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growth and yield of BLACK SPRUCE on Organic Soils in Minnesota

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FOREST SERVICE · U.S. DEPARTMENT OF AGRICULTURE

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GROWTH AND YIELD OF BLACK SPRUCE ON ORGANIC SOILS IN MINNESOTA

Donald A. Perala

Black spruce (*Picea mariana* (Mill.) B.S.P.) is the dominant timber species on lowland organic soils in northern North America; it ranges from Labrador and the northeastern United States to the Bering Strait. Within the contiguous United States, black spruce is most abundant in the Lake States, where it occupies 2 million acres of commercial timber land. Two-thirds of this acreage is in Minnesota, where the type is limited to the northeastern third of the State.

Black spruce forms virtually pure stands in peatland areas occupying former glacial lakes, such as Lake Agassiz. Even-aged stands are commonly initiated after a fire. The species is tolerant of its own shade, and the stands eventually become uneven-aged through seeding, layering, and eventual deterioration of the original stand that provides openings for reproduction. Black spruce stands suffer high mortality throughout their development.

Black spruce has a straight bole with little taper, a narrow, symmetrical crown, and short, slender branches. It attains heights exceeding 80 feet, averages 5 to 9 inches in diameter at maturity, and is used almost exclusively for pulpwood. The wood is light in color and produces high-quality paper. The silvical characteristics of black spruce are presented in greater detail by Heinselman (1957b), Fowells (1965), and Vincent (1965).

The ability to forecast growth and yield is fundamental to timber management. This paper presents the analysis of growth and yield information from a number of study plots in black spruce stands growing on organic soils in northern Minnesota. Furthermore, growth and yield data for the merchantable portion of the stand are included, which should be of most use to the land manager. Growth as defined in this paper is periodic net 10-year increment, unless otherwise specified. Yield is defined here as the volume on a given site at a given age and basal area density. No deduction for defect has been assumed for either growth or yield.

METHODS

The data for this study were collected from permanent sample plots in black spruce stands growing on organic soils in north central Minnesota (Koochiching and Itasca counties). The growth analysis is based on 128 observations on 84 plots. These plots, along with others unsuited for growth analysis, contributed 291 yield observations. The remeasurement interval was mostly 5 years but ranged from 4 to 14 years (table 1). All growth observations were adjusted to reflect a 5-year period. All plots were 0.1 acre, in essentially pure, unthinned,[1] disease- and insect-free black spruce stands of even-aged origin.

Plot summaries produced the following variables for basal area projection analysis:

1. Initial total age (T_O) – obtained from increment cores taken from dominant and codominant sample trees at breast height at the beginning of the growth period. It was determined that 12 years was the average age difference between stump and breast height, and this was added to obtain total age.
2. Site index (S) – obtained from average total age and average total height of dominant and codominant sample trees measured by Abney level. Reference age was 50 years based on site index curves fitted by Gevorkiantz (1957) to the data of Fox and Kruse (1939) (fig. 1).
3. Initial per-acre basal area (G_O) – in square feet for all live trees 3.6 inches d.b.h. and greater at the beginning of the growth period. Diameters were measured by tape to the nearest 0.1 inch.
4. Final per-acre basal area (G_5) – in square feet 5 years later for all live trees 3.6 inches d.b.h. and greater, including ingrowth.
5. Final per-acre basal area plus mortality ($G_5 + G_M$) – as in (4) above except the square foot basal area of all trees 3.6 inches d.b.h. and greater that died during the period was added. Since dead trees were not remeasured, their basal area was considered to be that at the beginning of the period.
6. Final per-acre basal area plus mortality minus recruitment, or ingrowth ($G_5 + G_M - G_R$) – as in (5)

[1] *Ninety-three thinned-plot observations were also included in the yield analysis.*

Table 1. – Data summary for the study of growth and yield of black spruce in Minnesota

Permanent sample plots	Date established	Dates remeasured	Site index 1/	Total age	Basal area density 2/	Number of plots	Number of growth observa-tions 3/
				Years	Sq. ft. per acre		
Big Falls Compartment Study 4/	1948-1950	1954, 1955, 1960	23-44	61-202	51-170	73	107
Noncommercial thinning study 4/	1954	1967	31-34	24-39	11-35	4	4
Section 18 plots 4/	1940	1945, 1950 1960	36-41	84-164	126-184	3	9
Wilderness plots 5/	1947	1952, 1957	31-36	75-84	104-139	4	8

1/ Average total height in feet of dominants and codominants at age 50 years.
2/ Trees 3.6 inches in diameter and larger.
3/ 291 observations were included in the yield analysis.
4/ Maintained in cooperation with the Division of Lands and Forestry, Minnesota Conservation Department.
5/ Maintained in cooperation with the Chippewa National Forest, USDA Forest Service.

