Growth & development of older PLANTATIONS in northwestern Pennsylvania

by Ted J. Grisez

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Contents

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A New Look at Old Plantations

BY RE-EXAMINING some of the oldest plantations in northwestern Pennsylvania, we have gained new insights into the survival and growth of these planted trees. And we have changed some of our ideas about which species should be favored for planting in this area.

Most evaluations of the species used in plantations are based on survival and growth at an early age. Formal measurements commonly are discontinued after 5 to 10 years; and later evaluations, if any, are based on only general observations.

But the volume and value of wood products that a plantation will produce cannot be estimated with any reasonable precision until height growth has shown how the site suits each species, and volume growth is well under way. The performance of a species

may change markedly between age 10 and age 50. The relative heights of two or more planted species may differ greatly between youth and middle age.

In northwestern Pennsylvania, thanks to a previous study by J. E. Hetzel,[1] we have records on enough plantations now close to 50 years old so we can get a good idea of how valuable a number of species are for reforestation, particularly on old fields. Hetzel in 1939 had located and examined more than 40 plantations in this area, most of which were then between 18 and 27 years old. Besides his published report *(Hetzel 1941)*, we have his study files, which enabled us to relocate the plantations. His records also contained information about planting each species in each plantation.

Having this excellent data, we decided to revisit and re-measure as many of these plantations as possible. Our purpose was to evaluate the species, mainly in terms of volume production, and to compare the results in a general way with those Hetzel got in 1939.

Hetzel had recorded the height, diameter, crown class and form of a sample (usually 20 or 25 trees) of each species in each plantation. Presumably the trees were randomly selected. The records are not clear as to whether the trees were selected as a group or were scattered. In some of the smaller plantations, nearly all suitable trees obviously had to be measured.

His planting information included date, age of stock, spacing, and use of land before planting. Site data—such as elevation, frost danger, soil texture, drainage, pH, humus, and litter—were recorded. He also described the condition of each plantation and noted the presence of insects and damage due to other causes.

All but 7 of Hetzel's 41 plantations were suitable for re-measurement. We also measured three other plantings for which age records were available, making a total of 37 plantations for our study.

Although Hetzel examined only 41 separate plantations, his plantation numbers went up to 72 because he assigned a number to each species that he measured in the mixed plantings. Thus, for

[1] Then Junior Forester with the Allegheny Forest Experiment Station, which was later combined with the Northeastern Forest Experiment Station.

example, his numbers 3 and 4 refer to a single mixed planting of two species—red pine and scotch pine. Not every species was numbered in every mixture; the unnumbered species were the near or total failures. To facilitate cross reference, we have retained Hetzel's numbers in our study.

The 37 plantations ranged in age from 36 to 64 years from seed, and averaged 45 years. All but 3 of them were between ages 39 and 54.

Methods

The plantations were scattered through northwestern Pennsylvania from Erie County to Potter County and south to Venango, Armstrong, and Jefferson Counties. All were on private land or on the grounds of a state institution.

We established one temporary plot in each plantation. In larger plantations, we selected a location that had uniform site and stand conditions, particularly with regard to residual or volunteer hardwoods. This no doubt resulted in an upward bias of the stand stocking figures, but we wanted a measure of the productive capacity of a species or mixture on each site, not a sample of the average condition. We always excluded the outer two rows. Our original plan was to take plots of about 1/5 acre, but several plantations were not large enough for a plot of that size. However, all but six plots were 1/10 acre or larger. All mixed plantations were single-tree mixtures or some type of row mixture; hence only one plot was required to sample the two or more species that were involved.

On each plot, we measured diameter (breast high) to the nearest 0.1 inch on all living planted trees, and on all living volunteers that were 4.6 inches d.b.h. or larger. All basal area figures were derived from these same trees.

Crown class and form of each tree were recorded. Standard crown classes, as defined by the Society of American Foresters *(1944)*, were used. Form was defined as follows:

1. Entire stem straight enough for present or potential sawlogs; *no forks.*

2. Straight, as above, for the butt 16-foot log.
3. Not as above, but suitable for pulpwood—at least two consecutive 4-foot bolts. (May include sawlogs or potential sawlogs above a butt section.)
4. Not suitable for pulpwood because of forks or crooks.

About 20 trees of each species in each plantation sample plot were selected for measuring merchantable and total height. These were used for computing site index and volume.

Height and diameter of all stumps judged to have supported trees 4.6 inches d.b.h. or larger were measured. We used these measurements to estimate the diameter and volume of trees that had been removed in thinnings.

In our observations and records for each plantation we included aspect, slope, crown density, condition of the plantation, evidence of pests, area of ground covered by herbs, shrubs, or tree seedlings, and soil information. Soil data included pH, type of humus, and depth of litter, F- and H-layers at two spots, and soil type. Soil types were identified by scientists from the U.S. Soil Conservation Service.

Site-index values were obtained from applicable 50 year-site-index curves for the various species. Since most of the plantations were close to age 50, the estimates should be very good.

We computed volumes from the most appropriate volume tables available. Cubic volumes for most of the exotic species were computed as in the Lake States Composite Table *(Gevorkiantz and Olsen 1955)*, with appropriate corrections for bark volume and form quotient. Board-foot volumes of exotic species were obtained from Bickford's form-class volume tables for northern conifers *(1951)*. Cubic-foot volumes are net volume in all trees 4.6 inches d.b.h. and up, inside bark, to a 4.0-inch top. Board-foot volumes indicate gross volume in merchantable logs in softwood trees 9.6 inches d.b.h. and up, and in hardwoods 11.6 inches and up. This was virtually the same as net volume because very little cull was involved.

Results

To our surprise we found—in this day of road-building, utility-line clearing, strip-mining, and suburban sprawl—that not a single plantation had been destroyed by land-clearing in the 21 or 22 years since Hetzel visited them.

Less unexpected was that about two-thirds of the plantations had never been thinned. Only 13 of the 37 plantations had been thinned in the 5-inch or larger diameter classes, and in 7 of the 13 thinned ones less than 10 percent of the yield had been cut.

BASIC DESCRIPTIVE DATA

Each plantation, identified by Hetzel's numbers and located by county, is described as to soil characteristics and planted species in table 1. Mean annual increment in cubic feet and in board feet also is shown as totals for all the species in each plantation. The abbreviations used in table 1 are spelled out below:

Soil Drainage Class		*Soil Depth*	
W	=well-drained	D	=deep
MW	=moderately well-drained	MD	=moderately deep
SE	=somewhat excessively drained	MS	=moderately shallow
		S	=shallow
SP	=somewhat poorly drained	VS	=very shallow
P	=poorly drained	VD	=very deep

Species

EL	=European larch	SP	=Scotch pine
JL	=Japanese larch	JBP	=Japanese black pine
WP	=eastern white pine	NS	=Norway spruce
JP	=jack pine	SM	=sugar maple
PP	=pitch pine	YP	=yellow-poplar
RP	=red pine	V	=volunteers

Table 1.—Descriptive data and mean annual increments, by plantations

Plantation number	County	Soil type	Soil drainage	Soil depth	Species	Mean annual increment	Mean annual increment
						Cubic feet	*Board feet*
3-4	Venango	Hanover silt loam	W	D	RP, SP	74	95
5	Clarion	Sciotoville silt loam	MW	D	WP, V	69	221
6	Venango	Lordstown silt loam	W	S	SP	57	6
9	Jefferson	Brinkerton silt loam	P	D	JL, V	68	101
12-13	Venango	Lordstown silt loam	W	MS	RP, WP	87	92
14	Venango	Shelmadine silt loam	P	D	PP, WP	36	35
15	Venango	Titusville silt loam	MW	D	JBP	67	45
16	Venango	Gresham silt loam	SP	D	WP, V	47	40
17-19	Crawford	Meadville gravelly s. l.	W	D	RP, NS, EL, WP	123	146
21-23	Erie	Platea silt loam	MW-SP	D	WP, NS, SP	82	89
26-29	Crawford	Venango silt loam	SP	D	RP, WP, NS, SP, JP	67	50
32	Butler	Gilpin channery loam	W	MD	SP, WP, V	58	130
33-34	Clarion	Sciotoville silt loam	MW	D	EL, YP, V	79	226
36-37	Clarion	Clymer channery loam	W	D	SP, WP, V	50	67
38	Potter	Lackawanna channery s. l.	W	MD-VD	RP, WP, V	103	394
39	Potter	Dekalb sandy loam	SE	MD	WP	77	30
40	Potter	Dekalb sandy loam	SE	MD	SP, WP	44	69

