growth because of top dieback, but diameter and volume growth were not severely impacted. Thinning from above reduced net volume growth because of considerable mortality caused by windthrow and snow or ice damage, although surviving trees responded well to increased growing space. Thinning from below is recommended in previously unmanaged larch stands.

Keywords: Increment (stand volume), even-aged stands, stand density, thinning effects, growing stock (-increment/yield, western larch, *Larix occidentalis.*

Introduction

Long-term levels-of-growing-stock and spacing studies provide information needed to design thinning regimes to attain desired rates of diameter or volume growth to meet timber production and multiple use objectives. They also are needed to supply growth and yield data for the development of managed yield tables and to verify simulation models designed to predict growth and yield for various management alternatives. Western larch (*Larix occidentalis* Nutt.) is an important species in the mixed-conifer forests of eastern Oregon, and many stands require thinning to produce salable trees in a reasonable time.

This paper reports 15-year results from a levels-of-growing-stock study begun in 1970 in the Blue Mountains of northeastern Oregon.[1] The purpose of the study was to obtain information on the growth and mortality of even-aged larch stands thinned to several density levels by two methods. It supplements earlier reports of results for the first 5 and 10 years (Seidel 1975, 1980).

Study Area and Methods

The study site is on Boise-Cascade land about 6 miles northwest of Elgin, Oregon; the site and the timber stand are described in an earlier report (Seidel 1980). Study results are applicable to larch stands of similar site quality throughout northeastern Oregon and southeastern Washington.

[1]A cooperative research effort between the Boise-Cascade Corporation and Pacific Northwest Research Station.

K.W. SEIDEL is a research forester at the Silviculture Laboratory, Pacific Northwest Research Station, 1027 N.W. Trenton Avenue, Bend, Oregon 97701.

The study consists of a 2 by 4 factorial randomized complete block design replicated two times for a total of sixteen 0.286-acre plots. It is designed for thinning at 10-year intervals, with remeasurement every 5 years. The first factor, density, consists of four levels: 50, 90, 130, and 170 square feet of basal area per acre. These levels correspond to 21, 38, 55, and 72 percent of the basal area of normal (fully stocked) larch stands at age 55 and site index 80 given by Schmidt and others (1976).[2] The second factor is the thinning method: from above (cutting the largest trees—dominants and codominants) and from below (cutting the smallest trees—suppressed, intermediate, and small codominants). Split-plot analyses of variance were used to test significance of treatment effects for three 5-year periods (1970-74, 1975-79, and 1980-84). Tukey's test was used to determine significant differences among treatment means. Regression analyses related diameter, basal area, and volume growth to residual basal area for each period.

All plots were well stocked, ranging from 191 to 226 square feet of basal area per acre before treatment (table 1). Trees were spaced from 8.5 to 10.3 feet apart; average d.b.h. (diameter at breast height) ranged from 8.2 to 9.8 inches before thinning. After thinning from above, all plots contained 2 to 8 percent of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), or Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), except one plot where 22 percent of the residual basal area was grand fir and Douglas-fir. All plots thinned from below were pure larch.

Plots were thinned with a Drott "feller-buncher"[3] before growth began in 1970. This machine uses shears and a grapple mounted on a 25-foot boom with a crawler tractor undercarriage. Operation of this equipment required prior removal of all trees (clearcut) in swaths 20 feet wide. Swaths were spaced 50 feet apart and oriented east and west through the stand. The feller-buncher moved along these clearcut strips, reaching 25 feet into the thinning strips to cut and remove the entire tree. Some variation in residual stocking levels between replications and between thinning methods for a given density level existed because a few trees marked for cutting were missed and some leave trees were accidentally pushed over by the feller-buncher. In plots thinned from above, the variation in residual basal area levels in 1970 ranged from a 4-percent undercut to a 10-percent overcut, whereas in plots thinned from below, variation from desired levels was only +1 to -3 percent.

[2] Site index of plots (83 feet at age 50) is based on curves in "Ecology and Silviculture of Western Larch Forests" (Schmidt and others 1976). These curves use total age (age at ground line).

[3] Mention of companies or products is for the convenience of the reader. Such mention does not imply endorsement by the U.S. Department of Agriculture to the exclusion of other products or services that may be suitable.

Table 1—Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975 and 1985[1/]

Density level 2/	Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height 3/	Volume 4/ Total	Merchantable, including ingrowth	
	Square feet		Feet	Inches	Feet	Cubic feet	Cubic feet	Board feet
BEFORE INITIAL (1970) THINNING								
Thinned from above:								
1	221.5	420	10.2	9.8	85.1	7,177	6,635	26,816
2	191.5	495	9.4	8.4	80.3	6,032	5,331	18,540
3	213.7	408	10.3	9.8	90.1	6,883	6,164	27,020
4	202.0	513	9.2	8.5	82.0	6,285	5,311	18,045
Thinned from below:								
1	211.0	490	9.4	8.9	95.3	6,892	6,202	24,555
2	205.5	557	8.8	8.2	91.8	6,688	5,942	20,898
3	221.5	596	8.5	8.3	93.7	7,192	6,366	19,479
4	226.0	525	9.1	8.9	92.4	7,402	6,689	26,446
AFTER 1970 THINNING 5/								
Thinned from above:								
1	50.6	133	18.1	8.4	85.1	1,647	1,439	2,816
2	93.8	257	13.0	8.2	80.3	2,906	2,506	5,687
3	126.0	231	13.7	10.0	90.1	4,091	3,792	13,990
4	153.0	400	10.3	8.4	82.0	4,670	4,080	10,054
Thinned from below:								
1	48.9	58	27.4	12.4	94.8	1,686	1,593	8,331
2	87.7	115	19.5	11.9	91.8	2,974	2,796	13,503
3	131.8	196	14.9	11.1	93.7	4,448	4,161	16,790
4	169.0	219	14.1	11.9	92.0	5,801	5,459	24,440
1975 5/								
Thinned from above:								
1	50.4	111	19.8	9.1	88.3	1,668	1,492	4,309
2	9.2	239	13.5	8.7	84.0	3,105	2,742	7,273
3	132.9	220	14.1	10.5	94.5	4,346	4,051	15,880
4	158.2	378	10.7	8.8	86.0	4,876	4,335	13,260
Thinned from below:								
1	55.5	58	27.4	13.3	99.1	1,925	1,825	10,005
2	96.5	115	19.5	12.5	95.1	3,312	3,125	16,141
3	141.4	196	14.9	11.5	96.9	4,775	4,480	19,732
4	183.6	219	14.1	12.4	96.4	6,274	5,914	28,440
BEFORE 1980 THINNING 5/								
Thinned from above:								
1	59.3	110	19.9	9.9	83.4	1,919	1,819	5,382
2	105.3	221	14.2	9.5	81.7	3,333	3,120	8,868
3	152.1	220	14.1	11.3	88.5	5,022	4,712	19,103
4	161.9	348	11.2	9.2	84.4	5,002	4,586	15,294

See footnotes at end of table.

