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Growth and Yield of Western Larch: 15-Year Results of a Levels-of-Growing-Stock Study

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Abstract

The 15-year growth response from a levels-of-growing-stock study in an even-aged western larch (Larix occidentalis Nutt.) stand in northeastern Oregon, first thinned at age 33, showed that trees growing at lower stand densities grew more rapidly in diameter but did not grow faster in height than trees in high density plots. Both basal area and total cubic volume increment increased as stand density increased. Despite the large reduction in volume increment at the lower densities, however, most of the wood is concentrated on fewer, faster growing trees that can reach usable size sooner.

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

Introduction

Levels-of-growing-stock and spacing studies provide information on long-term growth and yield for managed stands that is needed to verify simulation models and design thinning schedules to meet timber production and multiple use objectives. In 1966, a levels-of-growing-stock study was begun in young, even-aged western larch (Larix occidentalis Nutt.) in northeastern Oregon. The study was done to provide information on the growth response of western larch to a wide range of stocking levels. This paper reports results 15 years after the study was begun. Results for the first 5 and 10 years were reported by Seidel (1971, 1977).

Study Area and Methods

The study is located on the Union District of the Wallowa-Whitman National Forest about 15 miles southeast of Union, Oregon, at an elevation of about 4,000 feet. The stand was 33 years old in 1966 and has a site index of about 80 feet at age 50.[1]

[1] Site index based on curves in "Ecology and Silviculture of Western Larch Forests" (Schmidt et al. 1976).

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All plots were well stocked before the initial thinning, each containing at least 25,000 square feet of bole area per acre (table 1). There were about 1,300 trees per acre, averaging 4.5 inches in diameter at breast height (d.b.h.) and 45 feet tall. All trees are larch except for one plot at the highest density level and one plot at the second highest level where about 40 percent of the bole area and basal area left after the initial thinning was lodgepole pine (Pinus contorta Dougl. ex Loud.).

The soil is a Tolo silt loam, which is a well-drained Regosol developed from dacite pumicite originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. It is underlain at a depth of about 3 feet by a buried soil developed from basalt.

Ground vegetation on the study area is typical of the Abies grandis/ Calamagrostis rubescens plant community (Franklin and Dyrness 1973). Genera of shrubs and herbs such as Arnica, Hieracium, and Ribes are common.

The experiment is a levels-of-growing-stock study designed for thinning at 10-year intervals. It consists of a completely randomized design with two replicates of five levels of growing stock installed on ten 0.4-acre plots (each surrounded by a 30-foot-wide buffer strip). The growing-stock levels selected for testing are 5,000, 10,000, 15,000, 20,000, and 25,000 square feet of bole area per acre.[2/] Actual stand densities after thinning in terms of bole area and basal area are given in table 1. The two plots assigned to each density level were thinned to the same bole area level in 1966 and 1976.

In general, plots were thinned from below to leave the required number of the largest and most vigorous trees as evenly spaced as possible (fig. 1). None of the slash from the thinnings was removed from the plots.

Diameters of all plot trees were measured to the nearest 0.1 inch after the 1965, 1970, 1975, and 1980 growing seasons. On each plot, about 15 trees, proportionately distributed over the range of diameters, were measured with an optical dendrometer in 1966, 1970, 1975, and 1980. The measurements were used to calculate an equation expressing volume and bole area of the entire stem inside bark as a function of diameter. New equations were calculated after each measurement and used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the three 5-year growth periods (1966-70, 1971-75, 1976-80). Height growth of trees chosen for volume equation measurements was measured by dendrometer.

Split-plot-in-time analyses of variance were used to test significance of treatment effects; and nonlinear regression analyses related diameter, basal area, and volume growth to residual bole area and basal area.

[2/] Bole area is a close approximation of the cambial area of the main stem. See Lexen (1943) and Smith (1962, p. 102) for a discussion of the advantages of bole area as a measure of stand density.

Table 1--Stand characteristics per acre of western larch before and after the 1966 and 1976 thinnings and in 1971 and 1981