41	Potter	Dekalb sandy loam	SE	MD	NS, WP	71	68
43-44	Potter	Cattaraugus channery s. l.	W	D-VD	PP, EL, JP	93	85
46-47	Potter	Cattaraugus channery s. l.	W	D-VD	NS, WP, V	81	10
48	McKean	Ernest silt loam	MW-SP	D	NS, V	75	288
49	McKean	Ernest silt loam	SP	D	NS, V	48	52
50	Potter	Wellsboro silt loam	MW	D-VD	WP, V	114	138
51-54-56	Potter	Dekalb channery silt loam	W	VS-MD	RP, NS, EL, WP	112	223
52-53	Potter	Dekalb channery silt loam	W	VS-MD	WP, SP, EL	57	45
53A	Potter	Dekalb channery silt loam	W	VS-MD	SP, V	45	0
55	Potter	Dekalb channery silt loam	W	VS-MD	JL, WP, NS, V	95	282
55A	Potter	Dekalb channery silt loam	W	VS-MD	JL, WP	98	101
56A	Potter	Dekalb channery silt loam	W	VS-MD	WP, EL	67	24
57	Potter	Dekalb flaggy silt loam	W	VS-MD	SM, V	20	24
60-61	Potter	Oquaga silt loam	W	S	EL, NS, WP, V	53	20
63-65	Clarion	Gilpin shaly silt loam	W	S	WP, NS	56	120
64	Clarion	Gilpin shaly silt loam	W	VS	EL, V	91	278
66	Armstrong	Wharton silt loam	MW	D	NS, V	26	80
68	Armstrong	Gilpin-Montevallo s. l.	W	S	PP	18	0
70	Armstrong	Gilpin channery loam	W	MD	SP, V	36	49
71	Clarion	Cavode silt loam	SP-MW	MD-D	EL, WP, V	58	149

VOLUME AND YIELD

The yield in some of the plantations has been remarkable, and in many of them it has been eminently satisfactory (table 1). In four of the plantations, the yield exceeded 100 cubic feet per acre per year; seven plantations produced more than 1 cord peeled (92 cubic feet) per acre per year. In board measure, seven plantations had yielded more than 200 board feet per acre per year over the full age-span of the trees.

One outstanding plantation (No. 38) of red and white pines had a volume of 17,712 board feet per acre at age 45—a mean annual increment of 394 board feet! From age 30 to age 45, the periodic annual increment probably had exceeded 1,000 board feet (fig. 1).

Table 2 presents site-index, age, stocking, volume, and growth data by individual species in each plantation. Stocking and volume data are on an acre basis. Standing volume and total yield were identical, or practically so, in the 24 plantations that had not been thinned, and differed but little in the 7 lightly thinned ones. For the 6 plantations where more than 10 percent of the yield had been removed by thinning, the estimated volumes removed were:

Plantation No.	*Species*	*Volume removed*	
		Cubic Feet	*Board Feet*
5	WP	467	0
12	RP	647	2,020
39	WP	484	0
41	WP	1,004	0
48	NS	1,825	4,228
49	NS	861	1,060

It is interesting to note that 4 of the 7 plantations that produced over 200 board feet annually had never been thinned. Three of these unthinned plantations, including No. 38, were mixed plantings in which one species—either red pine or Japanese larch (fig. 2)—markedly outgrew the other planted species. This growth differential had acted like a well-timed gradual thinning, enabling the dominant trees to maintain rapid diameter growth.

Table 2.—Performance data, by species and plantation

Plantation number	Species	Site index	Age	Trees	Dominant and codominant trees	Basal area	Volume	Volume	Dominant and codominant trees: Mean d.b.h.	Dominant and codominant trees: Mean annual diameter growth	Dominant and codominant trees: Mean height	Dominant and codominant trees: Mean annual height growth
		Feet	*Years*	*No.*	*No.*	*Square feet*	*Cubic feet*	*Board feet*	*Inches*	*Inches*	*Feet*	*Feet*
3	RP	73	36	138	86	37	679	568	8.0	0.22	52.8	1.47
4	SP	72	36	318	207	110	1,984	2,867	8.7	.24	54.9	1.53
5	WP	65	51	350	192	156	3,038	11,278	10.7	.21	61.9	1.21
	V	—	—	6	0	1	8	0	—	—	—	—
6	SP	68	39	407	274	122	2,080	307	8.3	.21	56.3	1.44
9	JL	73	46	293	205	112	2,467	4,655	9.2	.20	66.1	1.44
	V	—	—	146	44	40	670	0	—	—	—	—
12	RP	74	40	235	175	82	1,678	1,425	8.4	.21	57.2	1.43
13	WP	68	40	255	150	74	1,161	225	7.9	.20	49.0	1.23
14	PP	61	40	305	185	88	1,305	861	8.0	.20	49.6	1.24
	WP	—	—	5	5	5	119	555	—	—	—	—
15	JBP	64	39	594	388	177	2,580	1,748	8.0	.21	48.7	1.25
16	WP	56	43	620	360	150	1,930	1,720	7.6	.18	42.6	.99
	V	—	—	10	10	5	86	0	—	—	—	—
17	RP	79	43	525	391	193	4,823	5,623	8.8	.20	67.7	1.57
18	NS	—	43	44	—	2	0	—	—	—	—	—
19	EL	82	43	27	18	11	244	649	9.9	.23	74.0	1.72
	WP	—	—	9	—	2	44	—	—	—	—	—
21	WP	62	44	302	241	121	1,981	2,394	9.3	.21	52.3	1.19
22	NS	58	44	121	101	41	649	0	8.3	.19	51.4	1.17

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Table 2. — Continued

Plantation number	Species	Site index	Age	Trees	Dominant and codominant trees	Basal area	Volume	Volume	Dominant and codominant trees: Mean d.b.h.	Dominant and codominant trees: Mean annual diameter growth	Dominant and codominant trees: Mean height	Dominant and codominant trees: Mean annual height growth
		Feet	*Years*	*No.*	*No.*	*Square feet*	*Cubic feet*	*Board feet*	*Inches*	*Inches*	*Feet*	*Feet*
23	SP	54	44	201	101	68	973	1,509	9.1	.21	47.8	1.10
26	RP	58	43	200	155	69	1,218	540	8.3	.19	49.8	1.16
27	WP	66	44	255	195	93	1,558	1,637	8.7	.20	52.9	1.20
28	NS	65	43	15	15	4	91	0	7.4	.17	56.3	1.31
29	SP	—	44	5	0	1	16	0	—	—	—	—
	JP	—	—	5	0	1	21	0	—	—	—	—
32	SP	71	48	275	165	94	1,941	3,845	9.0	.19	67.6	1.41
	WP	68	48	85	30	25	483	1,435	9.4	.20	63.5	1.32
	V	—	—	35	25	20	369	950	—	—	—	—
33	EL	86	53	151	105	87	2,205	7,109	11.0	.21	80.9	1.53
34	YP	83	53	130	80	59	1,538	3,747	10.4	.20	79.7	1.50
	V	—	—	15	5	5	75	0	—	—	—	—
36	SP	64	44	193	119	53	839	536	7.8	.18	54.8	1.25
37	WP	67	45	169	134	66	1,219	2,486	8.8	.20	55.9	1.24
	V	—	—	40	40	14	166	0	—	—	—	—
38	RP	72	45	285	165	173	4,198	17,712	12.1	.27	64.8	1.44
	WP	—	45	289	0	27	154	0	—	—	—	—
	V	—	—	35	30	17	268	0	—	—	—	—
39	WP	56	46	660	420	194	3,057	1,370	8.1	.18	49.3	1.07
40	SP	49	48	399	199	122	1,412	1,186	8.6	.18	42.0	.88
	WP	51	48	126	74	48	662	2,120	10.2	.21	46.1	.96

41	NS	60	46	259	123	58	917	1,580	8.1	.18	52.0	1.13
	WP	56	46	272	136	87	1,358	1,531	9.1	.20	48.1	1.05
43	PP	54	45	631	271	202	3,047	2,615	8.8	.20	49.6	1.10
44	EL	63	45	391	150	66	708	0	7.3	.16	59.0	1.31
	JP	—	45	30	30	19	420	1,202	10.4	.24	—	—
46	NS	58	46	253	166	42	489	383	6.1	.13	50.1	1.09
47	WP	55	46	1,046	584	219	3,061	82	7.1	.15	45.5	.99
	V	—	—	17	17	8	73	0	—	—	—	—
48	NS	70	54	110	110	92	2,214	11,330	12.3	.23	66.3	1.23
	V	—	—	14	0	3	4	0	—	—	—	—
49	NS	50	54	615	325	145	1,755	1,735	7.8	.14	42.0	.78
	V	—	—	0	0	0	0	0	—	—	—	—
50	WP	63	52	846	525	292	5,890	7,192	8.9	.17	61.1	1.17
	V	—	—	5	5	2	24	0	—	—	—	—
51	RP	71	44	364	284	156	3,654	9,432	9.3	.21	62.3	1.42
54	NS	70	44	301	91	43	780	364	7.3	.17	60.8	1.38
56	EL	69	44	45	5	6	58	0	6.8	.15	63.3	1.44
	WP	63	44	216	23	30	438	0	7.0	.16	54.0	1.23
52	WP	58	46	109	100	37	639	824	8.0	.17	52.1	1.13
53	SP	60	46	534	326	136	1,981	1,232	7.4	.16	48.6	1.06
	EL	—	46	9	0	1	0	0	—	—	—	—
53A	SP	58	41	835	288	153	1,662	0	7.6	.19	46.0	1.12
	V	—	—	58	58	13	202	0	—	—	—	—
55	JL	90	41	291	221	136	3,598	11,546	10.0	.24	76.1	1.86
	WP	—	41	441	0	45	298	0	—	—	—	—
	NS	—	41	5	0	0	0	0	—	—	—	—
	V	—	—	5	0	1	1	0	—	—	—	—
55A	JL	78	41	562	375	164	3,689	4,153	7.8	.19	63.5	1.55
	WP	—	41	562	0	45	343	0	—	—	—	—
56A	WP	56	45	698	547	155	2,377	1,075	6.6	.15	46.9	1.04