Table 1—Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975 and 1985[1/] (continued)

Density level 2/	Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height 3/	Volume 4/ Total	Volume 4/ Merchantable, including ingrowth	
	Square feet		Feet	Inches	Feet	Cubic feet	Cubic feet	Board feet
			BEFORE 1980 THINNING 5/ (continued)					
Thinned from below:								
1	64.3	58	27.4	14.3	101.7	2,288	2,218	11,636
2	107.2	115	19.5	13.2	96.8	3,729	3,591	18,869
3	151.5	196	14.9	11.9	96.9	5,136	4,998	21,478
4	196.3	219	14.1	12.9	97.3	6,740	6,493	32,225
			AFTER 1980 THINNING 5/					
Thinned from above:								
1	53.3	98	21.1	10.0	80.4	1,726	1,636	4,921
2	96.2	214	14.5	9.2	78.1	3,050	2,841	7,361
3	140.0	209	14.4	11.1	85.3	4,623	4,336	17,118
4	160.6	347	11.2	9.2	84.0	4,958	4,543	15,082
Thinned from below:								
1	54.9	46	30.8	14.8	102.4	1,955	1,895	10,171
2	99.2	102	21.2	13.7	98.3	3,409	3,290	17,425
3	139.7	175	16.0	12.3	98.3	4,782	4,659	20,402
4	183.6	190	15.3	13.4	100.4	6,327	6,112	31,991
			1985 5/					
Thinned from above:								
1	58.4	82	23.1	11.4	81.5	1,998	1,894	8,311
2	99.2	168	16.1	10.4	81.5	3,328	3,098	11,986
3	157.0	189	15.2	12.3	86.5	5,527	5,184	24,773
4	156.3	278	12.7	10.1	87.2	5,315	4,869	20,086
Thinned from below:								
1	65.6	46	31.0	16.3	105.4	2,366	2,293	13,782
2	109.6	98	21.5	14.6	99.2	4,015	3,874	21,946
3	140.0	149	17.1	13.2	100.3	4,913	4,785	23,252
4	203.2	182	15.6	14.4	103.0	7,396	7,145	40,107

1/ Based on plots without clearcut strips.

2/ 1 is lowest; 4, highest.

3/ Measured with a dendrometer (about 15 trees per plot).

4/ Total cubic-foot volume--entire stem, inside bark, all trees. Merchantable cubic-foot volume--trees 5.0-inch d.b.h. and larger to a 4-inch top d.i.b. Board-foot volume--international 1/4-inch rule, trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.

5/ Basal area, number of trees, and volume per acre should be reduced by 29 percent if clearcut strips are included in plot area.

In April 1980, 10 years after the first thinning, plots were thinned for the second time with chain saws. Plots were not thinned to the original density levels after the 1970 thinning but were marked to allow an 8-percent increase in basal area, approximately the normal increase in stand density with age for fully stocked stands. The adjusted density levels after the second thinning were 54, 97, 140, and 184 square feet of basal area per acre, again corresponding to 21, 38, 55, and 72 percent of the density of normal stands at age 65.

Diameter at breast height of all plot trees was measured to the nearest one-tenth inch in the spring of 1970 and in the fall of 1974, 1979, and 1984. In addition, about 15 trees per plot covering the range of diameters were measured with an optical dendrometer in 1970, 1974, 1979, and 1984 to derive an equation expressing volume of the entire stem inside bark as a function of diameter for each plot. The volume equations developed from the 1970 measurements were used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the first 5-year period. New equations developed from the 1979 measurement were used to compute plot volumes at the end of the second and third 5-year periods. Height growth was measured by dendrometer only on trees chosen to provide data for volume equations.

Because of the mechanized thinning equipment used in this stand, 29 percent of the total area was occupied by clearcut strips, which resulted in a reduction in volume growth compared with a thinned area completely occupied by trees. Therefore, growth per acre is presented two ways—based on the 0.286-acre plot completely occupied by trees and on a larger 0.4-acre plot that includes the clearcut strips.

Examination of data on basal area and volume growth for the plot containing 22 percent of the basal area in fir revealed an unusually high growth rate because of the more rapid growth of the fir. Therefore, data from this plot were not used in the growth and statistical analyses.

Results

Mortality and Damage

Considerable mortality and damage occurred during the 15 years of this study because of wind, snow, and ice damage and attacks of the larch casebearer (*Coleophora laricella* (Hübner)). During the first 10 years of the study, all mortality occurred in plots thinned from above and was caused by either windthrow or shock after release. Of the 570 trees in these plots, 12 percent died—7 percent during the first 5-year period and 5 percent during the second. Most of these trees were in the intermediate and suppressed crown classes and thus had not developed sufficient windfirmness or large enough crowns to keep pace with the increased respiratory rate after release. During the third period, an additional 15 percent of the trees in plots thinned from above died as the result of a severe ice storm in January 1984 that broke tree boles below the live crown. Also, 6 percent of the 377 trees in plots thinned from below died during the third period from storm damage. To summarize, 20 percent or 167 of the 855 trees present at the beginning of the study in all plots died during the 15 years of this study. Eight-five percent of the mortality (142 trees) occurred in plots thinned from above but only 15 percent (25 trees) in plots thinned from below.

Wind or ice also damaged 12 percent of the trees in plots thinned from above compared with 3 percent in plots thinned from below during the 15 years. This damage consisted of trees leaning from 10 to 35 degrees from the vertical or several feet of the top broken off. In 1976, the larch casebearer moved into the study area and attacked larch in all plots. Dieback of terminals occurred on many trees during the second period from 1976 to 1979. No casebearer damage was observed during the third period.