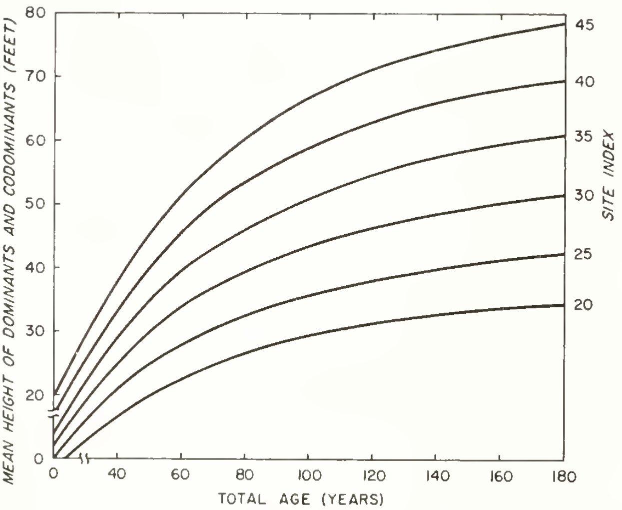

Figure 1. – Site curves for black spruce in the Lake States (Gevorkiantz (1957), Fox and Kruse (1939)).

above except the square foot basal area of trees that grew past the 3.6 inch d.b.h. minimum was not included.

For the yield analysis the following variables were obtained:

1. Per-acre cubic-foot volume (V cubic feet) – the total cubic-foot stem volume, inside bark, of all trees 3.6 inches d.b.h. and greater (based on table 3, Gevorkiantz and Olsen 1955).

2. Per-acre cordwood volume (V cords) – the total gross volume in rough cords to a variable top diameter inside bark of not less than 3 inches of all trees 3.6 inches d.b.h. and greater (based on table 5, Gevorkiantz and Olsen 1955).

3. Total age, site index, and basal area density obtained the same way as in the growth plots.

The Volume Yield Equations

As a first step, the analysis required the development of regression equations to predict per-acre volume yields in total cubic feet and merchantable cords from site, age, and basal area. Several prediction equations were tested and the one with the best fit to the data (highest R^2 and lowest standard error) was chosen for this study. In general form the equation is

EQUATION 1.

$$l_eV = b_0 + b_1 (l_eS) + b_2 (l_eG) + b_3 T^{-1},$$

where

l_eV = natural, or Naperian, logarithm of volume
l_eS = logarithm of site index in feet
l_eG = logarithm of basal area per acre in square feet
T^{-1} = inverse of total stand age in years.

Rewritten in terms of V rather than l_eV, the equation becomes

EQUATION 2.

$$V = e^{b_0 + b_1 (l_eS) + b_2 (l_eG) + b_3 T^{-1}},$$

where e = natural logarithm base, 2.718....

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[eq]uations resulted, expressed in the form of Equation 6.

[EQU]ATION 7.

$$\frac{G_0}{100} \cdot e^{4.63540 + .28818\ 100\ T_0^{-1} + .0005615\ G_0 - .0024652\ 100\ G_0 T_0^{-1}}$$

EQUATION 8.

$$G_{\sim}\ \ 4.64732 + .28443\ 100\ T_0^{-1} + .0007212\ G_0 - .0025269\ 100\ G_0 T_0^{-1}$$

$$.07054\ 100\ T_0^{-1} + .0001306\ G_0 - .0006465\ 100\ G_0 T_0^{-1}$$

[Equation] 7 expressed 5-year projected net basal area [as a functi]on of growth percent, or compound interest. [Equation 8], where G_M is 5-year basal area mortality, was [used] to estimate 5-year projected gross basal area; [by determi]ning the difference between the Equation 7 [and 8 pre]dictions, 5-year basal area mortality can be [estimated.] Equation 9, where G_R is 5-year basal area [recruitmen]t, or ingrowth, goes one step further and [estimates] 5-year projected gross basal area not including [ingrowth.] The difference between the predictions of [Equations] 8 and 9 therefore gives an estimate of 5-year [basal are]a ingrowth. Additional analysis provided the [following] statistics:

n	R^2	SE log scale	Percent SE natural scale
	.77	.07890	8.2
	.78	.07379	7.6
	.66	.02568	2.6

Testing the Equations

[A c]heck of 14 black spruce sales near the study area [showed] Equation 4 volumes compared favorably with [the] cords cut (table 2). A 54-acre sale area, of which [two-th]irds was site indexes 22 to 28 and the rest site [index] 33, yielded 562 cords; the Equation 4 prediction [for th]is sale was 411 cords, or 73.1 percent of actual. [Anoth]er area with site indexes ranging from 33 to 42 [yielde]d 1,948 cords, compared with 1,868 predicted, or [96] percent of actual. From these checks, it appears Equation 4 may overestimate volume on the best and underestimate it on poor sites. On the other [hand], it is suspected that closer utilization on poor sites and underutilization on the best sites occurred, although no formal utilization checks were made on these sales.