Level[1]	Density: Bole area	Density: Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height[2]	Volume[3]: Total	Volume[3]: Merchantable (including ingrowth)	Volume[3]: Merchantable (including ingrowth)
	- Square feet -			Feet	Inches	Feet	- - Cubic feet - - -		Board feet
Before initial (1966) thinning:									
1	25,800	118.6	924	6.9	4.9	48.4	1,995	1,180	48
2	31,125	132.7	1,161	6.1	4.6	46.2	2,287	1,088	--
3	34,180	139.2	1,406	5.6	4.3	46.5	2,367	855	193
4	32,880	143.7	1,377	5.6	4.4	42.9	2,322	1,125	--
5	32,700	135.6	1,459	5.5	4.1	42.0	2,200	964	--
Average	31,337	134.0	1,265	5.9	4.5	45.2	2,234	1,048	48
After 1966 thinning:									
1	4,708	26.0	96	21.3	7.0	48.4	474	389	48
2	9,524	49.6	215	14.2	6.5	46.2	902	648	--
3	14,242	70.9	355	11.1	6.1	46.5	1,272	782	193
4	19,313	96.4	546	8.9	5.7	42.9	1,616	1,039	--
5	24,203	109.8	745	7.6	5.2	42.0	1,847	961	--
1971:									
1	6,374	40.3	96	21.3	8.8	55.4	794	678	948
2	12,069	68.2	215	14.2	7.6	51.7	1,333	1,060	294
3	17,797	93.4	354	11.1	7.0	53.3	1,780	1,261	532
4	23,810	120.5	539	9.0	6.4	49.1	2,250	1,562	345
5	29,121	134.3	740	7.7	5.8	48.0	2,510	1,435	102
Before 1976 thinning:									
1	8,730	56.3	96	21.3	10.4	62.7	1,222	1,164	3,654
2	15,207	86.1	215	14.2	8.6	56.6	1,870	1,716	2,366
3	21,716	114.8	354	11.1	7.7	58.2	2,471	2,173	1,464
4	29,244	143.9	534	9.0	7.0	55.5	3,103	2,584	1,168
5	33,917	155.7	734	7.7	6.2	53.6	3,317	2,445	706
After 1976 thinning:									
1	5,078	34.2	51	29.2	11.1	64.9	760	731	2,876
2	10,006	59.3	129	18.4	9.2	62.8	1,301	1,216	2,368
3	15,012	82.7	225	13.9	8.2	62.7	1,808	1,627	1,464
4	20,029	104.0	333	11.4	7.6	60.9	2,248	1,957	1,168
5	24,779	121.0	464	9.7	6.9	61.7	2,621	2,138	706
1981:									
1	6,592	44.6	51	29.2	12.6	72.8	1,146	1,116	5,110
2	12,505	72.9	129	18.5	10.3	68.9	1,862	1,770	4,949
3	18,737	99.3	224	13.9	9.0	67.8	2,412	2,264	3,583
4	24,433	121.2	329	11.6	8.3	66.4	2,986	2,740	2,797
5	29,960	137.6	462	9.8	7.4	66.0	3,398	2,959	1,357

[1]Two plots for each density level.

[2]Average height of trees measured with dendrometer (about 15 per plot).

[3]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 (International 1/4-inch rule) volume--trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.

Figure 1.--One of the 10,000-square-foot-bole-area density plots after initial thinning in 1966, with an average spacing of 14 feet. Basal area is about 50 square feet per acre.

Results

Diameter Growth

Diameter growth showed a consistent relationship to stand density during all three 5-year growth periods. Growth was greatest on the most heavily thinned plots and decreased as bole area increased (table 2), partly because the number of smaller, slower growing trees in the high density plots was larger. During the second period, the diameter growth rate (0.32 inch per year) at the lowest density was four times the growth at the highest density (0.08 inch per year). All differences in diameter growth rate between growing-stock levels were significant ($P < 0.01$).

Diameter growth was significantly greater ($P < 0.01$) in the first period at each density level than in the second and third periods, but there was no significant difference in growth between the second and third periods. No significant interaction existed between growth periods and growing-stock levels.

The effect of the second thinning (1976) was to prevent the normal decline in diameter growth associated with age and greater stand density, rather than increasing growth above that of the second period.

Table 2--Periodic annual increment and mortality per acre of western larch by age and density level after thinning at age 33 and 43

Age and density level	Residual density: Bole area	Residual density: Basal area	Diameter growth[1]	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	Ingrowth	75 largest trees: Diameter growth[1]	75 largest trees: Gross total volume growth
	- Square feet -		Inch	- - Square feet - -			- - Cubic feet - -			- - Board feet - - -			Board feet	Percent	Inches	Cubic feet
Age, 33-38 years:																
1	4,700	26.0	0.36	2.86	--	2.86	64	—	64	180	—	180	170	94.4	0.36	54
2	9,500	50.0	.23	3.72	--	3.72	86	--	86	59	--	59	59	100.0	.27	40
3	14,250	71.0	.18	4.50	0 03	4.53	102	1	103	68	—	68	43	63.2	.24	31
4	19,300	96.0	.14	4.82	.19	5.01	127	4	131	69	--	69	69	100.0	.22	30
5	24,200	110.0	.11	4.90	.17	5.07	133	3	136	22	—	22	22	100.0	.19	28
Age, 38-43 years:																
1	6,400	40.0	.32	3.20	—	3.20	85	—	85	541	—	541	403	74.5	.33	73
2	12,100	68.0	.19	3.58	--	3.58	107	—	107	414	--	414	374	90.5	.20	48
3	17,800	93.0	.15	4.28	—	4.28	138	—	138	186	—	186	130	70.2	.18	48
4	23,800	120.1	.12	4.69	.16	4.85	170	3	173	164	--	164	125	76.2	.16	44
5	29,100	134.0	.08	4.29	.11	4.40	161	2	163	120	—	120	96	80.0	.14	32
Age, 43-48 years:																
1	5,078	34.0	.31	2.07	—	2.07	78	--	78	447	—	447	129	28.1	.31	78
2	10,006	59.0	.20	2.73	--	2.73	113	—	113	517	--	517	333	66.4	.22	79
3	15,012	83.0	.15	3.32	—	3.32	121	--	121	424	--	424	323	76.6	.18	55
4	20,029	104.0	.13	3.44	.05	3.49	147	1	148	326	--	326	227	73.1	.15	51
5	24,779	121.0	.10	3.32	.06	3.38	156	1	157	131	—	131	101	77.4	.13	44