Diameter Growth

Diameter growth from 1970 through 1984 was greatest at the lowest density level for both thinning methods (table 2). As stand density increased, diameter growth generally decreased, although this trend was not completely consistent. The growth rate at the lowest density was about twice that at the highest density (0.2 vs. 0.1 inch per year) when averaged over all periods and thinning methods. Diameter growth was significantly greater ($P < 0.01$) at the lowest density level, but no statistical differences were found among the other three levels (0.14, 0.11, and 0.10 inch per year).

Diameter growth rates also changed over time. Significant diameter growth differences ($P < 0.01$) were found among all periods (fig. l). Only small differences in growth existed between the first and second periods, but during the third period growth accelerated considerably. Averaged over all density levels and thinning methods, diameter growth was 0.10 inch per year in the first period and 0.13 inch in the second, but growth increased to 0.20 inch per year in the third period. The more rapid diameter growth during the third period can be attributed to the combined effects of the second thinning in 1980 and the decline in larch casebearer populations about that time. A significant ($P < 0.01$) period-density interaction occurred because of the relatively greater growth differences among periods at the lowest density level than at the other levels.

The thinning method did not affect diameter growth. Differences in diameter growth between thinning methods were not significant; they averaged 0.13 inch per year in plots thinned from above and 0.15 inch in those thinned from below.

After 15 years of growth and two thinnings, the average stand diameter in plots thinned from below at the lowest density level was 16.3 inches compared with 11.4 inches in plots thinned from above (table 1). This difference of almost 5 inches is caused primarily by removal of larger trees in plots thinned from above versus removal of smaller trees in plots thinned from below. Annual diameter growth in these plots during the 15-year period was 0.13 inch (above) and 0.15 inch (below).

Table 2—Periodic annual increment and mortality per acre of western larch by age, density level, and thinning method after thinning at ages 55 and 65

Density level 1/	Residual basal area	Diameter growth 2/	Basal area growth: Net	Basal area growth: Mortality	Basal area growth: Gross	Total volume growth: Net	Total volume growth: Mortality	Total volume growth: Gross	Merchantable volume growth, including ingrowth: Net	Merchantable volume growth, including ingrowth: Mortality	Merchantable volume growth, including ingrowth: Gross	Ingrowth	
	Square feet	Inches	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Board feet	Board feet	Board feet	Board feet	Percent
AREA WITHOUT CLEARCUT STRIPS, AGE 55-60 (1ST PERIOD)													
Thinned from above:													
1	51	0.10	-0.04	1.12	1.08	4	34	38	299	0	299	225	75.2
2	94	.08	1.08	.85	1.93	40	25	65	317	0	317	163	51.4
3	126	.08	1.38	1.12	2.50	51	37	88	378	132	510	202	39.6
4	153	.05	1.04	.91	1.95	41	24	65	641	0	641	456	71.2
Thinned from below:													
1	49	.16	1.32	0	1.32	48	0	48	335	0	335	33	9.8
2	88	.12	1.76	0	1.76	68	0	68	528	0	528	109	20.6
3	132	.08	1.92	0	1.92	65	0	65	588	0	588	278	47.2
4	169	.09	2.92	0	2.92	95	0	95	800	0	800	248	31.0
AREA WITH CLEARCUT STRIPS, AGE 55-60 (1ST PERORD)													
Thinned from above:													
1	36	.10	-0.03	.81	.78	3	24	27	213	0	213	161	75.6
2	67	.08	.78	.61	1.39	29	18	47	227	0	227	116	49.8
3	89	.08	.98	.80	1.78	36	26	62	268	94	362	143	39.6
4	109	.05	.74	.65	1.39	29	18	47	458	0	458	326	71.2
Thinned from below:													
1	35	.16	.94	0	.94	34	0	34	239	0	239	24	10.0
2	63	.12	1.25	0	1.25	48	0	48	377	0	377	78	20.7
3	94	.08	1.36	0	1.36	47	0	47	420	0	420	198	47.1
4	121	.09	2.07	0	2.07	68	0	68	571	0	571	177	31.0
AREA WITHOUT CLEARCUT STRIPS, AGE 60-65 (2D PERIOD)													
Thinned from above:													
1	50	.17	1.78	.06	1.84	50	2	52	215	0	215	83	38.6
2	99	.10	1.22	1.10	2.32	46	33	79	319	32	351	188	53.6
3	133	.14	3.84	0	3.84	135	0	135	645	0	645	267	41.4
4	158	.06	.75	1.72	2.47	25	50	75	407	84	491	295	60.1
Thinned from below:													
1	56	.20	1.76	0	1.76	73	0	73	326	0	326	0	0
2	97	.12	2.13	0	2.13	83	0	83	545	0	545	28	5.1
3	141	.08	2.03	0	2.03	72	0	72	350	0	350	96	27.4
4	184	.09	2.55	0	2.55	93	0	93	757	0	757	113	14.9
AREA WITH CLEARCUT STRIPS, AGE 60-65 (2D PERIOD)													
Thinned from above:													
1	36	.17	1.27	.05	1.32	36	1	37	153	0	153	59	38.6
2	71	.10	.86	.78	1.64	33	23	56	228	23	251	133	53.0
3	95	.14	2.73	0	2.73	96	0	96	458	0	458	190	41.5
4	113	.06	.53	1.22	1.75	18	36	54	289	60	349	209	59.9
Thinned from below:													
1	40	.20	1.25	0	1.25	52	0	52	233	0	233	0	0
2	69	.12	1.52	0	1.52	60	0	60	390	0	390	20	5.1
3	101	.08	1.45	0	1.45	52	0	52	250	0	250	69	27.6
4	131	.09	1.83	0	1.83	66	0	66	541	0	541	81	15.0
AREA WITHOUT CLEARCUT STRIPS, AGE 65-70 (3D PERIOD)													
Thinned from above:													
1	53	.27	1.02	1.54	2.56	55	49	104	678	109	787	401	51.0
2	96	.19	.59	2.90	3.49	56	87	143	926	54	980	370	37.8
3	140	.20	3.40	1.56	4.96	159	45	204	1,531	0	1,531	510	33.3
4	161	.12	-.86	4.37	3.51	26	131	157	1,071	84	1,155	326	28.2
Thinned from below:													
1	55	.29	2.13	0	2.13	82	0	82	722	0	722	0	0
2	99	.20	2.08	.31	2.39	121	10	131	1,094	0	1,094	63	5.8
3	140	.15	0.06	2.59	2.65	26	98	124	746	226	972	96	9.9
4	184	.18	3.91	.86	4.77	168	31	199	1,623	102	1,725	343	19.9
AREA WITH CLEARCUT STRIPS, AGE 65-70 (3D PERIOD)													
Thinned from above:													
1	38	.27	.72	1.09	1.81	39	35	74	481	77	558	285	51.0
2	68	.19	.42	2.06	2.48	40	62	102	657	38	695	263	37.8
3	99	.20	2.41	1.11	3.52	113	32	145	1,087	0	1,087	362	33.3
4	114	.12	.61	3.10	2.49	18	93	111	760	60	820	231	28.2
Thinned from below:													
1	39	.29	1.51	0	1.51	58	0	58	513	0	513	0	0
2	70	.20	1.48	.22	1.70	86	7	93	777	0	777	45	5.8
3	99	.15	.04	1.84	1.88	18	70	88	530	160	690	68	9.9
4	131	.18	2.78	.61	3.39	119	22	141	1,152	72	1,224	244	19.9