To test the basal area projection equations (Equations 7, 8, 9), 5-year projected basal areas from 30 stands not

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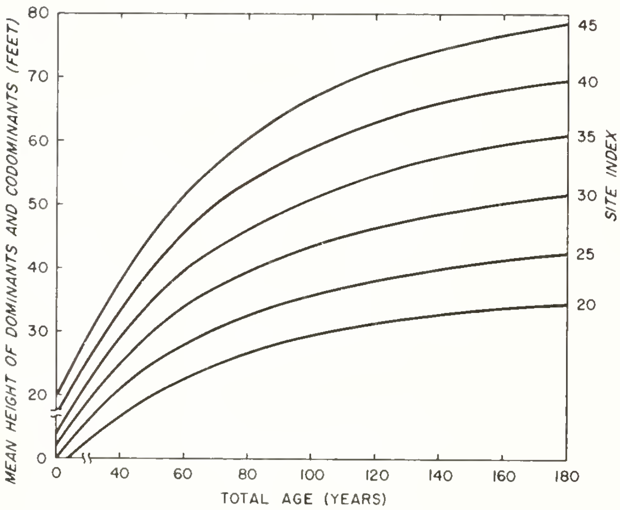

Figure 1. – Site curves for black spruce in the Lake States (Gevorkiantz (1957), Fox and Kruse (1939)).

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where

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l_eG = logarithm of basal area per acre in square feet
T^{-1} = inverse of total stand age in years.

Rewritten in terms of V rather than l_eV, the equat becomes

EQUATION 2.

$$V = e^{b_0 + b_1 (l_eS) + b_2 (l_eG) + b_3 T^{-1}},$$

where e = natural logarithm base, 2.718....

This prediction equation is essentially the one used by Clutter (1963), except he used "S" rather than the logarithmic transformation "$l_e S$."

Equation 1 was fitted to the cubic foot and cord data. All variables were significant, and after rewriting in the form of Equation 2, resulted in these yield prediction equations:

EQUATION 3.

$$V \text{ cubic feet} = e^{1.07542 + .61265\, l_e S + .96861\, l_e G - 9.450\, T^{-1}}$$

EQUATION 4.

$$V \text{ cords} = e^{-5.16547 + 1.09987\, l_e S + .95519\, l_e G - 18.716\, T^{-1}}$$

Equation 3 had an R^2 of 0.98 and a standard error of 0.05683 on the logarithmic scale equivalent to 5.8 percent standard error at the mean when converted to natural volume (Spurr 1952, p. 73-74). Equation 4 had an R^2 of .93 with a standard error of 0.10629 (log scale), equivalent to 11.2 percent standard error.

The Basal Area Projection Equations

The growth equations of Buckman (1962) and Clutter (1963) were tested, but proved to be inadequate for black spruce. However, a satisfactory equation was adapted from Evert (1967) and used here:

EQUATION 5.

$$l_e \frac{100\, G_5}{G_0} = b_0 + b_1\, 100\, T_0^{-1} + b_2\, G_0 + b_3\, 100\, G_0 T_0^{-1} + b_4 S$$

where

$l_e \frac{100\, G_5}{G_0}$ = natural logarithm of 100 times the ratio of basal area 5 years later (G_5) to the initial basal area (G_0),

T_0^{-1} = inverse of initial total stand age, and

S = site index.

Rewriting the equation in terms of G_5 gives

EQUATION 6.

$$G_5 = \frac{G_0}{100} \cdot e^{b_0 + b_1\, 100\, T_0^{-1} + b_2 G_0 + b_3\, 100\, G_0 T_0^{-1} + b_4 S}$$

Equation 5 was fitted to the basal area data. All variables except site index were significant, and the final equations resulted, expressed in the form of Equation 6:

EQUATION 7.

$$G_5 = \frac{G_0}{100} \cdot e^{4.63540 + .28818\, 100\, T_0^{-1} + .0005615\, G_0 - .0024652\, 100\, G_0 T_0^{-1}}$$

EQUATION 8.

$$G_5 + G_M = \frac{G_0}{100} \cdot e^{4.64732 + .28443\, 100\, T_0^{-1} + .0007212\, G_0 - .0025269\, 100\, G_0 T_0^{-1}}$$

EQUATION 9.

$$G_5 + G_M - G_R = \frac{G_0}{100} \cdot e^{4.68605 + .07054\, 100\, T_0^{-1} + .0001306\, G_0 - .0006465\, 100\, G_0 T_0^{-1}}$$

Equation 7 expressed 5-year projected net basal area as a function of growth percent, or compound interest. Equation 8, where G_M is 5-year basal area mortality, was developed to estimate 5-year projected gross basal area; by determining the difference between the Equation 7 and 8 predictions, 5-year basal area mortality can be estimated. Equation 9, where G_R is 5-year basal area recruitment, or ingrowth, goes one step further and estimates 5-year projected gross basal area not including ingrowth. The difference between the predictions of Equations 8 and 9 therefore gives an estimate of 5-year basal area ingrowth. Additional analysis provided the following statistics:

Equation	R^2	*SE log scale*	*Percent SE natural scale*
7	.77	.07890	8.2
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Testing the Equations

A check of 14 black spruce sales near the study area showed Equation 4 volumes compared favorably with actual cords cut (table 2). A 54-acre sale area, of which two-thirds was site indexes 22 to 28 and the rest site index 33, yielded 562 cords; the Equation 4 prediction for this sale was 411 cords, or 73.1 percent of actual. Another area with site indexes ranging from 33 to 42 yielded 1,948 cords, compared with 1,868 predicted, or 95.9 percent of actual. From these checks, it appears that Equation 4 may overestimate volume on the best sites and underestimate it on poor sites. On the other hand, it is suspected that closer utilization on poor sites and underutilization on the best sites occurred, although no formal utilization checks were made on these sales.