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Table 2. -- Continued

Plantation number	Species	Site index	Age	Trees	Dominant and codominant trees	Basal area	Volume	Volume	Dominant and codominant trees: Mean d.b.h.	Dominant and codominant trees: Mean annual diameter growth	Dominant and codominant trees: Mean height	Dominant and codominant trees: Mean annual height growth
		Feet	*Years*	*No.*	*No.*	*Square feet*	*Cubic feet*	*Board feet*	*Inches*	*Inches*	*Feet*	*Feet*
	EL	63	45	358	245	52	632	0	5.5	.12	52.1	1.15
57	SM	53	64	146	129	65	1,248	1,535	9.1	.14	53.6	.84
	V	—	—	8	4	1	8	0	—	—	—	—
60	EL	72	46	294	164	72	632	768	7.9	.17	64.7	1.41
61	NS	65	46	275	60	41	400	0	7.3	.16	55.0	1.20
	WP	60	46	369	115	76	1,189	130	7.9	.17	54.4	1.18
	V	—	—	55	40	16	188	0	—	—	—	—
63	WP	60	46	390	265	138	2,233	5,169	8.9	.19	51.5	1.11
65	NS	60	47	183	50	26	342	340	7.3	.16	53.5	1.15
64	EL	84	46	315	207	150	3,535	12,021	10.4	.23	78.1	1.70
	V	—	—	99	33	30	640	753	—	—	—	—
66	NS	65	43	129	83	54	997	3,438	9.9	.23	52.2	1.22
	V	—	—	47	26	10	97	0	—	—	—	—
68	PP	45	43	436	244	74	774	0	6.3	.15	37.0	.86
70	SP	70	38	192	128	70	1,206	1,845	8.8	.23	53.4	1.41
	V	—	—	39	26	12	179	0	—	—	—	—
71	EL	80	47	150	85	72	1,637	5,807	11.0	.23	69.9	1.49
	WP	57	47	320	120	66	941	1,050	7.8	.17	48.0	1.02
	V	—	—	40	15	10	129	125	—	—	—	—

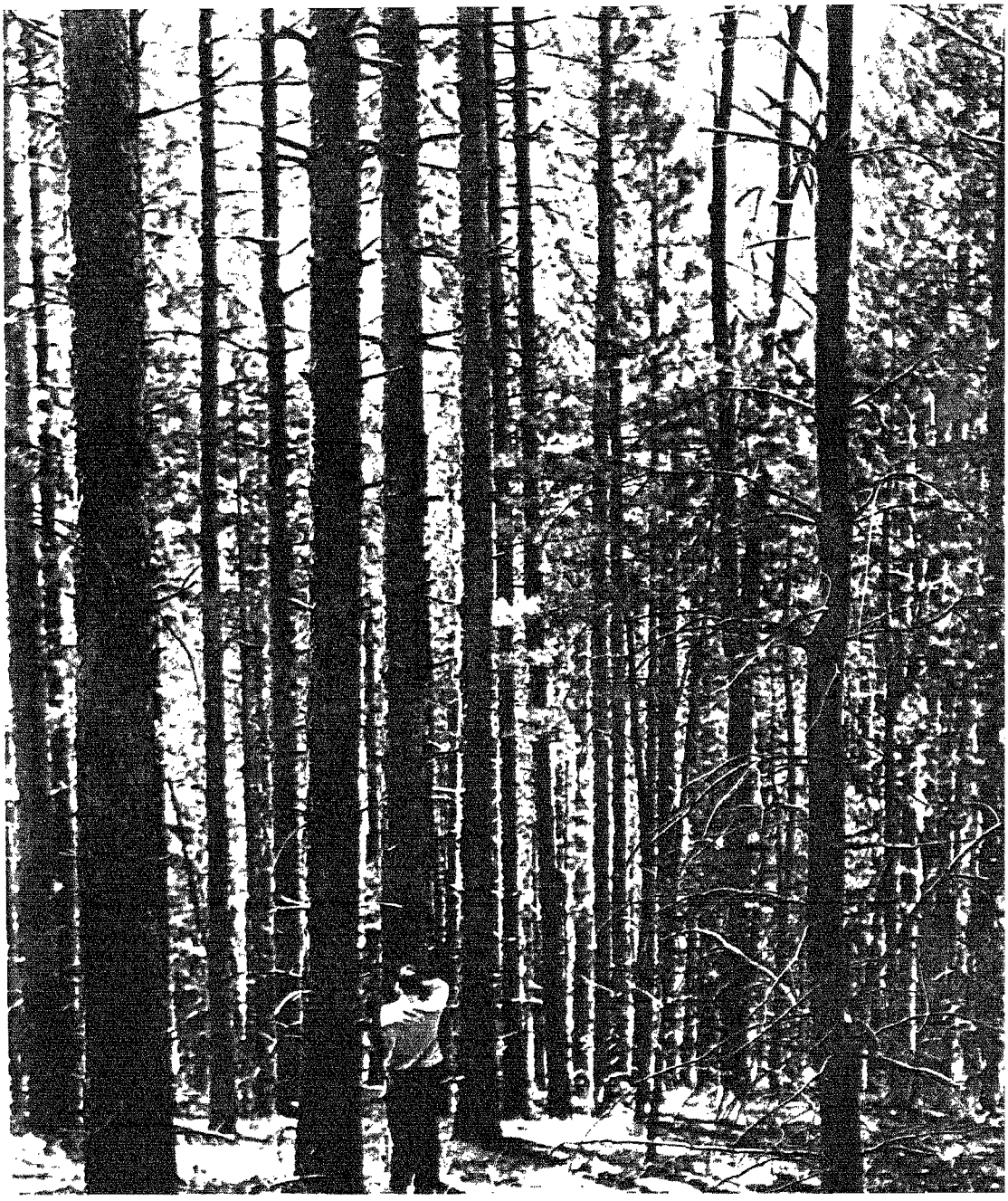


Figure 1.—A mixed red pine-white pine plantation (No. 38) that measured 17,712 board feet per acre of red pine at age 45—a yield of nearly 400 board feet per acre per year. This plantation, which was 50 years old when the photo was taken in 1965, was self-thinned through suppression of most of the white pine by the red pine.

Mixed plantings that did not produce such high board-foot volumes were either growing on less productive sites, were still fairly young, or had two or more species that grew about equally well, thereby failing to thin themselves. Nearly equal growth rates were well demonstrated in two mixed plantations on good sites involving Scotch pine. One was a Scotch pine-red pine mixture (fig. 3) and the other a Scotch pine-white pine mixture. In both, 70 percent of the trees were Scotch pine. Another plantation where mixed species grew at about the same rate was No. 12-13, which contained red pine and white pine.

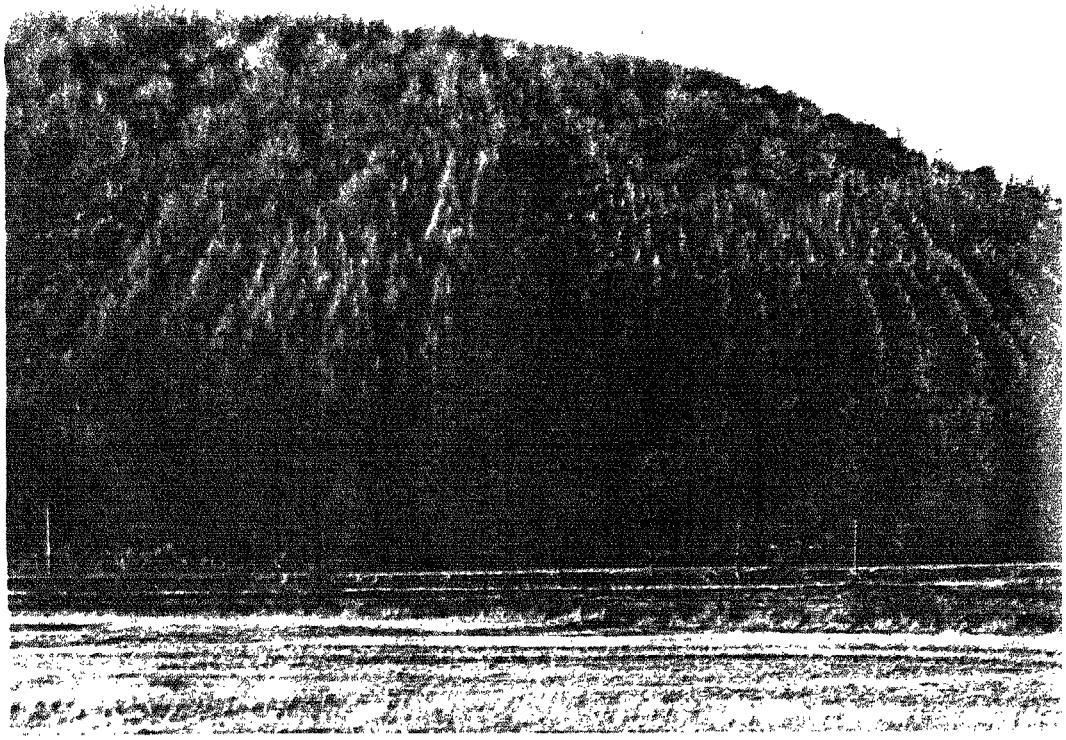


Figure 2.—A group of mixed plantations in Potter County. The Japanese larch of plantation 55 can be seen left of the center of the photograph and the red pine of plantation 51 to the right of center. These species maintained rapid growth without thinning through the suppression of the white pine and other species planted among them.