1/ 1 is lowest; 4, highest.

2/ Arithmetic diameter growth of trees living through three 5-year periods (1970-74, 1975-79, 1980-84).

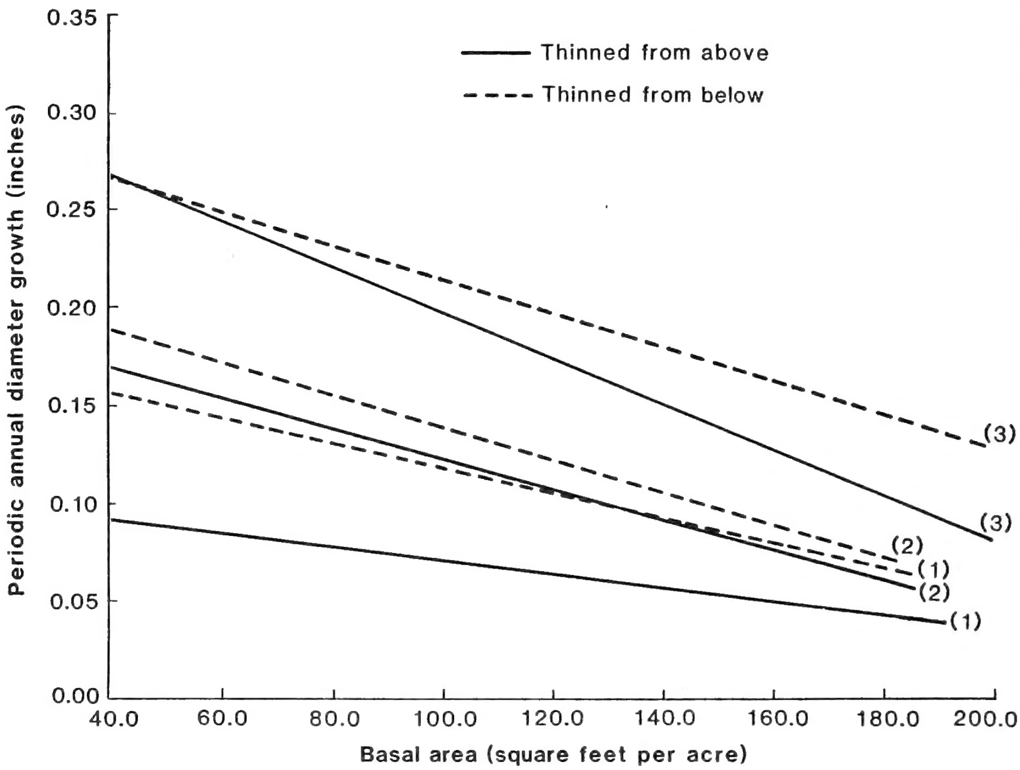

Figure 1—Periodic annual diameter growth by thinning method and growth period as a function of stand density; number in parentheses are growth periods.

Height Growth

Height growth was not affected by changes in stand density, but significant ($P < 0.05$) growth differences were found among periods and thinning methods. Increment ranged from a high of 0.88 foot per year during the first period to a low of -0.15 foot during the third period (fig. 2). Averaged over all density levels and thinning methods, height growth decreased significantly from 0.76 foot per year in the first period to 0.13 foot in the second period because of dieback caused by the larch casebearer. Height growth recovered slightly during the third period to 0.32 foot per year but was still significantly less than first period growth because of ice damage. Average annual height growth for the 15 years in plots thinned from above was about 0.30 foot per year compared with 0.51 foot in plots thinned from below, a significant difference.