To test the basal area projection equations (Equations 7, 8, 9), 5-year projected basal areas from 30 stands not used in the analysis were summed and compared with summed projected basal areas computed from the equations. The stands ranged in age from 96 to 154 years (mean 135) and had a mean initial basal area of 123.9 square feet. The predicted sums were in close agreement with the actual sums (table 3).

Growth and Yield Tables

Yield (tables 4 and 5) computed from Equations 3 and 4 is presented for each of three site index classes by combinations of basal area and age. Net basal area growth (table 6) during a 10-year period for all sites by initial age and basal area density was computed from Equation 7. Age and basal area density for Equation 7 are specified at the beginning of the growth period and the equation projects basal area for periods of 5 years. Therefore, to obtain 10 years' projected basal area growth, repeated solution of the equation by 5-year increments followed by subtraction of the initial basal area is required.

Volume growth (tables 7 and 8) by site classes for combinations of basal area density and age was computed simply as the difference between the initial yield and the final yield by applying Equations 3 and 4 to basal area projections obtained as above. Projected basal area and yield is given by site classes for 60-year-old stands at initial basal area densities of 20, 60, 100, and 140 square feet, and for 80- to 160-year-old stands at initial densities of 30 to 70 square feet (figs. 2 and 3, and tables 9, 10, 11). In addition, tables 9 to 11 show the contribution of mortality and ingrowth to 10-year projected net basal area as well as current annual increment and mean annual increment in total cubic feet and cords.

DISCUSSION

The yield equations (Equations 3 and 4) provide convenient estimates of volume when site, basal area density, and age of the stand are known. Total cubic foot volume is predicted especially well because diameter distribution has relatively little effect on this measure. However, when volume is estimated in rough cords, or in any other merchantable measure, diameter distribution and mean stand diameter introduce variation unaccounted for by the variables in Equation 4. This limitation should be considered when using Equation 4, which actually expresses yield in cords for stands of "average" diameter distribution and "average" mean diameter for a given age, site, and basal area density.

Table 2. – Comparison of actual and predicted volume yields from 14 black spruce harvest cuts in northern Minnesota

Site index	Age	Basal area	Actual volume	Predicted volume	Predicted as percent of actual
	Years	Square feet	Cords	Cords	
42	120	80	180	196	108.9
38	70-130	60-180	1,386	1,387	100.0
33	80-125	40-140	2,368	2,258	95.4

Table 3. – Comparison of summed actual and predicted basal area growth for 30 black spruce stands in northern Minnesota

Item	Basal area						
	Initial	Final net	Net growth	Final gross	Gross growth	Mortality	Ingrowth
	Square feet						
Actual	3,718.2	4,022.2	304.0	4,118.7	400.5	96.5	50.9
Predicted	3,718.2	4,029.0	310.8	4,123.5	405.3	94.5	73.2
Predicted as percent of actual	100	100.2	102.2	100.1	101.2	97.9	143.8

Table 4. – Minnesota black spruce yield in total cubic feet[1] per acre for trees 3.6 inches d.b.h. and larger (blocks indicate extent of basic data)

SITE INDEX 45

Stand age (years)	Stand basal area, square feet per acre							
	40	60	80	100	120	140	160	180
	Cubic feet per acre							
60	919	1,361	1,798	2,232	2,663	3,092	--	--
80	956	1,416	1,870	2,322	2,770	3,216	3,660	4,103
100	979	1,449	1,915	2,377	2,836	3,293	3,748	4,201
120	994	1,472	1,946	2,415	2,881	3,346	3,807	4,268
140	1,005	1,489	1,968	2,442	2,914	3,383	3,850	4,316
160	1,014	1,502	1,984	2,463	2,939	3,412	3,883	4,352
180	1,021	1,512	1,997	2,479	2,958	3,434	3,909	4,381
200	1,026	1,520	2,008	2,492	2,974	3,452	3,929	4,404
	SITE INDEX 35							
60	788	1,167	1,542	1,914	2,283	2,651	--	--
80	819	1,214	1,604	1,990	2,375	2,757	3,138	--
100	839	1,242	1,642	2,038	2,432	2,823	3,213	3,601
120	852	1,262	1,668	2,070	2,470	2,868	3,264	3,658
140	862	1,276	1,687	2,094	2,498	2,900	3,301	3,700
160	869	1,287	1,701	2,112	2,519	2,925	3,329	3,731
180	875	1,296	1,712	2,125	2,536	2,944	3,351	3,756
200	880	1,303	1,721	2,137	2,549	2,960	3,368	3,776
	SITE INDEX 25							
60	641	949	1,254	1,557	1,858	--	--	--
80	667	988	1,305	1,620	1,932	2,244	--	--
100	683	1,011	1,336	1,658	1,979	2,297	2,614	2,930
120	694	1,027	1,357	1,685	2,010	2,334	2,656	2,977
140	701	1,039	1,373	1,704	2,033	2,360	2,686	3,011
160	707	1,048	1,384	1,718	2,050	2,380	2,709	3,036
180	712	1,054	1,393	1,730	2,064	2,396	2,727	3,056
200	716	1,060	1,401	1,739	2,074	2,408	2,741	3,072