[1] Arithmetic diameter growth of trees living through three 5-year periods (1966-70, 1971-75, 1976-80).

A significant ($P < 0.01$) curvilinear relationship existed between periodic annual diameter increment and bole area or basal area of the stand at the beginning of each growth period (figs. 2 and 3). Bole area and basal area each accounted for about 98 percent of the variation in diameter growth between plots. Because of the excellent correlation between diameter growth and stand density, land managers can, with a high degree of confidence, predict diameter growth rates after thinning larch stands of this age and site index (80 at age 50).

During the 15 years of this study, the mean stand diameter increased by 7.7 inches in the lowest density plots compared with a 3.3-inch increase in the highest density plots (table 3). About one-half of this increase in diameter during the 15-year period is the result of removing the smaller trees in the two thinnings. Because of the cutting of these smaller trees and faster growth on the residual trees in the lowest density plots, the mean diameter in these plots was 70 percent greater in 1981 than in the highest density plots (12.6 vs. 7.4 inches) (table 1). Diameter growth of larch and lodgepole pine was similar during all periods.

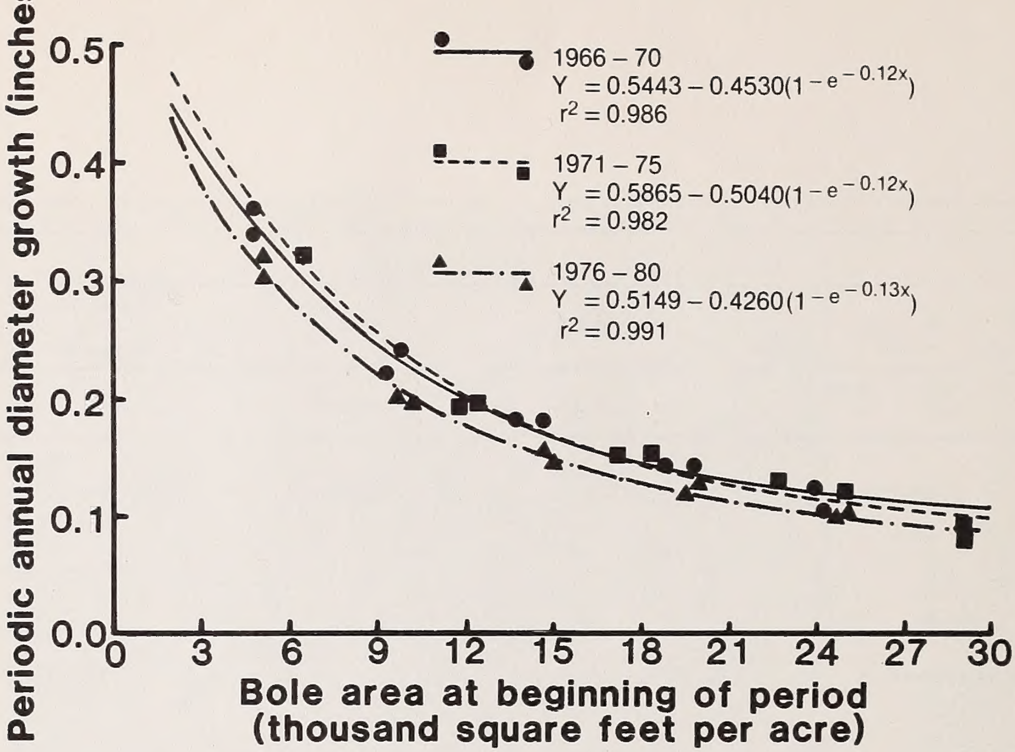

Figure 2.--Periodic annual diameter increment by density level (bole area) and growth period.