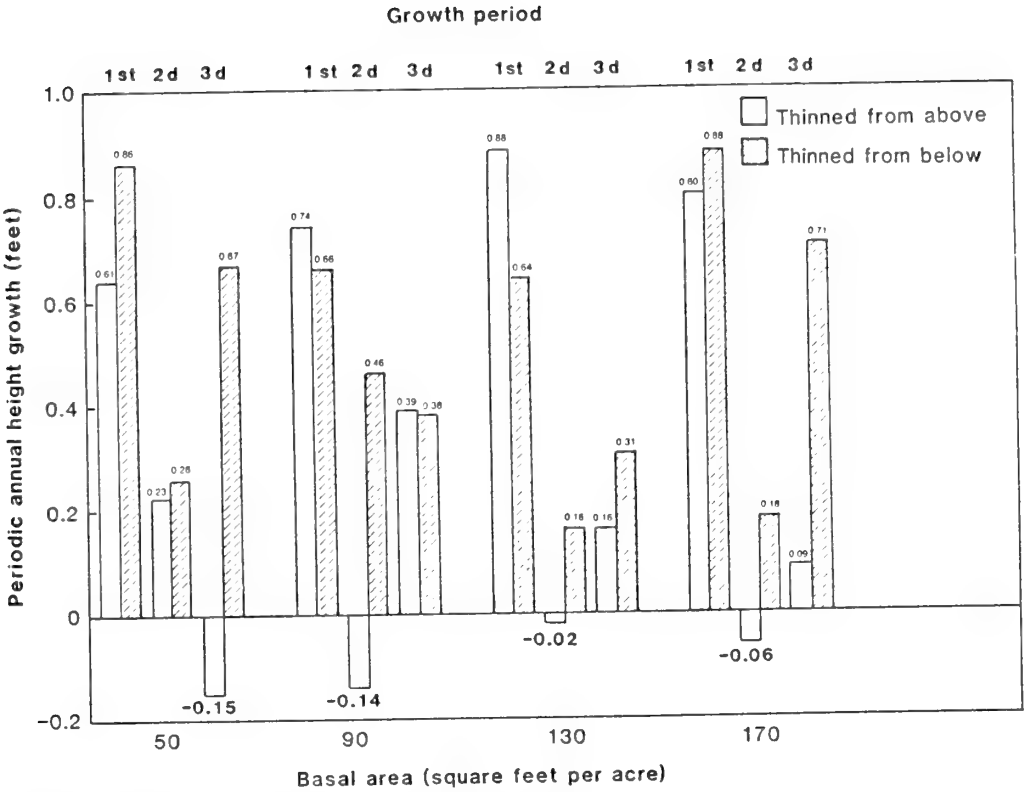

Figure 2—Periodic annual height growth by density level, thinning method, and growth period.

Basal Area Growth

Periodic gross annual basal area increment showed a linear upward trend for both thinning methods and all periods as stand density increased (table 2, fig. 3). Trees in plots thinned from above to the lowest density level in the first period grew 0.78 square foot per acre compared with a maximum growth rate of about 3.5 square feet in high density plots in the third period.

Significant differences ($P < 0.01$) in basal area growth were found among density levels and periods (table 3). The growth rate at the highest level was significantly greater than that at the lowest level (3.03 vs. 1.78 square feet per acre), but all other comparisons were nonsignificant. Average gross basal area growth increasd from 1.92 to 3.20 square feet per acre from the first to the third period, and all differences were significant.

Because of considerable mortality which tended to minimize differences in net growth (table 3), no significant differences were found in net basal area growth among density levels, periods, or thinning methods. For example, mortality offset 54 percent of the gross basal area growth during the third period compared with only 15 to 20 percent during the first two periods. This resulted in a net growth rate during the third period about equal to that of the first period. Mortality in plots thinned from above amounted to 55 percent of the gross growth compared with only a 15-percent loss in plots thinned from below.

Volume Growth

Total gross cubic volume increment showed a positive linear relationship to stand density similar to the basal area stand density relationship (table 2, fig. 4). Gross annual increment varied greatly, ranging from a low of 27 cubic feet per acre during the first period to a high of 204 cubic feet during the third period. The relationship of volume growth to stand density was similar during the first two periods, but during the third period the slope of the curves increased, which suggested greater volume production per square foot of basal area (fig. 4).

Gross cubic volume growth increased significantly ($P < 0.01$) with increasing stand density from 66 cubic feet per acre annually at the lowest level to 114 cubic feet at the highest (table 3). The growth rate at the lowest level was significantly less than that at the other three levels, and level 2 was also significantly less than level 4. Net cubic volume growth was considerably less than gross growth because of the mortality, which ranged from 21 to 34 percent among density levels, and all differences in net growth were nonsignificant.

Gross cubic volume growth increased from the first through the third period, but differences between the first and second period were not significant (table 3). The greatest increase occurred during the third period when the average annual growth rate rose to 141 cubic feet per acre. A 40-percent mortality rate, however, reduced net growth to 84 cubic feet per acre, which was not significantly different from the first two periods. Gross growth in plots thinned from above was not significantly different from growth in plots thinned from below, but the much greater mortality in the plots thinned from above resulted in a significant net growth advantage for the plots thinned from below.

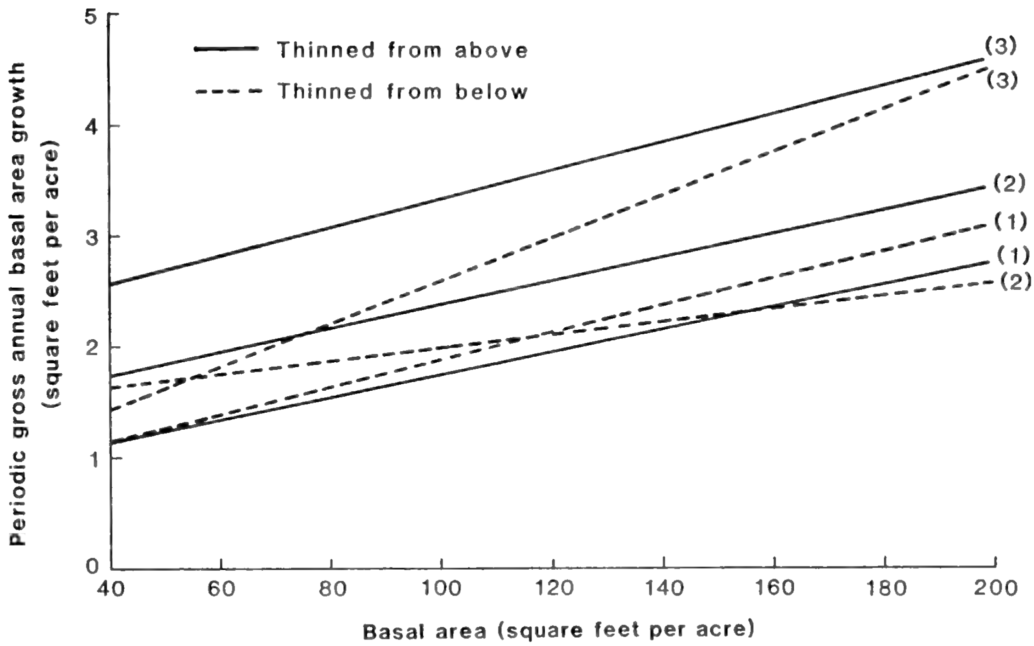

Figure 3—Periodic annual gross basal area growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

Table 3—Average annual net and gross basal area, total cubic volume and board-foot volume growth and mortality per acre, by density level, growth period, and thinning method [1/]