1/ Gross peeled volume entire stem based on table 3, Gevorkiantz and Olsen (1955).

The composite tables by Gevorkiantz and Olsen (1955) used to determine volumes in this study provide an underlying flexibility for predicted volume growth and yield. The growth and yield tables presented here may be adjusted for local differences in species taper, form quotient, bark volume, care in piling, and actual utilization practices in the same manner as outlined by the authors for the composite tables, or through past experience with the tables.

In five checks of 20 to 27 trees each, Gevorkiantz and Olsen found their composite total cubic foot volume table (table 3) to deviate from actual black spruce tree volume by -7.7 to +0.4 percent (mean -2.6 percent). Kirby (1960) also found composite table 3 to underestimate black spruce volume by 2 to 5 percent in Saskatchewan.

According to Gevorkiantz and Olsen, the composite cordwood volume table 5 should need adjustment primarily only for actual utilization practices and care in piling. Other factors are largely compensating, except that adjustments may be necessary if form varies greatly from the average.

Although site index is an important variable for predicting volume yields, it was not significant in the analysis of the basal area projection Equations 7, 8, and 9. Evert (1967, p. 8) also found that site index did not contribute significantly to his basal area regressions, and concluded that "the presence of a certain amount of

Table 5. -- Minnesota black spruce yield in cords[1] per acre for trees 3.6 inches d.b.h. and larger (blocks indicate extent of basic data)

SITE INDEX 45

Stand age (years)	Stand basal area, square feet per acre							
	40	60	80	100	120	140	160	180
	Cords per acre							
60	9.3	13.7	18.1	22.4	26.6	30.9	--	--
80	10.1	14.8	19.6	24.2	28.8	33.4	37.9	42.4
100	10.6	15.6	20.5	25.4	30.2	35.0	39.7	44.4
120	10.9	16.0	21.1	26.2	31.1	36.1	41.0	45.9
140	11.1	16.4	21.6	26.7	31.8	36.9	41.9	46.9
160	11.3	16.7	22.0	27.2	32.4	37.5	42.6	47.7
180	11.5	16.9	22.3	27.6	32.8	38.0	43.2	48.3
200	11.6	17.1	22.5	27.8	33.1	38.4	43.6	48.8
	SITE INDEX 35							
60	7.1	10.4	13.7	17.0	20.2	23.4	--	--
80	7.6	11.3	14.8	18.4	21.8	25.3	28.8	--
100	8.0	11.8	15.5	19.2	22.9	26.5	30.1	33.7
120	8.3	12.2	16.0	19.8	23.6	27.4	31.1	34.8
140	8.4	12.4	16.4	20.3	24.1	28.0	31.8	35.6
160	8.6	12.7	16.7	20.6	24.6	28.4	32.3	36.2
180	8.7	12.8	16.9	20.9	24.9	28.8	32.7	36.6
200	8.8	13.0	17.1	21.1	25.1	29.1	33.1	37.0
	SITE INDEX 25							
60	4.9	7.2	9.5	11.7	14.0	--	--	--
80	5.3	7.8	10.2	12.7	15.1	17.5	--	--
100	5.5	8.2	10.7	13.3	15.8	18.3	20.8	23.3
120	5.7	8.4	11.1	13.7	16.3	18.9	21.5	24.0
140	5.8	8.6	11.3	14.0	16.7	19.3	22.0	24.6
160	5.9	8.7	11.5	14.2	17.0	19.6	22.3	25.0
180	6.0	8.9	11.7	14.4	17.2	19.9	22.6	25.3
200	6.1	9.0	11.8	14.6	17.4	20.1	22.8	25.6

1/ Gross rough volume to a variable top d.i.b. of not less than 3.0 inches, based on table 5, Gevorkiantz and Olsen (1955).