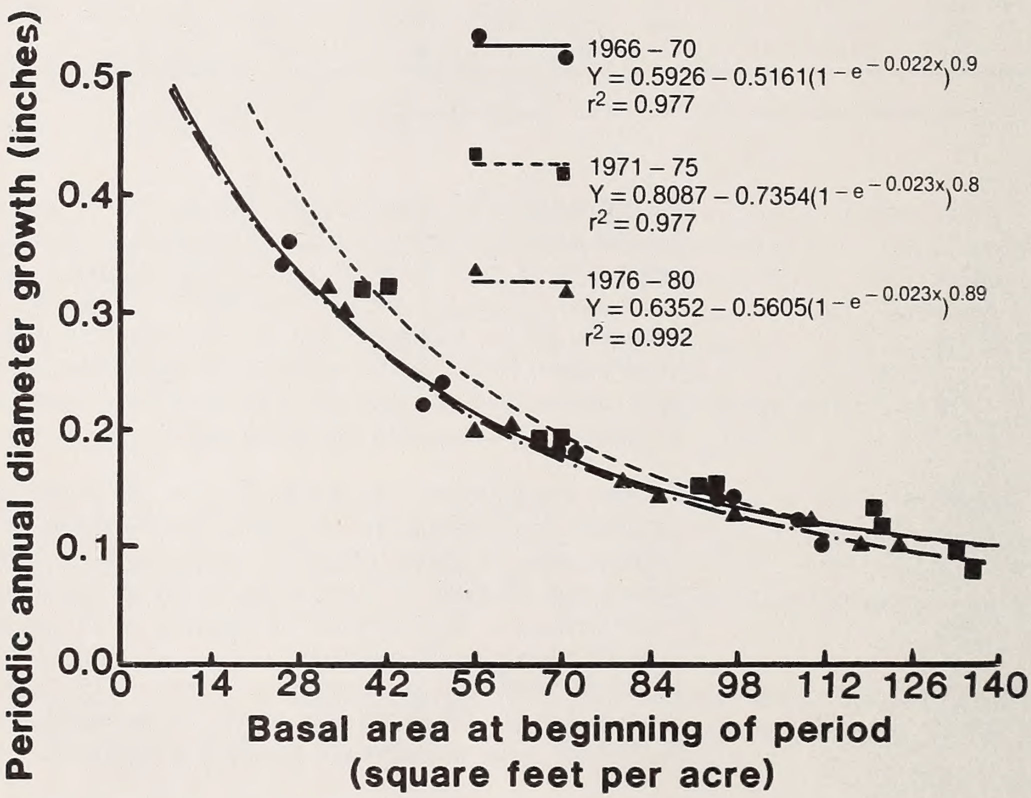

Figure 3.--Periodic annual diameter increment by density level (basal area) and growth period.

Table 3—Increase in quadratic mean diameter of a western larch stand from 1966 to 1980 as a result of growth and 2 thinnings

Period and bole area level	Increase in quadratic mean diameter	Increase attributed to--		
		Thinning	Growth	
Thousand square feet per acre	Inches	Inches	Inches	Percent
1966-70:				
5	3.9	2.1	1.8	46
10	3.0	1.9	1.1	37
15	2.7	1.8	.9	33
20	2.0	1.3	.7	35
25	1.7	1.1	.6	35
1971-75:				
5	2.3	.7	1.6	70
10	1.6	.6	1.0	63
15	1.2	.5	.7	58
20	1.2	.6	.6	50
25	1.1	.7	.4	36
1976-80:				
5	1.5	--	1.5	100
10	1.1	--	1.1	100
15	.8	--	.8	100
20	.7	--	.7	100
25	.5	--	.5	100
1966-80:				
5	7.7	2.8	4.9	64
10	5.7	2.5	3.2	56
15	4.7	2.3	2.4	51
20	3.9	1.9	2.0	51
25	3.3	1.8	1.5	45

Height Growth

Height growth was relatively uniform among density levels, average increment ranging from 0.9 foot to 1.6 feet annually (fig. 4). A significant difference ($P < 0.05$) in height growth among density levels was found because of the increased growth at the lowest level. Differences in growth between periods were not significant, but there was a tendency for height growth to decline during the third period at the two highest stocking levels. Larch and lodgepole pine both grew in height at about the same rate.

Mortality

Mortality was light during the 15 years of this study. Only 12 of the 1,567 study trees died during the first period, 7 during the second period, and 3 during the third period. All mortality occurred in the two highest density levels, except for one tree that died in one of the middle density plots. During the third period (1976-80), a light to moderate infestation of the larch casebearer (*Coleophora laricella* Hbn.) was present on all plots.