Item	Basal area growth				Total volume growth				Merchantable volume growth			
	Net	Gross	Mortality		Net	Gross	Mortality		Net	Gross	Mortality	
	- - - Square feet - - -			Percent	- - Cubic feet - -			Percent	- - Board feet - - -			Percent
By density level averaged over all periods and thinning methods:												
1 (low)	1.40a	1.78a	0.38a	21	52a	66a	14a	21	429a	448a	19a	4
2	1.41a	2.34ab	.93a	40	69a	94b	25a	27	622b	627ab	5a	1
3	1.98a	2.73ab	.75a	27	77a	107bc	30a	28	625b	690b	65a	9
4 (high)	1.75a	3.03b	1.28a	42	75a	114c	39a	34	883c	928c	45a	5
By periods averaged over all density levels and thinning methods:												
1970-74	1.50a	1.92a	.42a	22	51a	66a	15a	23	482a	502a	20ab	4
1975-79	1.95a	2.30b	.35a	15	69a	80a	11a	14	430a	444a	14a	3
1980-84	1.47a	3.20c	1.73b	54	84a	141b	57b	40	1,008b	1,073b	65b	6
By thinning methods averaged over all density levels and periods:												
Above	1.27a	2.38a	1.31a	55	54a	96a	42a	44	579a	618a	39a	6
Below	2.01a	2.36a	.35b	15	83b	94a	11b	12	701b	729b	28a	4

1/ Based on plots without clearcut strips. Means followed by the same letter are not significantly different.

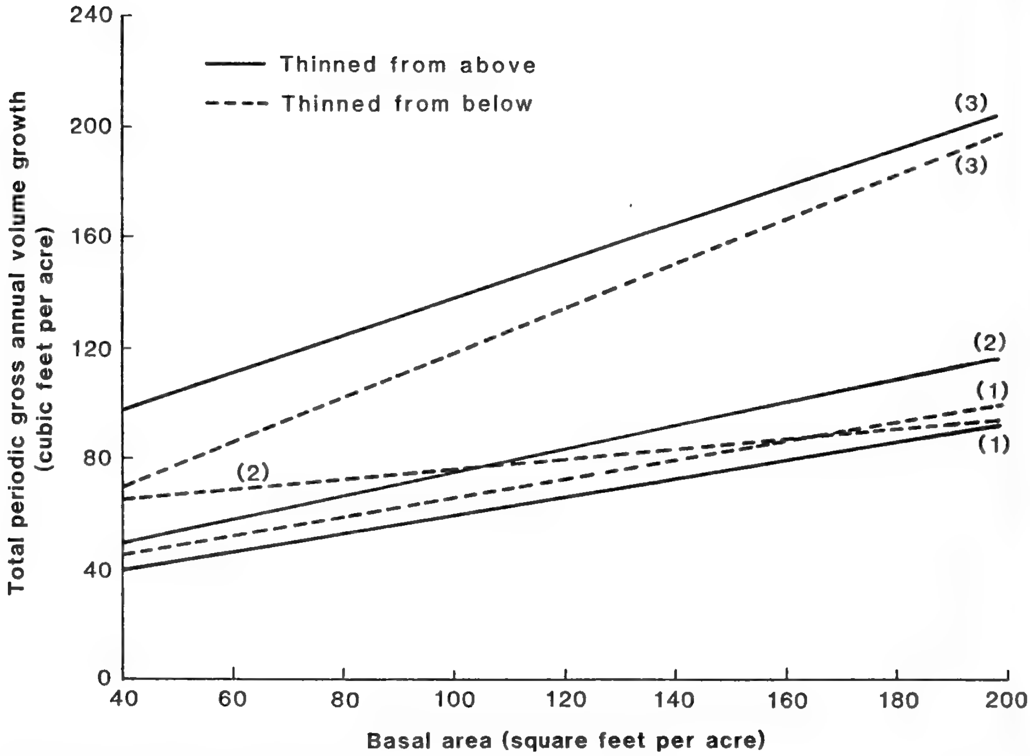

Figure 4—Total periodic gross annual cubic volume growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

At high stand densities, volume increment is generally greater but is distributed over a large number of trees, many of which are smaller and slow growing. Thinning transfers growth to fewer but faster growing trees in addition to utilizing potential mortality. For example, during the second period, in plots thinned from below, 58 trees per acre at the low density produced 78 percent of the cubic volume grown by 219 trees per acre at the high level.

Gross board-foot volume increment increased linearly with greater stand density during all periods (fig. 5). Annual growth at the lowest level averaged 448 board feet per acre over all periods and thinning methods and increased to 928 board feet at the highest density; significant differences existed among levels (table 3). Board-foot mortality was less than 10 percent of gross growth, so significant differences in net growth are similar to those of gross growth. Both gross and net growth decreased nonsignificantly from the first to the second period but more than doubled during the third period to about 1,000 board feet per acre annually (table 3). The board-foot growth rate was significantly greater in plots thinned from below for both gross and net increment. Ingrowth accounted for a considerable amount (up to 75 percent) of the volume during the first two periods but decreased during the third period as fewer trees remained to enter board-foot size (table 2).