Figure 3.—Mixed red pine-Scotch pine plantation (No. 3-4) exhibiting excellent, nearly equal height growth by the two species. Of the Scotch pine, 78 percent were straight trees, but 8 percent were spiral-shaped like the tree being measured here.

Two single-species plantations that had done remarkably well without thinning were European larch No. 64 and white pine No. 50. The larch had made good diameter growth because the trees were well differentiated, ranging from 4.7 to 13.1 inches in diameter, and the stand was not overstocked. Survival in 1939 was 25 percent, and our sample in 1961 showed 18 percent. The white pine plantation, even though dense (851 trees per acre) had not stagnated; diameters ranged from 4.1 to 11.9 inches. It had the highest cubic-foot volume (5,914) among all the plantations examined, and also had a good board-foot yield (7,192). Had it been thinned, this plantation no doubt would have produced an even greater board-foot yield.

SITE INDEX

Site index, expressed as total height in feet at age 50, was obtained for each species in each plantation, except where not enough dominant and codominant trees were available for a determination. There was a wide range in site-index values—from 45 for one planting of pitch pine to 90 for one of Japanese larch.

Soil characteristics and other site factors that influence site index are discussed later by species.

BASAL AREA

Knowledge of desirable levels of stocking in terms of basal area or number of trees at different ages is necessary for good plantation management. Although no controlled comparisons are available in this study, a record of the stocking of the better plantations should be helpful.

Basal areas ranged up to 294 square feet per acre. This maximum was recorded for the above-mentioned white pine plantation No. 50. This stand obviously needed thinning; but No. 38, with 217 square feet, did not appear seriously overstocked. However, the red pine overstory had 173 square feet, and it was reaching a point where thinning would help (fig. 1).

Several plantations in which the stocking appeared to be ade-

quate but not overly dense, and in which the dominant trees had attained good average diameters, ran around 130 to 160 square feet of basal area per acre either overall or in the dominant species. A majority of these plantations had mean annual increments of more than 200 board feet per acre; only one of them fell below 100 board feet. Basal areas and numbers of dominant-codominant trees per acre in this group of plantations are tabulated below:

Plantation number	*Principal species*	*Basal area (square feet)*	*Dominant and codominant trees (number)*
5	White pine	157	192
9	Japanese larch	152	249
12-13	Red pine-white pine	156	325
33-34	European larch-yellow poplar	151	190
38	Red pine	217 (173)	195 (165)
51-54-56	Red pine-Norway spruce-white pine	235 (156)	403 (284)
55	Japanese larch	182 (136)	221 (221)
64	European larch	180 (150)	240 (207)
71	European larch-white pine	148	220

Plantations 5 and 9 were pure plantings; all others were mixed, though all but one of the associated species in Nos. 38, 55, 64, and 71 appeared so suppressed in 1939 that they were not given plantation numbers. In the mixed plantings, values in parentheses are for species that definitely were dominant; no parenthesis means the two species were essentially codominant.

There were about seven plantations within the same basal-area range that definitely were overstocked. Four of these were on below-average sites. The sites for the other three plantations (Nos. 3-4, 32, and 36-37) were reasonably good, but in each case the two species in the mixture had grown at about the same rate.

In general, plantations with less than 100 square feet of basal area appeared to be understocked. Optimum stocking will of course vary somewhat among species; so each species should be considered separately. For example, Scotch pine is unable to maintain as much basal area as most other species. It appears that a good residual basal area for most species would be in the range of 100 to140 square feet, exclusive of suppressed and understory stems.

NUMBER OF TREES

The number of trees per acre ranged from 124 to 1,316; the high number was in a 46-year-old white pine-Norway spruce plantation. Numbers of dominant and codominant trees ranged from 109 to 792 per acre. Those plantations that appeared to be understocked, based on visual judgments of spacing and crown size, had 110 to 154 dominant and codominant trees per acre. The well-stocked ones had 190 to 325 dominant and codominant trees per acre and the obviously overstocked plantations had 200 trees and up—mostly over 250. The gap between the first two ranges of stocking figures and the overlap between the second and third ranges were a result of differences in species, age, and site of the plantations from which the figures were derived.

STEM FORM

Red pine, Japanese and European larches, and Norway spruce had excellent stem form. A simple average of the percentages of trees falling in the previously defined form classes follows for each planted species:

Species	*Stem form 1 (percent)*	*Stem form 2 (percent)*	*Stem form 3 and 4* (percent)*	*Plantations (Nos)*
Red pine	74	22	4	6
White pine	29	27	44	12
Scotch pine	29	28	43	9
Pitch pine	37	35	28	3
Japanese black pine	56	23	21	1
Japanese larch	78	14	8	3
European larch	85	9	6	7
Norway spruce	79	5	16	10
Yellow-poplar	35	27	38	1
Sugar maple	66	6	28	1

*Predominantly stem form 3.

The figures for white pine include only the plantations where it was the principal species. Figures for the other species are based on data from all plantations where the species were well represented.

SOIL OBSERVATION

The pH values for the plantation soils ranged from 4.2 to 6.0. However, pH or soil acidity in itself did not appear to be a limiting factor for any species. Although height growth was comparatively poor in the plantations on highly acid soils (pH 4.4 or lower), soil drainage was either somewhat poor or somewhat excessive on all these sites, and is believed to have been largely responsible for the slow growth. This interpretation is supported by the fact that some of the best plantations were on soils of pH 4.5 or 4.6 where the soils also were well drained.

A large variety of humus types was encountered, but we could detect no relation between humus type and tree growth.

Site index-soil correlations are discussed under each species below. Soil drainage and depth designations are standard terms as defined in the U.S. Department of Agriculture Soil Survey Manual *(Soil Survey Staff 1951)*.

GROUND COVER

Volunteer tree seedlings and saplings were found in nearly all plantations. Black cherry, red maple, and white ash were recorded on 76, 65, and 54 percent of the sample plots, respectively, and may have been sparsely represented but not tallied on other plots. One or more species of oak were listed on 30 percent of the plots. Briars (*Rubus* spp.) were the most common shrub. Ferns occurred on 40 percent and grasses on 24 percent or more of the plots. *Maianthemum* and *Mitchella* were the next most common herbs. Some of the plantations have excellent prospects for conversion to hardwood stands.

SPECIES EVALUATIONS

Red Pine

Red pine was present on plots in six plantations. It was an outstanding performer, the chief component in plantation 17-19, which had the highest mean annual increment in cubic feet, and in No. 38 (fig. 1), which had the highest mean annual increment in

board feet. It was represented among the dominant trees wherever it had been planted. Average annual diameter growth of dominant and codominant trees on the six plantations was 0.22 inch, and average height growth was 1.40 feet.

The well known requirement of good soil drainage for red pine was substantiated in this study. Site indexes ranged from 58 to 79 feet, with a mean of 71, and showed a distinct correlation with soil drainage. Five of the six red pine plantations were on well-drained soils and showed site indexes of 71 or better; the other was on a level, somewhat poorly drained soil, and here the site index was 58. Another plantation (No. 21-23), on a level and moderately well to somewhat poorly drained soil, had a few red pines outside the plot and here again the site index for this species was low—59 feet. The best site index, by 5 feet, was on a deep, well-drained Meadville gravelly silt loam. However, not all good sites were deep soils. On one such site the soil was moderately shallow and on a steep slope, but on a northwest aspect. Another was not more than moderately deep and faced southeast.

The mean annual rate of height growth by red pine had held up well at around 1.4 feet during the 21 years since Hetzel's measurements in 1939, but diameter growth had dropped from the relatively high rate of 0.28 inch per year in 1939 to 0.22 inch as the stands aged (fig. 4).