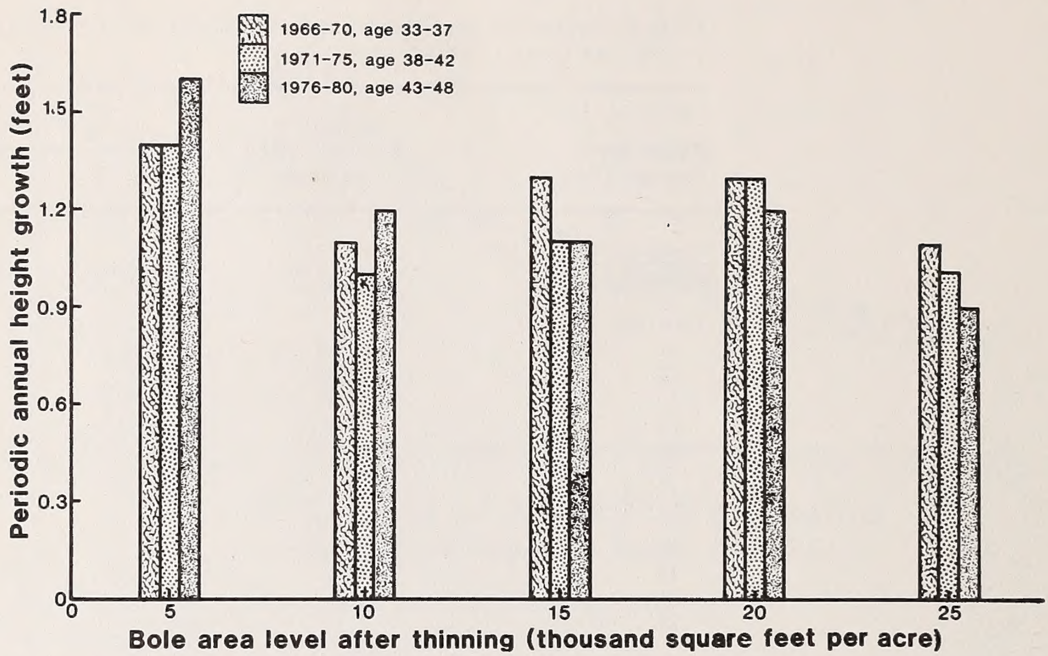

Figure 4.--Periodic annual height increment by density level (bole area) and growth period.

Basal Area Growth

Basal area increment increased during all periods with increasing stand density, although there was a slight decline at the highest level during the second and third periods (table 2). Differences among density levels were significant ($P < 0.01$). Growth slowed significantly ($P < 0.01$) from the first to second period and from the second to third period (figs. 5 and 6). Bole area and basal area were about equal as predictors of basal area increment. The interaction between density and growth period was also significant ($P < 0.01$), primarily because of the increase in growth at the lowest density level from the first to the second period in contrast to a decrease at the other four levels.

Volume Growth

Total gross cubic volume increment was excellent during the 15-year study period, reaching a high of 173 cubic feet per acre annually during the second period (table 2). Volume growth increased with rising growing stock level during all periods, and difference among density levels was significant ($P < 0.01$). Gross cubic increment increased significantly ($P < 0.01$) from an average of 104 cubic feet per acre per year during the first period to 134 the second period and then declined slightly to 123 cubic feet per acre annually during the third period. Net volume growth was essentially the same as gross volume growth because of the small amount of mortality during the study.

Volume increment was about twice as great on the highest density plots as on the lowest during all periods; but much of the growth at high densities is distributed on a large number of smaller, slower growing trees.