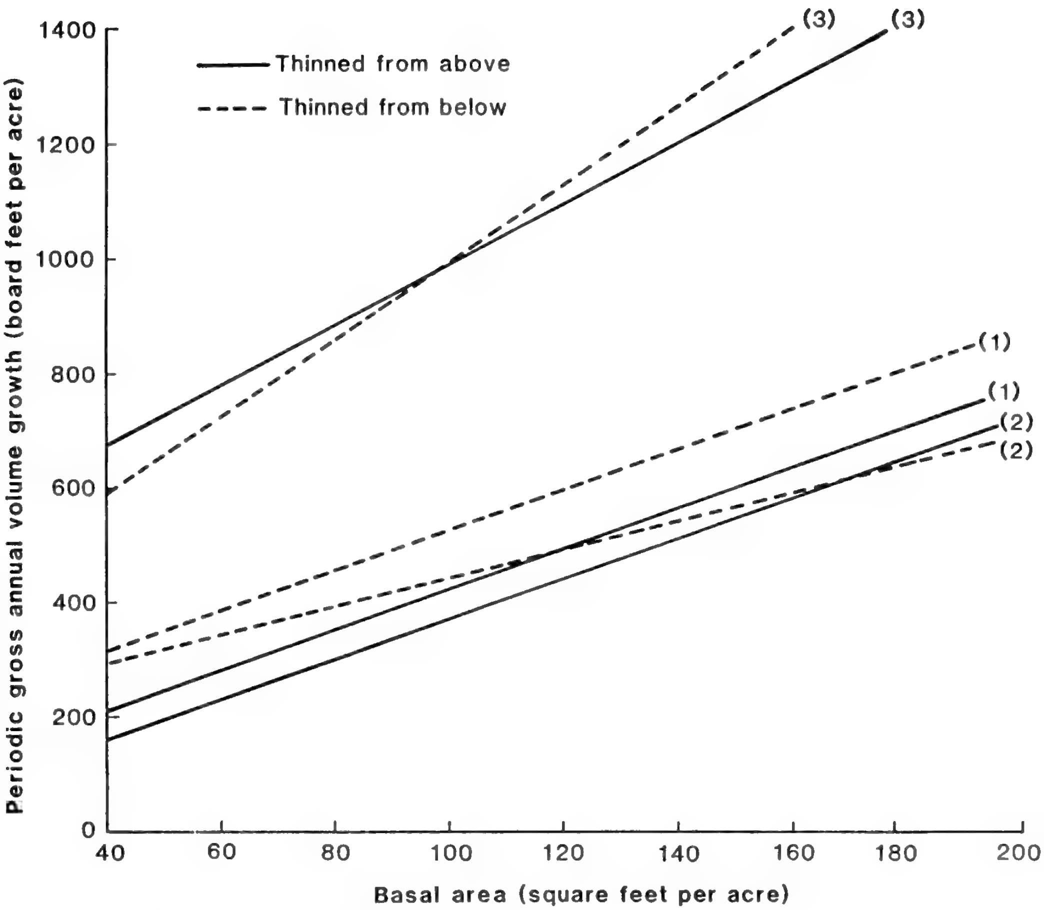

Figure 5—Perioic annual gross board-foot (International 1/4-inch rule) volume growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

Culmination of mean annual cubic increment appears to have occurred at about age 55; as expected, board-foot increment is still increasing (table 4). Cubic-and board-foot volume growth rates measured in this study from age 55 to 70 agree well with data from yield tables developed for larch in Montana (Schmidt and others 1976). Based on the Montana data, mean annual cubic increment in this study could be expected to decline slowly to about 100 cubic feet per acre at age 140 while mean annual board-foot increment increases to about 650 board feet per acre at the same age.

Thinning with the feller-buncher caused about 29 percent of the total area to be occupied by clearcut strips, with a corresponding 29-percent reduction in volume growth compared with a thinned area completely occupied by trees. The growth and mortality data on an area that includes the clearcut strips are shown in table 2.

Table 4—Net mean annual increment of western larch per acre

Basal area per acre	Age 55	60	65	70	Age 55	60	65	70
Square feet	- - - - Cubic feet - - - -				- - - Board feet - - - -			
AREA WITHOUT CLEARCUT STRIPS								
Thinned from above:								
50	130	120	115	110	488	472	452	468
90	110	104	99	96	337	335	334	376
130	125	119	120	125	491	482	494	568
170	114	108	102	100	328	354	358	409
Average	120	113	109	108	411	411	410	455
Thinned from below:								
50	125	119	115	113	446	437	429	450
90	122	117	115	116	380	392	363	453
130	131	125	121	120	354	374	372	473
170	135	131	128	134	481	507	527	605
Average	128	123	120	121	415	428	423	495
AREA WITH CLEARCUT STRIPS								
Thinned from above:								
50	93	85	82	78	347	335	321	332
90	78	74	70	68	239	238	237	267
130	89	84	85	89	349	342	351	403
170	81	77	72	71	233	251	254	285
Average	85	80	77	77	292	292	291	322
Thinned from below:								
50	89	84	82	80	317	310	305	320
90	87	83	82	82	270	278	258	312
130	93	89	86	85	251	266	264	336
170	96	93	91	95	342	360	374	430
Average	91	87	85	86	295	304	300	350

Total Yield and Tree Size

Total net yield in plots thinned from below increased as stand density became greater. Cubic-foot yield ranged from about 7,900 cubic feet per acre at the lowest density level to about 9,400 cubic feet at the highest level in 1985 (table 5). Board-foot yield was greatest at the highest level (42,000 feet per acre) in plots thinned from below, but only small differences were found between the other three levels (31,000 to 33,000 board feet per acre). Total yield in plots thinned from above did not show a consistent relationship to stand density but varied from about 6,700 to 8,600 cubic feet per acre. Averaged over all density levels, total net cubic-foot yield 15 years after the initial thinning was about 12 percent greater in plots thinned from below than in those thinned from above. In terms of board feet, plots thinned from below have a 9-percent advantage in yield.

Table 5—Total net growth and yield of western larch per acre, by density level and thinning method[1]

	Residual basal area level (square feet) and thinning method							
	50		90		130		170	
Item	Above	Below	Above	Below	Above	Below	Above	Below
				Number of trees				
Total trees, 1970	420	490	495	557	408	596	513	525
Cut, 1970	287	432	238	442	177	400	113	306
Left, 1970	133	58	257	115	231	196	400	219
Cut, 1980	35	12	43	13	22	21	53	29
Left, 1980	98	46	214	102	209	175	347	190
Total trees, 1985	82	46	168	98	189	149	278	182
15-year mortality	37	--	82	3	31	26	121	7
				Inches				
Quadratic mean diameter, 1985	11.4	16.3	10.4	14.6	12.3	13.2	10.1	14.4
				Percent				
Trees, 10 inches in d.b.h. and larger, 1985	57.0	100	45.7	100	72.2	88.8	49.0	100
				Cubic feet				
Total volume:								
Total stand, 1970	7,177	6,892	6,032	6,688	6,883	7,192	6,285	7,402
Cut, 1970	5,530	5,206	3,126	3,714	2,792	2,744	1,615	1,601
Left, 1970	1,647	1,686	2,906	2,974	4,091	4,448	4,670	5,801
Cut, 1980	193	333	283	320	399	354	44	413
Left, 1980	1,726	1,955	3,050	3,409	4,623	4,782	4,958	6,327
Net 15-year growth	545	1,015	710	1,360	1,725	1,208	715	1,978
Total net yield, 1985	7,722	7,907	6,742	8,048	8,608	8,400	7,000	9,380
				Board feet (International 1/4-inch rule)				
Merchantable volume:								
Total stand, 1970	26,816	24,555	18,540	20,898	27,020	19,479	18,045	26,446
Cut, 1970	24,000	16,224	12,853	7,395	13,030	2,689	7,991	2,006
Left, 1970	2,816	8,331	5,687	13,503	13,990	16,790	10,054	24,440
Cut, 1980	461	1,465	1,507	1,444	1,985	1,076	212	234
Left, 1980	4,921	10,171	7,361	17,425	17,118	20,402	15,082	31,991
Net 15-year growth	5,960	6,915	7,810	10,835	12,770	13,631	10,595	15,900
Total net yield, 1985	32,776	31,470	26,350	31,733	39,790	33,110	28,640	42,346