Table 6. -- Ten-year net basal area growth in square feet per acre on all sites of black spruce in Minnesota for trees 3.6 inches d.b.h. and larger (blocks indicate extent of basic data)

Stand age (years)	Stand basal area, square feet per acre							
	40	60	80	100	120	140	160	180
60	37.0	39.9	36.5	28.6	17.5	4.1	-11.1	--
80	28.2	32.2	31.5	27.0	19.5	9.7	- 2.1	--
100	23.1	27.5	28.2	25.8	20.8	13.7	4.7	- 5.9
120	19.8	24.3	25.9	24.9	21.7	16.6	9.8	1.5
140	17.4	22.0	24.2	24.3	22.4	18.9	13.8	7.3
160	15.7	20.3	22.9	23.7	22.9	20.6	17.7	12.1
180	14.4	19.0	21.9	23.3	23.3	22.1	19.7	16.1

Table 7. – Minnesota black spruce ten-year net total cubic foot growth per acre for trees 3.6 inches d.b.h. and larger

SITE INDEX 45

Stand age (years)	Stand basal area, square feet per acre							
	40	60	80	100	120	140	160	180
	Cubic feet per acre							
60	853	920	849	681	444	160	-162	--
80	668	759	744	644	477	261	1	--
100	556	657	673	617	504	343	140	- 98
120	482	587	623	598	524	406	250	60
140	428	535	585	586	541	459	340	190
160	388	497	557	574	554	499	430	299
180	358	467	534	566	564	535	477	392
SITE INDEX 35								
60	732	783	728	583	381	137	-139	--
80	573	651	637	552	409	224	1	--
100	477	564	577	529	432	294	120	- 84
120	414	503	534	513	449	348	214	52
140	366	459	502	503	464	393	292	162
160	333	426	477	492	475	428	369	256
180	307	400	458	485	484	458	409	336
SITE INDEX 25								
60	595	642	592	475	310	112	-113	--
80	466	529	519	449	333	182	1	--
100	388	459	469	431	351	239	98	- 69
120	336	409	434	418	365	283	174	42
140	298	373	408	409	377	320	237	132
160	271	346	388	400	386	348	300	209
180	250	326	373	395	394	373	333	274

basal area at any age is, partly at least, itself a function of site quality." Buckman (1962) cited several references where site index was nonsignificant and discussed the problems associated with relating site index to basal area growth. Both he and Clutter (1963) found considerable positive effect of site index on basal area growth of red pine and loblolly pine.

The projection of basal area with time (fig. 2) points out that Equation 7 provides a self-limiting maximum possible basal area density for any given age, which ranges from about 140 square feet at 60 years to about 210 square feet at 180 years. Also the growth curves are sigmoidal, which is most easily seen by following the lowest initial densities at age 60 and 80. Also the trend is evident for understocked stands to have higher growth rates and approach full stocking. All three of these characteristics are generally accepted principles of stand development and support this equation as a growth predictor for forest stands.

One characteristic of this equation is open to question, however. As stands closely approach the maximum basal area limit, there is a slight trend toward an increasing growth rate. This causes a small increase in periodic volume growth, as shown in tables 9 to 11. Whether this slight increase is real is doubtful. However, the effect is so small that it can be disregarded for all practical purposes.

Black spruce on organic soils has potential for accumulating growth even at very old ages. Fifteen of the study observations were in stands older than 160

Table 8. – Minnesota black spruce ten-year net cordwood growth per acre for trees 3.6 inches d.b.h. and larger

SITE INDEX 45

Stand age (Years)	Stand basal area, square feet per acre							
	40	60	80	100	120	140	160	180
	Cords per acre							
60	8.9	9.6	9.0	7.4	5.1	2.3	-0.8	--
80	7.1	8.1	8.0	7.0	5.3	3.1	.5	--
100	6.0	7.1	7.3	6.8	5.6	3.9	1.8	-0.6
120	5.3	6.4	6.8	6.6	5.8	4.6	2.9	.9
140	4.7	5.9	6.4	6.5	6.0	5.1	3.8	2.2
160	4.3	5.5	6.2	6.4	6.1	5.6	4.8	3.4
180	4.0	5.2	5.9	6.3	6.3	6.0	5.3	4.4
SITE INDEX 35								
60	6.8	7.3	6.8	5.6	3.8	1.8	-0.6	--
80	5.4	6.2	6.1	5.3	4.0	2.4	.4	--
100	4.6	5.4	5.6	5.1	4.2	3.0	1.4	-0.5
120	4.0	4.9	5.2	5.0	4.4	3.4	2.2	.7
140	3.6	4.5	4.9	4.9	4.5	3.9	2.9	1.7
160	3.3	4.2	4.7	4.8	4.6	4.2	3.6	2.6
180	3.0	3.9	4.5	4.8	4.8	4.5	4.0	3.3
SITE INDEX 25								
60	4.6	5.0	4.7	3.9	2.7	1.1	-0.4	--
80	3.7	4.2	4.2	3.7	2.8	1.6	.3	--
100	3.2	3.7	3.8	3.5	2.9	2.0	1.0	-0.3
120	2.8	3.4	3.6	3.4	3.0	2.4	1.5	.5
140	2.5	3.1	3.4	3.4	3.1	2.7	2.0	1.2
160	2.3	2.9	3.2	3.3	3.2	2.9	2.5	1.8
180	2.1	2.7	3.1	3.3	3.3	3.1	2.8	2.3

years, and only two had negative net growth (barely) over the measurement period. Whether this potential can be realized probably depends largely on wind-caused mortality (Heinselman 1957a) and the incidence and severity of butt rot (LeBarron 1948).