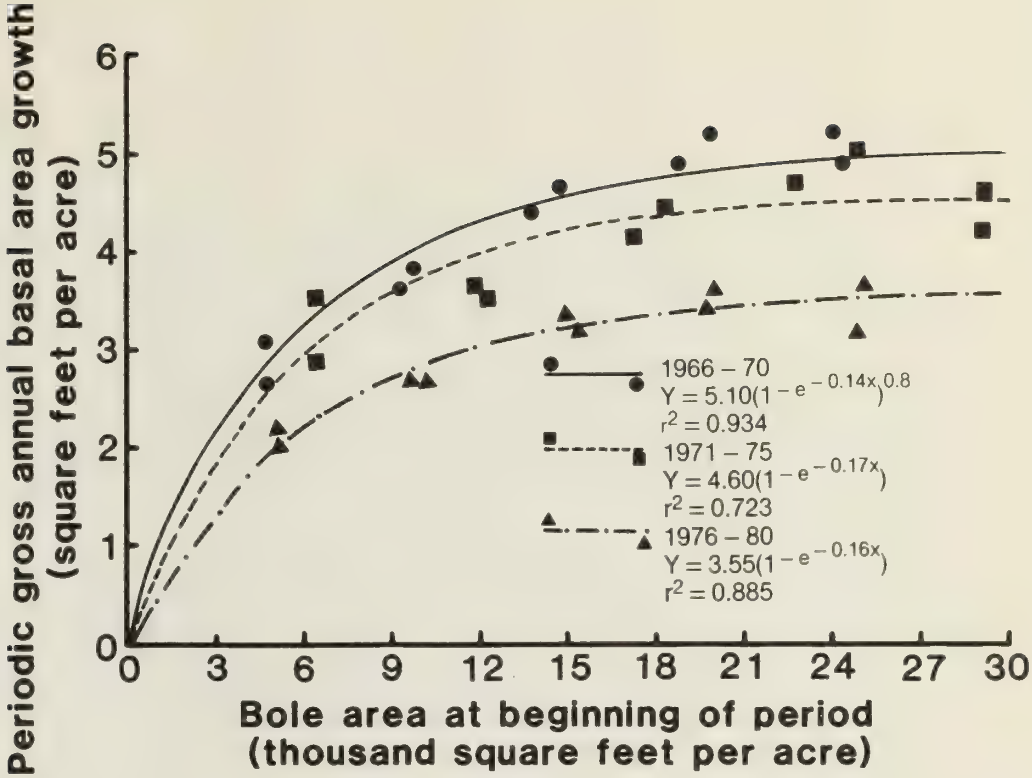

Figure 5.--Periodic gross annual basal area increment by density level (bole area) and growth period.

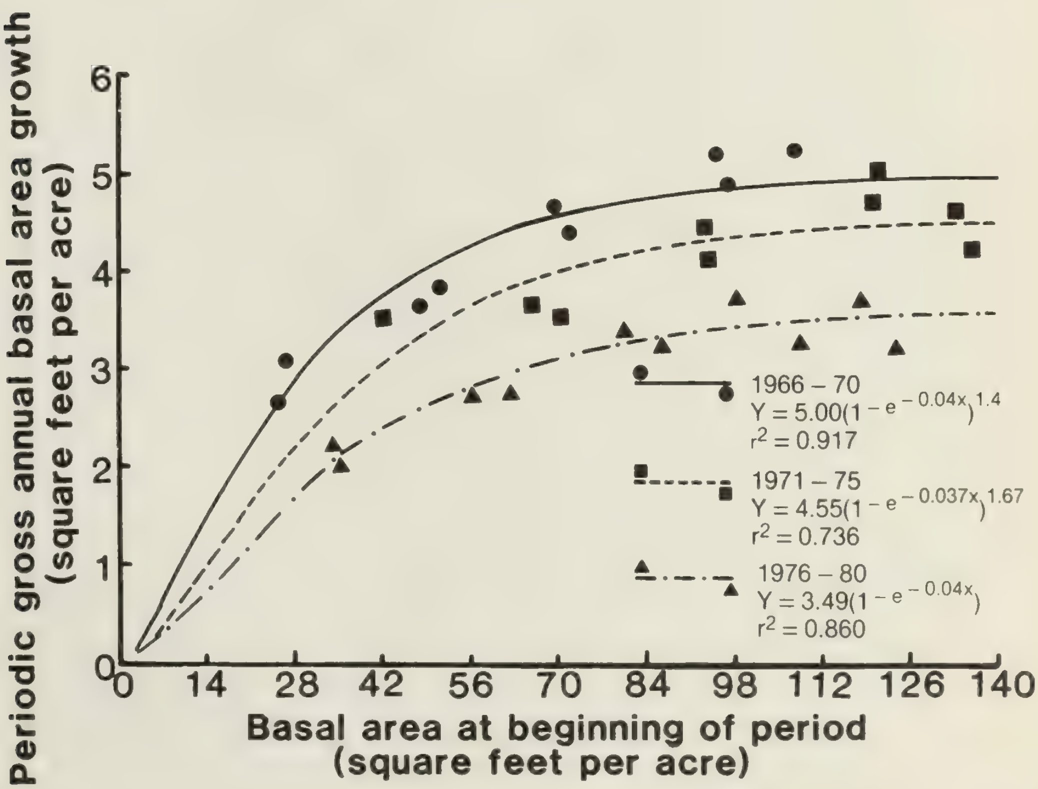

Figure 6.--Periodic gross annual basal area increment by density level (basal area) and growth period.

The regressions of volume increment on bole area (fig. 7) and on basal area (fig. 8) accounted for about 80 to 92 percent of the variation in volume increment during the three periods. Although these regressions show increased growth with rising stand density, increment was only slightly more at the highest density than at the second highest level during the first period and decreased somewhat during the second and third periods (table 2). This suggests that full site utilization occurs as stocking approaches 25,000 square feet of bole area per acre and that increasing stocking beyond this level may not result in an increase in total volume increment.

Gross volume growth of the 75 largest trees per acre responded to stand density in the same manner as diameter growth during all three periods--growing faster at the lowest density level (table 2). Growth of these larger trees was about twice as great at the lowest density as at the highest, showing how growth is transferred to the larger trees more rapidly in the low density plots.