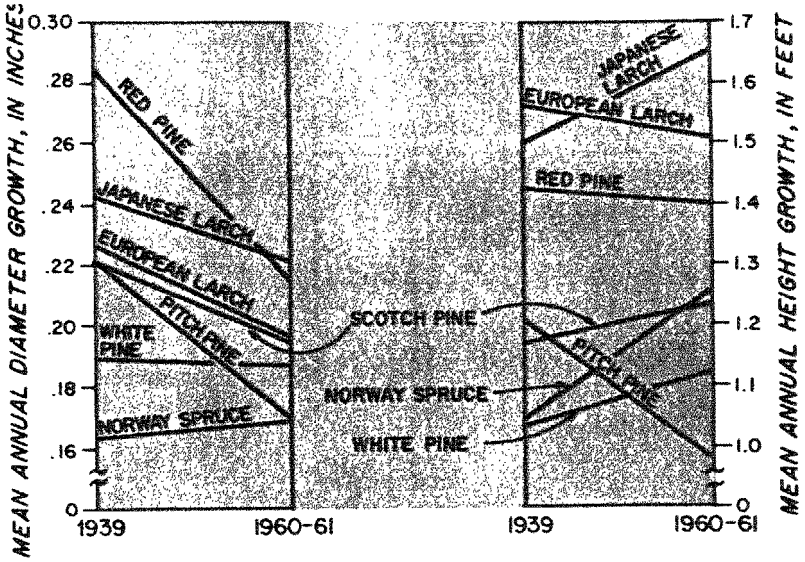
The form of red pine stems was excellent. In all but one heavily damaged plantation, 78 to 100 percent of the red pine trees were straight for their entire length. In four of the six plantations that contained red pine, 100 percent of the red pines were in stem-form classes 1 and 2.

The only damage noted on red pine was in plantation 26-29, where Hetzel recorded top breakage caused by roosting starlings before 1939. None of the red pines in this plantation were rated stem-form 1.

Eastern White Pine

White pine was the most widely used species. It had been planted in 22 of the 37 plantations and was still represented in the dominant and codominant crown classes in 18 of them. It has done

Figure 4.—Changes in mean annual diameter and height growth for the seven best represented species, 1939 to 1960-61. Pitch pine and Japanese larch were represented by 2 plantations each, other species by 5 to 10 plantations each.



well in several instances despite varying degrees of weevil damage. In one of the few well-thinned plantations (No. 5, fig. 5), white pine had produced 221 board feet per acre per year. One unthinned plantation (No. 50) had a mean annual increment of 114 cubic feet.

White pine lost out to red pine where the two species were planted in mixture on well-drained soils; in two instances the white pine site index was 6 to 8 feet lower. The reverse was true on a somewhat poorly drained soil; here the white pine site index was 8 feet higher than for red pine. White pine had also fallen behind Japanese larch in mixtures, but had held its own with Norway spruce. It had grown well on some, but not all, soils classed in the range of somewhat poorly drained to well-drained. The mean site index for 16 plantations where white pine was fairly well represented in the dominant-codominant crown classes was 61 feet.

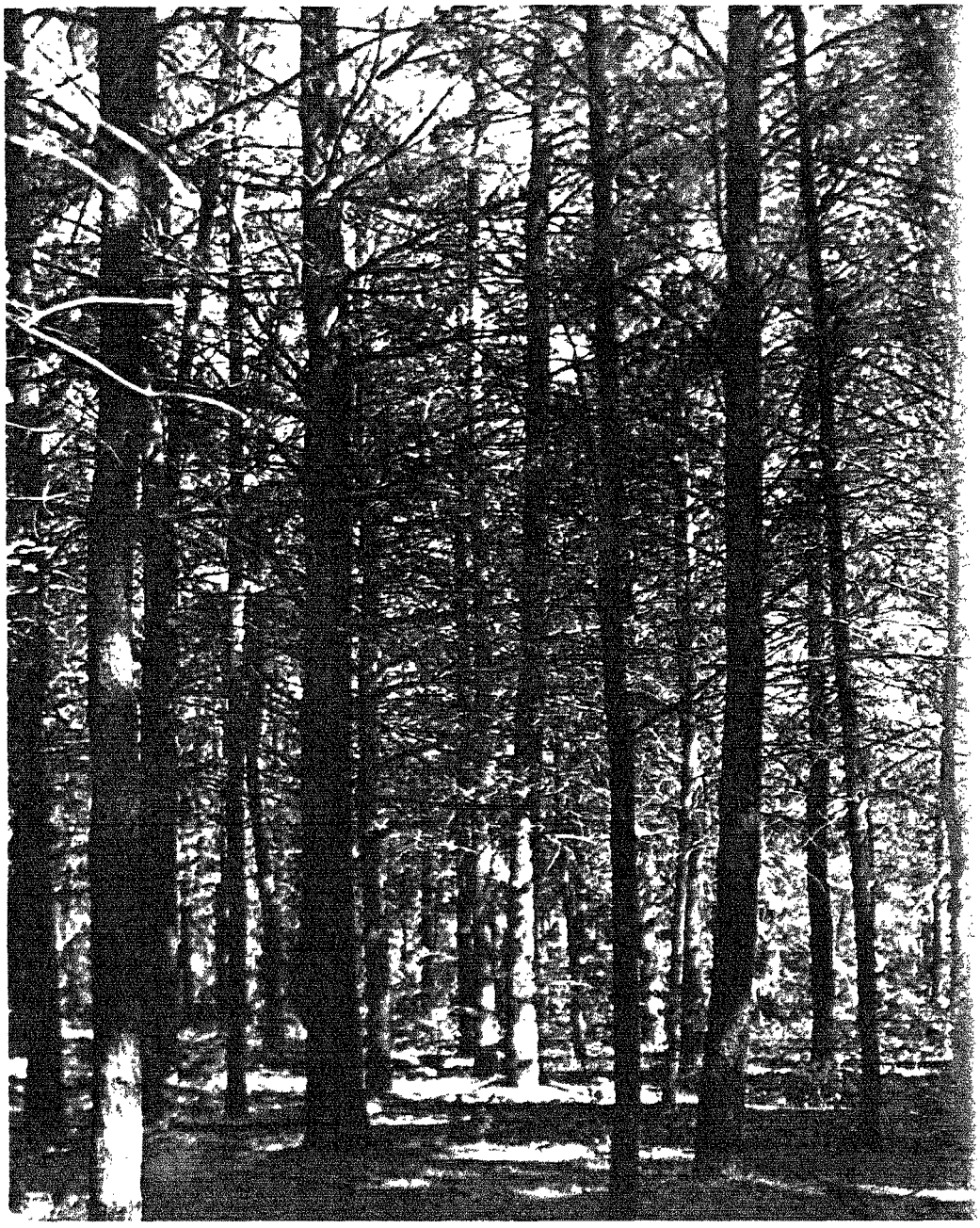


Figure 5.—White pine in one of the few well-thinned plantations (No. 5). At age 51, it had produced 221 board feet per acre per year.

Almost all plantations had been damaged, in varying degrees, by the white-pine weevil. The close spacing that was always used in planting *(Hetzel 1941)* was fortunate because it usually resulted in enough well-formed trees to meet stocking requirements for crop trees.

Presumably the white pine in several of the mixtures developed better than appeared likely in 1939. In four plantations where Hetzel did not measure the white pine, dominant and codominant trees were found on our plots. In two of the four plantations he noted that the white pine was heavily weeviled and very poor; but he predicted that a fair crop might be brought through. In another of the plantations where he did not measure the white pine, a Scotch pine-white pine mixture (No. 32), he noted that the white pine was almost a complete loss. Yet, at the time of our survey, white pine made up nearly one quarter of the sawtimber volume on the sample plot.

Pine bark aphids were observed in at least four plantations but had caused no mortality. Recent top breakage, obviously caused by ice, had occurred in one plantation. Hetzel had noted top damage in two others.

Surprisingly, the diameter growth of white pine dominant and codominant trees had held up at 0.19 inch annually through the 1939-61 period (fig. 4), even though only two of the stands had been thinned. Height growth had increased from 1.03 feet annually as of 1939 to 1.12 feet at the time of our survey. This may have been due to a reduction in weevil injury with increasing height of the trees.

Scotch Pine

Scotch pine had not shown high volume production, compared to some of the other species, on any of the nine plantations where it had been planted. The seed sources are unknown. Height growth was good on four plantations (site index 68 to 72). Three of these four plantations were 36 to 39 years old and may be expected to increase their board-foot production considerably by age 50. On the seven plantations where comparison with Hetzel's figures was possible, the mean annual height growth of dominant and codom-

inant trees apparently increased, on the average, from 1.17 to 1.23 feet between 1939 and 1960-61. The mean annual diameter increment fell slightly, from 0.22 to 0.20 inch (fig. 4).

Average site index for the nine Scotch pine plantations was 63 feet. On well-drained soils the site index was 58 or better. However, it was lower on a moderately well to somewhat poorly drained soil and still worse on a moderately deep, somewhat excessively drained Dekalb sandy loam.