Tables 9 to 11 (column 5) show that ingrowth is an important source of total net merchantable growth for understocked black spruce in both young and old stands. The average periodic net annual per-acre basal area growth was 2.23 square feet. Of this, .58 square feet, or 26 percent, was due to ingrowth. The average periodic gross annual per-acre basal area growth was 2.79 square feet; .56 square feet, or 20 percent, was lost to mortality. Obviously, both ingrowth and mortality must be considered as important components of black spruce productivity.

SUMMARY

Equations have been developed and tables presented here for estimating growth and yield in total cubic feet and cords of the merchantable portion of black spruce stands growing on organic soils in northern Minnesota when basal area density, age, and site index are known. With this basic tool forest managers can more accurately forecast the productivity of black spruce stands growing on organic soils. This information can be valuable too in evaluating the potential of once-forested but now unproductive organic soils if something is known about black spruce site quality. It should be cautioned that growth and yield predictions should not be extrapolated beyond the range of values given here.

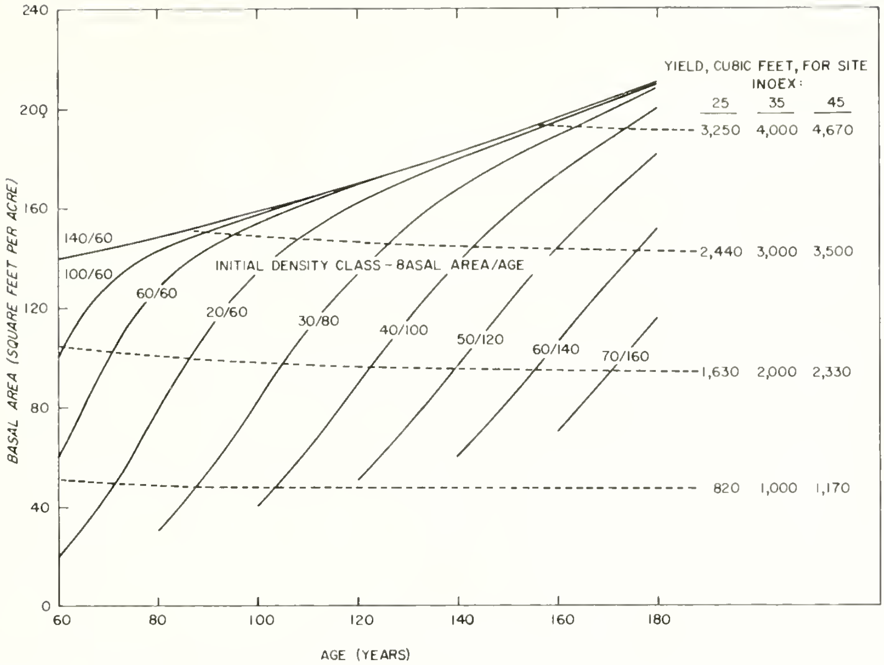

Figure 2. – Per-acre projected basal area and total cubic foot yield of trees 3.6 inches d.b.h. and larger for black spruce site indexes 25, 35, and 45. Example of use: Assume a present basal area of 96 square feet at age 140. The present yield is 1,630 cubic feet for site index 25 (2,000 and 2,330 cubic feet for site indexes 35 and 45, respectively). Assume we wish to project the stand 20 years. Follow the basal area growth curve to age 160. The projected basal area of 144 square feet is read off the left vertical scale and the projected yield is 2,440 cubic feet for site index 25 (3,000 and 3,500 cubic feet for site indexes 35 and 45).