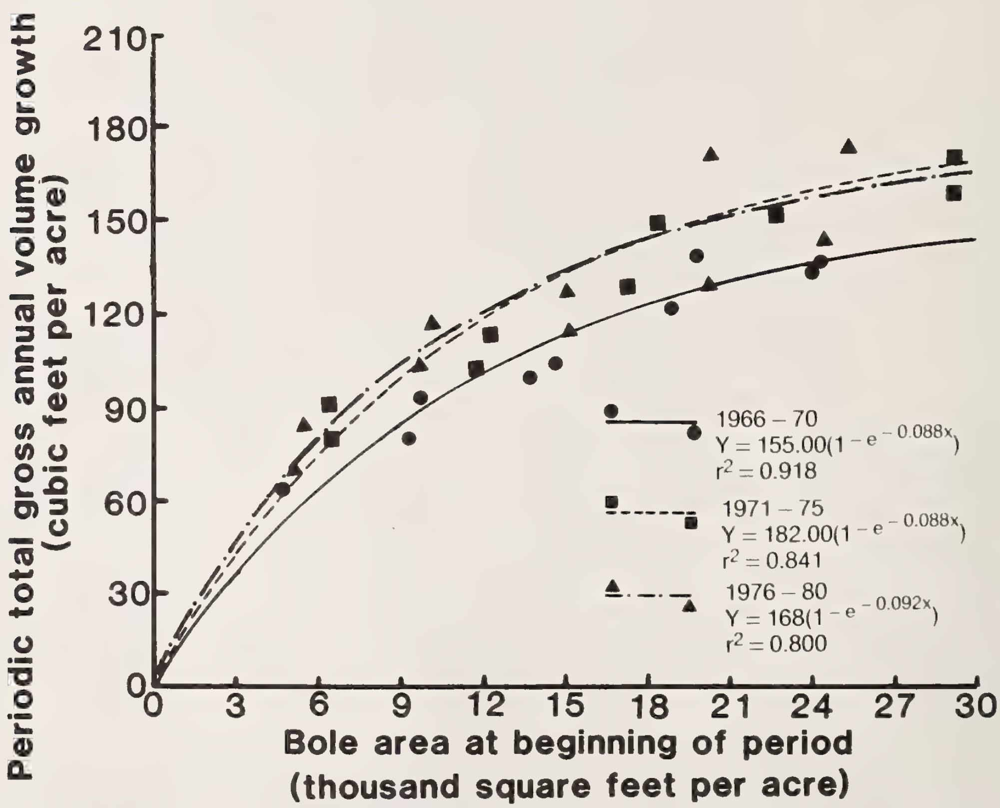

Figure 7.--Periodic total gross annual cubic volume increment by density level (bole area) and growth period.

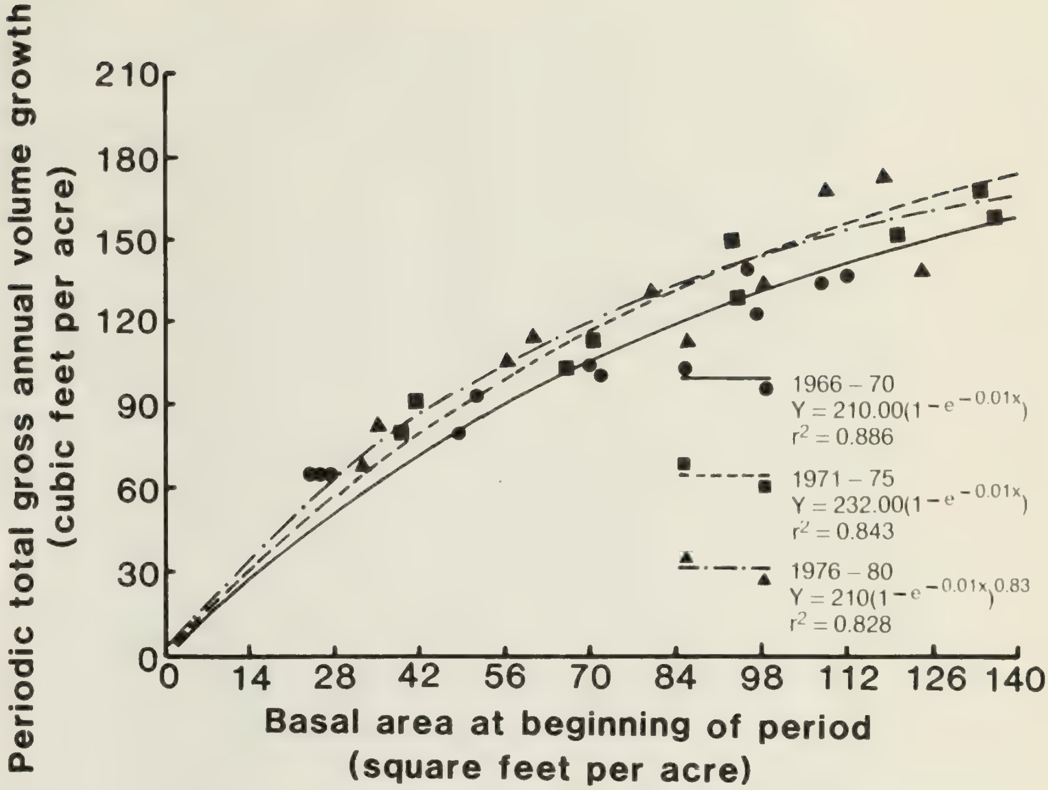

Figure 8.--Periodic total gross annual cubic volume increment by density level (basal area) and growth period.