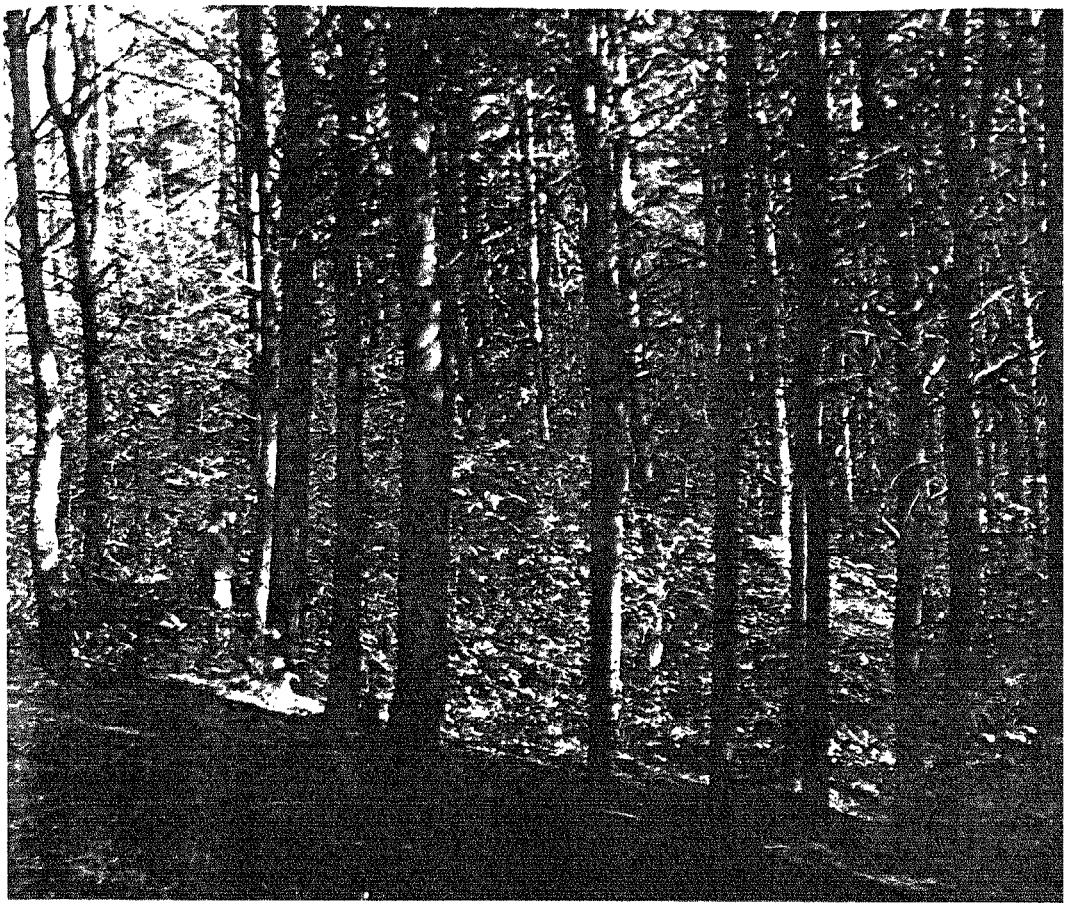
There was a marked tendency for Scotch pine on good sites to have better-than-average form (fig. 3). For all nine plantations, 58 percent of the trees were tallied stem-form 1 and 2, but in the four plantations where the site index was 68 or better, 74 percent of the stems were stem-form 1 and 2. Yet provenance tests have shown that the fastest growing sources tend to have the most bole defects *(Wright and Baldwin 1957)*.

Some mortality, of undetermined cause, was observed in plantations 36-37 and 70. No other significant damage or pests were noted.

Scotch pine stands typically have a comparatively thin, open canopy, which permits an abundance of understory plants to develop. Compared to the growth under other heavier-foliaged species, the ground cover in the Scotch pine plantations was outstanding. The two pure Scotch pine plantations had especially lush ground covers of herbs, shrubs, and tree seedlings and saplings. In one of these stands, 31 species of woody plants were found on one 0.12-acre plot. The contrast in understory growth was strikingly demonstrated in an area where one of the pure Scotch pine plantations bordered a white pine plantation; there the latter was nearly devoid of ground cover, while the Scotch pine had a profuse understory of young hardwoods (fig. 6).

This and similar understories demonstrate the value of Scotch pine as a nurse crop for native hardwoods—a value that has also been noted by Littlefield *(1949)*, Hough *(1958)*, and Wright and Bull *(1963)*. Perhaps Scotch pine, deliberately selected for the purpose, might have an important place in re-establishing hardwoods on old-field sites. The lower timber yield of the

Figure 6.—Adjoining white pine and Scotch pine plantations showing excellent hardwood regeneration under Scotch pine in the background, in contrast to the practically bare forest floor under white pine in the foreground. The white pine plantation had just been thinned when this photo was taken.



Scotch pine, as compared to certain other conifers, might be more than compensated for by the accelerated succession to hardwoods.

Pitch Pine

Pitch pine had done very poorly; we found nothing to recommend it. On the three plantations where it was planted, its site

index averaged only 53. It was planted on a good range of soils—shallow, well-drained; deep, well-drained; and deep, poorly drained. Oddly, its best height growth and by far the best form were on a poorly drained slope. But there were gaps in the wet spots and mortality was taking place around the edges of them.

Japanese Black Pine

There was one plantation of this species (No. 15) on a deep, moderately well-drained Titusville silt loam (fig. 7). Its age was 39; average height was 49 feet; and average diameter of dominant-codominant trees was 8.0 inches. No thinning of any consequence had been done; basal area was 177 square feet per acre. The trees seemed to have accelerated in diameter and height growth since 1939. The plantation was in good condition and, although some trees were forked, 56 percent of them were stem-form 1. The trees and stand looked like red pine. This species is worth further testing under various site and climatic conditions.

Jack Pine

Jack pine was represented only by single trees on or next to plots in three plantations. They had maintained dominance on deep well-drained soils, but had lost out on a somewhat poorly drained site. On the Meadville gravelly silt loam of plantation 17-19, which was the best red pine site, two jack pines averaged 71 feet feet in height at age 43. But Hetzel's plantation 69, on a shallow, well-drained soil, had died out completely since 1939. Some of the remains could still be found on the ground but the cause of failure is unknown.

European Larch

European larch had performed very well in several places, producing over 12,000 board feet per acre in 46 years in plantation 64. Mean annual increment was 278 board feet in this plantation and, including some intermixed yellow-poplar, 226 board feet in plantation 33-34. Cubic-foot volumes were not as high as for some other species because the larch was usually in mixtures, or in stands not fully stocked with it, and because larch requires wider spacing

Figure 7.—The 39-year-old Japanese black pine plantation 15 in Venango County.

than red and white pines or spruces. Height growth was excellent on good sites. There was a wide range in site index—from 63 to 86 feet, averaging 75 feet. The tallest tree in all these plantations was a European larch in No. 33-34 that measured 94 feet at age 53.

This larch species had done well on two moderately well-drained soils and on two well-drained ones. Four sites of below-average quality also involved well-drained soils. These soils were of various depths and the moisture supply may have differed considerably among them. This could have accounted for the differences in tree performance. The four below-average sites were on 31- to 47-percent southeast or southwest slopes. Of the two well-drained sites that were above average, one (plantation 64) had a very shallow soil but lay on the lower part of a gentle northwest slope. The other (plantation 17-19) was on a steep but very short northeast slope with a large level till area behind it and seepage at the base. This mixed plantation was predominantly red pine and the red pine site index here (79 feet) was the highest among all the red pine planting sites. Nevertheless the pine was being outgrown by the scattered European larch, which seems to be especially favored by moist sites. On drier slopes, red pine will usually outgrow the larch.

Mean annual height and diameter growth rates had held well, declining only slightly between 1939 and 1960 (fig. 4). Stem form was excellent, 85 percent of the trees being classed as stem-form 1.

No pests were noted, but a few of the larches in plantation 33-34 had suffered top damage from ice or snow when about 25 feet tall.

Japanese Larch

There were only three plantations of this species, two of them in the same locality. It had done very well. In two of the plantations the mean annual increment was 101 board feet, and in the third it was 282 board feet per acre. Cubic-foot production was also high in the two plantations (Nos. 55 and 55A) where it had been planted in mixture with white pine. Plantation 55 especially (fig. 2) is a fine example of a mixed planting in which suppression of one species resulted in a thinning and the release of the domi-

nant species. At only 41 years of age the volume was 11,500 board feet per acre.

Site indexes for Japanese larch were 73, 78, and 90 in plantations 9, 55A, and 55, respectively. The highest index measured for any species was 90, but even 73 could hardly be called low. Plantations 55 and 55A were both on Dekalb channery silt loam, a well-drained soil that may vary from very shallow to moderately deep. The slope was 40 to 45 percent and faced southeast. The difference in site index expressed on the two plots was surprising since the two plantations were adjacent to each other. Plantation 55A was just above No. 55 and its soil may have been shallower or dryer.