1/ Based on plots without clearcut strips.

In plots thinned from below, quadratic mean diameter in 1985 ranged from 13.2 to 16.3 inches (table 5). Although stand diameter was not greatly different among density levels, plots at the highest density contained more unmerchantable trees, which resulted in less merchantable volume when the second thinning was made. For example, at the 90-square-foot density level, 13 trees per acre removed in the second thinning from below yielded 1,444 board feet. In contrast, 29 trees per acre cut from the 170-square-foot level yielded only 234 board feet.

Discussion

It is evident that western larch stands have considerable ability to maintain diameter and volume growth despite attacks by the larch casebearer. In spite of heavy infestation of the casebearer during part of the second period, growth increased. Prolonged attacks, however, may have a more negative effect on growth. It is also encouraging to observe the excellent growth response during the third period after the second thinning when the casebearer was no longer present. Although the casebearer did not impact diameter growth at breast height[4/] or volume growth, it did have an adverse effect on height growth. In young stands a sustained reduction in height growth caused by insect damage can make the shade-intolerant larch lose its competitive advantage to its more shade-tolerant associates and eventually be eliminated from the stand.

Gross cubic volume growth in plots thinned from above was about equal to growth in plots thinned from below, but because of much greater mortality in plots thinned from above net growth was considerably less in these plots. The smaller trees remaining are not able to withstand wind, snow, and ice after the protection of the larger dominant and codominant trees is removed. Therefore, thinning from below is recommended in previously unmanaged larch stands.

Selecting a suitable stocking level after thinning is a compromise between high stand densities that produce the most wood volume and low densities that result in greater diameter growth. In this study, net periodic cubic volume increment and yield did not differ greatly among density levels; and diameter growth was also relatively uniform, except at the lowest level. Therefore, the land manager has considerable latitude in selecting an appropriate growing stock level to attain desirable product characteristics. In terms of timber management, stands should be thinned from below to a level that will maintain acceptable tree vigor and diameter growth and will minimize mortality without sustaining unacceptable volume losses.

Comparisons of the stand density levels in this study with stocking-level curves for larch prepared by Cochran (1985) show that plots initially thinned to 130 square feet of basal area per acre (level 3) fall between the lower (minimum) and upper (maximum) curves for site index 80 stands. The 50- and 90-square-foot levels are below the minimum stocking curve, whereas the 170 level is near the maximum curve. To reduce stand density to correspond to the minimum curve, a residual basal area of about 110 square feet per acre is indicated if the average stand diameter is about 12 inches.[5/]

[4/] Although diameter growth at breast height was not affected by defoliation, the effects of defoliation are usually greatest in the live crown and therefore diameter growth may have been reduced in the upper portions of the bole (Kulman 1971).

[5/] The lower and upper stocking-level curves given by Cochran (1985) are based on 45 and 75 percent of normal stocking, respectively.

In a shade-intolerant species such as western larch, early thinning is necessary. Although thinning in older stands can increase diameter and volume growth of residual trees, the greatest gain from thinning seral species (such as larch) is obtained when thinning is begun much earlier. Schmidt (1966) suggests that the ideal time for precommercial thinning of larch is when trees are about 10 years old and 10 to 15 feet tall. Such early thinning maintains vigorous, full-crowned trees and concentrates the rapid growth during the sapling and pole stages on crop trees. In addition, trees in stands thinned early develop greater resistance to wind, snow, and ice damage than trees growing in dense stands.

To summarize, early precommercial thinnings when trees are about 10 years old and 10 to 15 feet tall are recommended in overstocked young larch stands. The spacing selected should result in a diameter growth rate that will allow merchantable trees to be cut in the next (commercial) thinning. A range in spacings of 13 to 19 feet after the precommercial thinning should meet this objective. Using a closer spacing assumes that smaller trees will be salable at the time of the commercial thinning, whereas a wider spacing implies that larger trees are needed for the commercial thinning. After the stand reaches merchantable size, thinnings from below to reduce basal area to the minimum curve (Cochran 1985) are recommended.

Metric Conversions

1 mile = 1.61 kilometers
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.0700 cubic meter/hectare
1 tree/acre = 2.47 trees/hectare

Literature Cited

Cochran, P.H. Site index, height growth, normal yields, and stocking levels for larch in Oregon and Washington. Res. Note PNW-424. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 23 p.

Kulman, H.M. Effects of insect defoliation on growth and mortality of trees. Annual Review of Entomology. 16: 289-324; **1971.**

Schmidt, Wyman C. Growth opportunties for western larch. Res. Note INT-50. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; **1966.** 4 p.

Schmidt, Wyman C.; Shearer, Raymond C.; Roe, Arthur L. Ecology and silviculture of western larch forests. Tech. Bull. 1520. Washington, DC: U.S. Department of Agriculture, Forest Service; **1976.** 96 p.

Seidel, K.W. Response of western larch to changes in stand density and structure. Res. Note PNW-258. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1975.** 11 p.

Seidel, K.W. Growth of western larch after thinning from above and below to several density levels: 10-year results. Res. Note PNW-366. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1980.** 20 p.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

.S. Department of Agriculture
acific Northwest Research Station
19 S.W. Pine Street
O. Box 3890
ortland, Oregon 97208

fficial Business
enalty for Private Use, $300

BULK R
POSTAG
FEES P
USDA-
PERMIT No