Board-foot volume increment increased significantly ($P < 0.01$) during the second and third periods compared with the first period. Growth in the 15,000- and 20,000-square-foot-bole-area plots during the third period showed significant ($P < 0.01$) increases over the first two periods because trees were now merchantable size or reaching that size (ingrowth). Ingrowth still accounts for the largest portion of the board-foot growth on most plots during the third period, except for the lowest density plots where all trees are now merchantable.

Mean cubic annual increment continues to increase at all density levels (table 4). Based on data from yield tables developed for larch in Montana (Schmidt et al. 1976), culmination of mean annual increment will probably occur at 60 to 70 years of age.

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

Bole area level	Age (years)			
	33	38	43	48
Thousand square feet per acre	---------- Cubic feet ----------			
5	60	61	64	65
10	69	72	76	80
15	72	76	83	87
20	70	78	89	95
25	67	75	85	93

Discussion

Growth response to changes in stand density was similar during all three 5-year periods, with diameter growth decreasing and cubic volume and basal area growth increasing as stocking increased. Thinning from below has effectively concentrated growth on a small number of crop trees in the low density plots where the average diameter in 1981 was 12.6 inches compared with 7.4 inches in the high density plots (table 5).

Because the greatest diameter growth occurs at low stand densities, whereas high densities result in the most cubic volume growth, it obviously is not possible to maximize both diameter growth per tree and volume growth per acre. Therefore, if markets for small trees exist and frequent commercial thinnings are possible to utilize mortality, a high residual stand density is indicated to more fully use the productive capacity of the site and to maximize wood production. If, on the other hand, no pulpwood market exists and the management objective is to shorten the rotation and increase water and forage yields, a heavier precommercial thinning is necessary--with a sacrifice of some volume growth.

In a shade intolerant species such as western larch, early thinning should have a high priority. Competition in young, overstocked larch stands results in reduction of the crown with subsequent decreases in diameter and height growth. In addition, small, low-vigor trees are not as resistant to damage from wind, snow, insects, and diseases as trees having adequate growing space. Schmidt (1966) suggests that the ideal time for precommercial thinning of larch is when trees are about 10 years old and from 10 to 15 feet tall.

Although the greatest benefits from precommercial thinning occur in young, 10- to 15-year-old stands before crowns begin to shorten, considerable gains are still possible from precommercial thinning in older stands as demonstrated in this study. The younger stands, however, should be given preference for precommerial thinning.

Table 5--Total net growth and yield of western larch by stocking level (per acre)

Item	Residual bole area level (thousand square feet)				
	5	10	15	20	25
			Number of trees		
Total trees, 1966	924	1,161	1,406	1,377	1,459
Cut, 1966	828	946	1,051	831	714
Left, 1966	96	215	355	546	745
Cut, 1976	45	86	130	213	281
Left, 1976	51	129	225	333	464
15-year mortality	--	--	1	4	2
Total trees, 1981	51	129	224	329	462
			Inches		
Quadratic mean diameter, 1981	12.6	10.3	9.0	8.3	7.4
			Percent		
Trees 10 inches in d.b.h. and larger, 1981	100	51.7	24.3	14.1	4.7
			Cubic feet		
Total volume:					
Total stand, 1966	1,995	2,287	2,367	2,322	2,200
Cut, 1966	1,521	1,385	1,095	706	353
Left, 1966	474	902	1,272	1,616	1,847
Cut, 1976	462	569	663	855	696
Left, 1976	760	1,301	1,808	2,248	2,621
Net 15-year growth	1,134	1,529	1,803	2,225	2,247
Total net yield, 1981	3,129	3,816	4,170	4,547	4,447
			Board feet		
Merchantable volume:					
Total stand, 1966	48	--	193	--	--
Cut, 1966	--	--	--	--	--
Left, 1966	48	--	193	--	--
Cut, 1976	778	--	--	--	--
Left, 1976	2,876	2,366	1,464	1,168	706
Net 15-year growth	5,840	4,949	3,390	2,797	1,365
Total net yield, 1981	5,888	4,949	3,583	2,797	1,365

Metric Conversions

1 mile = 1.61 kilometer
1 foot = 0.3048 meter
1 inch = 2.54 centimeter
1 acre = 0.4047 hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare

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