This larch also had grown well in plantation 9, where the soil was poorly drained, at least in spots, along a brook. However, the stocking was irregular because of low survival and ice damage in the winter of 1938-39. Twenty to 40 percent of the crown area was occupied by volunteers.

Plantations 55A and 56A provide an interesting comparison of European and Japanese larches growing on a dryish site. The two plantations were just a few feet apart and at comparable positions on the slope. Both were larch-white pine mixtures. In No. 55A, Japanese larch was completely dominant over the white pine; its site index was 78 feet. In No. 56A, European larch was represented in the upper canopy by only a few codominant trees; its site index was 63 feet and the white pine was dominant.

It was not possible to compare the two larches on moister sites. However, Aird and Stone *(1955)* reported that Japanese larch made the greater height growth in soils of corresponding depth and drainage. It also gives a greater yield in young plantations in Great Britain *(Brit. Forestry Comn. 1938)*. Hummel *(1949)* stated that Japanese larch is superior to European larch in height growth and volume production in Great Britain, and that height growth of Japanese larch does not fall off as much in later years as had previously been assumed.

Japanese larch in these plantations maintained its diameter growth well, and increased its rate of height growth between 1939

and 1961 (fig. 4) Like European larch, it displayed excellent stem-form, except in plantation 9 where ice damage had occurred. No evidence of pest damage was seen.

Norway Spruce

Only one of the 10 plantations where the sample plot contained Norway spruce was outstanding. However, only 2 of the 10 plantations were well-stocked pure Norway spruce. No. 48, a pure plantation that had been thinned at least twice, had a stand volume of 11,300 board feet and an estimated yield of 15,500 board feet per acre at age 54. This was a mean annual increment of 288 board feet per acre. Norway spruce was most often planted in mixture, usually with white pine alone, but in three cases with a third species. In these mixtures the spruce tended to supplement the stocking and volume of the stands. It usually made up about 15 percent of the cubic volume.

Site index ranged from 58 to 70, with a mean of 63 feet, not including a badly weeviled plantation. This is a narrow range compared to other species. The outstanding plantation 48 (site index 70) is at the bottom of a slope on a deep, moderately well to somewhat poorly drained Ernest silt loam. Equally good height growth was made on a shallow to moderately deep, well-drained soil (No. 51-54-56).

Average site index and annual height growth of Norway spruce were the same as for Scotch pine, better than for white pine, and poorer than for the other common species. Norway spruce and other spruces are well known to be slow starters. This was evident in these plantations. Many of the spruce trees fell behind and became suppressed, but those that were still in a codominant position in 1960-61 should maintain their dominance. Their leaders were long and vigorous. Some of the intermediates seemed likely to become codominant. In 1939 the mean annual diameter and height increments of dominant and codominant spruces on nine plantations averaged 0.16 inch and 1.04 feet respectively. The average age then was 26. In 1960, at age 47, the respective values were 0.17 inch and 1.25 feet (fig. 4). This means that the trees had grown 1.50 feet in height annually since 1939. These figures are

simple averages for nine plantations—not weighted by numbers of trees.

The form of Norway spruce was good on the whole, and excellent in several plantations. The average proportion of stems classed as stem-form 1 was 79 percent. In three of the plantations, 100 percent of the sample-plot trees were stem-form 1, and in two others 99 or 100 percent of the trees qualified for stem-form 1 or 2.

One plantation of pure Norway spruce (No. 49) was badly weeviled and some possible weevil damage was noted in one mixed plantation. In plantation 66 some mortality of unidentified cause had occurred and, both before and after 1939, there had been some cutting thefts for Christmas trees.

Planted Hardwoods

Our survey included only two plantings of hardwood species: yellow-poplar in mixture with European larch in No. 33-34 and pure sugar maple in No. 57. This was hardly enough basis for drawing any conclusions, except perhaps that yellow-poplar can grow well. This species was planted on an admittedly good soil—Sciotoville silt loam. Its site index here was 83 feet. In spite of the excellent growth of the intermixed European larch, the yellow-poplar made up about 40 percent of both the basal area and the dominant and codominant trees, and about one third of the volume. The form of the yellow-poplar was good for planted hardwoods: 62 percent of the trees were stem-form 1 or 2.

The sugar maple plantation was very poor. Even though sugar maples were growing in the woods above this plantation, the site was probably too dry or too low in nutrients for good sugar maple growth. The soil was Dekalb flaggy silt loam, a very shallow to moderately deep, well-drained soil—in this case on a steep southeast slope. Wild saplings 8 to 10 feet tall had been planted in a 16-by-20-foot spacing. Although survival was excellent, the crowns had not closed by 1939. Hetzel estimated the age at that time as 42 years.

White ash and red oak also had been included in some of the plantings in Potter County, where the sugar maple and several other plantations were located. These were Hetzel's plantations 58,

59, and 72. Neither of these species had formed a stand, being either edge trees or scattered individuals among other species. Both form and growth rate of the white ash were poor. The red oak had done better. A group containing five dominant and codominant oaks grew next to Scotch pine plantation 53A. They were taller and straighter than the pine and, in fact, were taller than the white pine, Scotch pine, and European larch in other nearby plantations. The average diameter and height of dominant and codominant trees at age 37 was 8.7 inches and 58.2 feet. This was a healthy mean annual height growth of 1.57 feet.

Volunteers

About half of the sample plots contained vounteer hardwoods or white pines over 4.5 inches in diameter.

Black cherry was the most important species both in abundance and cubic volume. Red maple, red oak, white ash, and aspen were fairly common. Age was not determined, but the larger trees on sample plots should have been about the same age as the plantations. Large old residuals were avoided in locating plots. For the 18 plantations where volunteers were present, the average volume of the volunteers was 178 cubic feet or 102 board feet per acre. This of course was a bias on the low side because plots were selected in uniform portions of the plantations.

Form of the trees was generally poor. Only 11 percent of the volunteers in the average plantation were stem-form 1 and 18 percent stem-form 2. The proportions of trees in stem-form classes 1 and 2 to those in 3 and 4 were about the same among diameter classes and among crown classes. One might expect that small trees or trees with intermediate crowns would have better stem-form than large dominants, but such was not the case.

SPECIES COMPARISONS

In site-index values and volume growth, red pine, Japanese larch, and European larch excelled all the other species. Norway spruce and white pine ranked considerably lower in site-index values, but nevertheless were making fairly good volume growth. Scotch pine ranked about equal to the spruce and white pine in

site-index values; but, at least in part because of younger average age (39 years), volume growth of the Scotch pine was comparatively low. Pitch pine ranked lowest among the seven principal species in every respect (fig. 8).

In comparing species, the mean and maximum values are more significant than the minimums. A maximum value shows what a

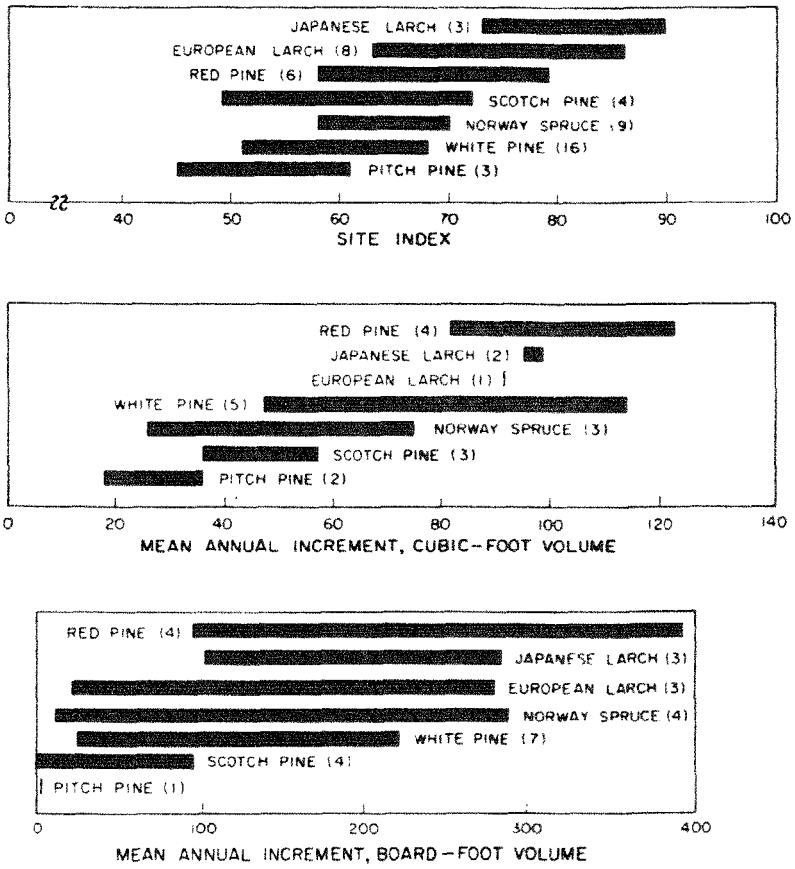


Figure 8.—Ranges of values for site index and mean annual increments for the seven principal species. Lines across the horizontal bars denote mean values. Volume increments for any one species were based on only those plantations in which that species comprised 80 percent or more of the cubic- or board-foot volume.

species is capable of doing, while a minimum value may represent an off-site plantation or, as regards volume increments, a very poorly stocked plantation. Board-foot volume growth is a better indicator of value increment than cubic-foot volume, but the latter depends less on age and spacing.

PURE vs. MIXED PLANTATIONS

In these plantations we have seen some excellent results in mixed plantations, even where no thinning had ever been done. Plantation 38, a red pine-white pine planting, and No. 55, a Japanese larch-white pine mixture, are the best examples. No. 38 contained 17,700 board feet of red pine at age 45, and No. 55 contained 11,500 board feet of Japanese larch at age 41 (figs. 1 and 2). In both, the white pine dropped into a subdominant position, thus releasing the other species, as in a well-timed thinning. Plantation 51-54-56 was another in which this happened. This was a four-species mixture by single rows of red pine, white pine, Norway spruce, and European larch. By 1960-61 most of the larch had died out and the white pine and spruce were in the understory. This plantation had about 9,400 board feet of red pine and 400 board feet of spruce per acre at age 44 (fig. 2).

Not all the mixed plantings resulted in suppression of all but one species. Yellow-poplar made up about a third of the 12,000 board feet per acre in plantation 33-34, where it was planted in good soil with European larch. Scotch pine kept up with red pine in No. 3-4 and with white pine in No. 32. White pine and Norway spruce grew well together in several plantations. Plantation 60-61 was a mixture of three species by double rows; and this pattern, as compared with a single-row pattern, helped each species to maintain itself in the mixture.

Of the pure plantations, only those where the stocking had been reduced by thinning or natural mortality had done well in board-foot volume growth. Three of the seven plantations that produced over 200 board feet per acre annually had been pure plantings. These were No. 5 (white pine), No. 48 (Norway spruce), and No. 64 (European larch). The first two were well-thinned. In No. 64 the stocking was low; Hetzel estimated survival in 1939 to be

only 25 percent. Hardwoods had filled the gaps and made up 17 percent of the basal area in 1960-61.

Discussion & Recommendations

One disadvantage of this type of study is that we have no knowledge of the plantations that failed completely. Nevertheless we could study the performance of several species on a considerable range of sites, and compare the results with earlier measurements.

Hetzel in his report recommended red pine over other commonly planted species on open upland sites in this area. On frost-free sites, he said, the larches also offer promise of rapid and successful development. He added that red pine and Japanese larch were superior in a rating based on form, height growth, and diameter growth, followed by jack pine and pitch pine, which he indicated could be used with reasonable assurance of success. He also listed Norway spruce as a useful species. Hetzel placed white pine at the bottom of his rating of eight species and Scotch pine just above it.

Based on our study, and assuming that species will be matched to suitable sites, red pine is still to be recommended, with Japanese and European larch very nearly equal to red pine and to each other. Red pine should be used on the drier, well-drained sites, and the larches on moderately well-drained or slightly wetter soils. Both red pine and the larches will do well on moist, well-drained soils.

These plantings gave no basis for recommending pitch pine. Perhaps jack pine did not have a fair trial here, but certainly nothing about its performance recommended it for production of sawlogs. For both of these species, measurements of older plantations led to different conclusions than those based on earlier measurements.

Another change in ranking occurred in white pine, which improved its position after the 1939 measurements. We consider it fourth on the list now. Norway spruce can still be rated a useful species. Scotch pine, while generally poor in yield thus far, has

shown some promise. Selected progenies may have use, particularly in the warmer portions of the region where the shoot moth causes severe damage to red pine. Scotch pine, as pointed out by Miller and Heikkenen *(1959)*, is damaged less by the shoot moth than red pine. Moreover, Scotch pine plantations may have value for purposes other than timber production in that they create conditions favorable for hardwood regeneration.

Not enough hardwood plantings were available for examination to justify any definite conclusions about performance of different hardwood species. However, a few plantings of yellow-poplar and red oak indicated that these species are capable of growing well on suitable sites.

Besides inherent growth characteristics, susceptibility to pests will influence the selection of species to plant. The two major pests of our planted trees are the white-pine weevil and the pine shoot moth on red pine. Both of these insects may attack certain other tree species besides the principal host, but the damage inflicted on these other species is spotty and usually less destructive.

In the present plantations, white pine did surprisingly well under weevil attack—considerably better than Hetzel expected in 1939. In fact, white pine could be an outstanding species in this region if a moderate effort were expended on weevil control. Heiberg *(1953)* reported that white pine in New York will overtake red pine in height growth at 40 to 50 years of age. This may yet happen in some of the red pine-white pine mixtures in northwestern Pennsylvania.

The pine shoot moth is not a serious pest on red pine at the higher elevations of northwestern Pennsylvania. It tends to be more damaging at lower elevations and southward as the climate becomes milder, and here some discrimination against red pine might be warranted. In Michigan, Heikkenen and Miller *(1960)* reported that red pines growing 15 inches or more per year in height were resistant to attack. All the red pine plantations on well-drained soils in our study exceeded that growth rate; those on somewhat poorly drained soils fell short of it.

Another factor that may have some influence on the selection of species to plant is their utilization value. However, this will usual-

ly be a secondary consideration; no great decisive differences in utilization potential exist among the coniferous species growing in the study plantations.

These plantations have shown the value of planting intimate mixtures for the purpose of natural or self-thinning. Where self-thinning took place through the suppression of one species by another, it made noncommercial thinnings unnecessary, prevented serious overstocking for the first 40 years or more, and improved the sawlog yield.

Although well-timed selection thinnings on a crop-tree basis would be preferable to self-thinning, these pre-commercial treatments are frequently not practical or economical. For this reason, small private plantations would be especially suitable for mixed plantings. Although wide initial spacings might also be used to avoid early thinning, trees grown under these conditions tend to become extremely rough and have excessive taper.

Intimately mixed plantations also afford some insurance against planting the wrong species on a particular site. The species best adapted to the site will ordinarily displace less well-adapted species and become dominant. But even as we learn more about the site requirements of each species, there will still be some uncertainty as to which one will thrive best in a particular location. And there often are many site variations in a small area that would be difficult to define and treat individually.

The self-thinning advantages of intimate mixtures have scarcely been mentioned in the literature. Skog *(1951)* observed that suppression of white pine by red pine in 25-year-old mixed plantations apparently served the same purpose as thinning and that additional thinning was not needed to maintain the good red pine growth rate. Where row mixtures are used in plantations in Maryland, one species is often regarded as a filler. Some of these fillers have been harvested as Christmas trees; others serve as trainers and then die or are removed in thinnings *(Soc. Amer. Foresters 1961)*.

Intimate mixtures have often been judged failures in the past because one of the basic criteria set up for success was that the different species survive and grow at approximately the same rate.

If one rejects this criterion and judges success on a basis of total growth in volume or value, he will find mixtures offer substantial advantages over single-species plantings where precommercial thinnings are impractical. If precommercial thinnings are avoided, the chances for making the planting investment a profitable one should be greatly increased. For most situations, the planter will find the combination of red pine or larch (or both) with white pine or Norway spruce is a good one.

Summary

Plantations in northwestern Pennsylvania examined and measured by Hetzel in 1939 were revisited by the author in 1960 and 1961. At this time the average age of all plantations was 45 years. In our re-examination, measurements of height and diameter, and estimates of form of individual trees were made as in 1939; in addition, sample plots were laid out to obtain data on yield.

In some plantations where two or more species had been planted in mixture, one species became dominant and the other, or others, died out or were suppressed. This demonstrated one important advantage gained by using intimate mixtures in plantations that were not destined for precommercial thinning: the plantations had thinned themselves naturally. Another advantage is that mixtures increase the chances of having at least one species in a plantation that is well adapted to the site. Therefore, it would seem that mixed planting deserves more consideration.

The differing performance expressed after 20 or 21 more years' growth, together with the addition of yield data, resulted in some changes in ratings of the several species planted in this area. As in 1939, red pine and the larches were still the leading species in growth and yield, but pitch pine and jack pine had slipped to a point where they could no longer be recommended. White pine looked better than it had 20 years earlier, and would be an outstanding species if weevil control were practiced in the younger plantations. Norway spruce retained its rating as a useful species. Although Scotch pine was favored over white pine in the earlier study, it appeared in 1960-61 to merit planting only in certain special situations.

Growth and yield of some of the plantations has been remarkable, and in many it has been eminently satisfactory. Seven of the 37 plantations produced more than 1 cord (92 cubic feet) of peeled wood per acre per year, and 7 plantations yielded more than 200 board feet per acre per year over the full age-span of the trees. Thirty of the 37 plantations produced more than a half cord of peeled wood per acre per year. Height growth of the dominant and codominant trees in almost all plantations averaged over 1 foot per year. Diameter growth of the dominant and codominant trees in many of the plantations averaged over 0.20 inch per year.

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