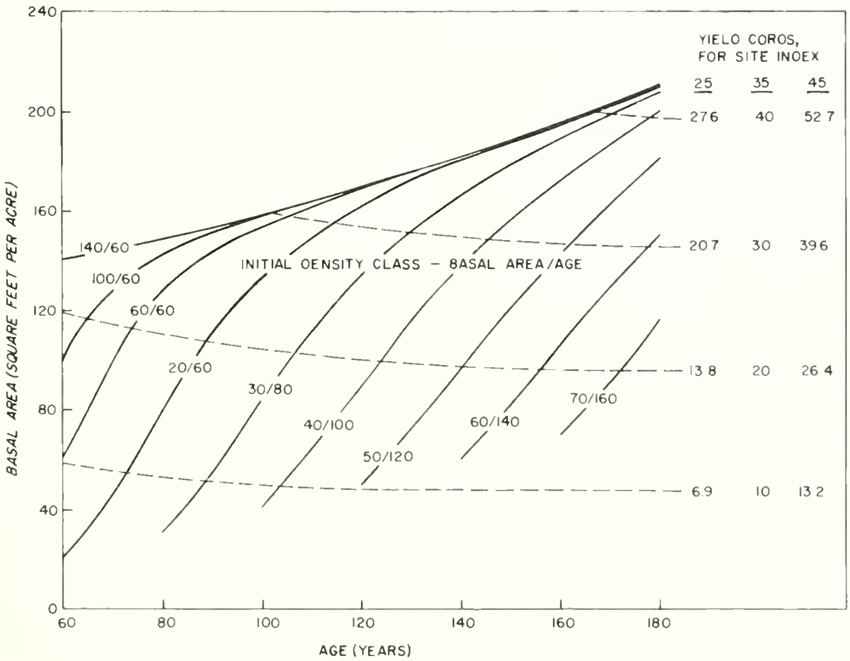

Figure 3. – Per-acre projected basal area and yield in cords for trees 3.6 inches d.b.h. and larger for black spruce site indexes 25, 35, and 45. For example of use, see figure 2.

Table 9. – Projected yield table for site index 45 black spruce in Minnesota by various initial densities and ages (all data are per acre for trees 3.6 inches d.b.h. and larger)

Total age (years)	Height of dominants and codominants	Basal area			Volume			Volume		
		Accumulated	10-year mortality	10-year ingrowth	Accumulated	Current annual increment	Mean annual increment	Accumulated	Current annual increment	Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
INITIAL BASAL AREA 20 AT AGE 60										
60	51	20.0	--	--	470	--	7.8	4.8	--	0.08
70	56	45.1	0.5	16.2	1,056	58.6	15.1	10.9	0.61	.16
80	60	78.6	1.5	19.4	1,839	78.3	23.0	19.2	.83	.24
90	64	110.3	3.1	14.7	2,587	74.8	28.7	27.3	.81	.30
100	67	133.8	4,9	6.2	3,152	56.5	31.5	33.5	.62	.34
110	69	149.9	6.6	.4	3,549	39.7	32.3	38.0	.45	.34
120	71	161.5	7.9	.0	3,842	29.3	32.0	41.3	.33	.34
130	73	170.7	9.1	.0	4,078	23.6	31.4	44.1	.28	.34
140	74	178.8	10.4	.0	4,288	21.0	30.6	46.6	.25	.33
150	76	186.6	11.4	.0	4,489	20.1	29.9	49.0	.24	.33
160	77	194.3	12.6	.0	4,687	19.8	29.3	51.3	.23	.32
170	78	202.2	13.7	.0	4,888	20.1	28.8	53.6	.23	.32
180	79	210.5	14.9	.0	5,098	21.0	28.3	56.1	.25	.31
INITIAL BASAL AREA 60 AT AGE 60										
60	51	60.0	--	--	1,361	--	22.7	13.7	--	.23
70	56	99.9	1.9	22.4	2,281	92.0	32.6	23.4	.97	.33
80	60	127.7	3.6	9.7	2,942	66.1	36.8	30.6	.72	.38
90	64	143.7	5.2	.5	3,342	40.0	37.1	35.1	.45	.39
100	67	153.8	6.5	.0	3,607	26.5	36.1	38.2	.31	.38
110	69	161.4	7.7	.0	3,812	20.5	34.6	40.7	.25	.37
120	71	168.2	8.7	.0	3,996	18.4	33.3	43.0	.23	.36
130	73	174.7	9.7	.0	4,171	17.5	32.1	45.1	.21	.35
140	74	181.4	10.6	.0	4,348	17.7	31.0	47.2	.21	.34
150	76	188.2	11.7	.0	4,526	17.8	30.2	49.4	.22	.33
160	77	195.4	12.6	.0	4,713	18.7	29.4	51.6	.22	.32
170	78	203.0	13.8	.0	4,907	19.4	28.9	53.8	.22	.32
180	79	211.0	15.0	.0	5,110	20.3	28.4	56.2	.24	.31
INITIAL BASAL AREA 100 AT AGE 60										
60	51	100.0	--	--	2,232	--	37.2	22.4	--	.37
70	56	128.6	3.1	10.0	2,913	68.1	41.6	29.8	.74	.42
80	60	142.6	4.7	.0	3,274	36.1	40.9	34.0	.42	.42
90	64	150.8	6.0	.0	3,502	22.8	38.9	36.8	.28	.41
100	67	157.3	6.9	.0	3,687	18.5	36.9	39.1	.23	.39
110	69	163.2	7.9	.0	3,853	16.6	35.0	41.2	.21	.37
120	71	169.2	8.8	.0	4,019	16.6	33.5	43.2	.20	.36
130	73	175.3	9.8	.0	4,185	16.6	32.2	45.2	.20	.35
140	74	181.7	10.7	.0	4,355	17.0	31.1	47.3	.21	.34
150	76	188.4	11.7	.0	4,531	17.6	30.2	49.4	.21	.33
160	77	195.6	12.6	.0	4,717	18.6	29.5	51.6	.22	.32
170	78	203.1	13.9	.0	4,909	19.2	28.9	53.9	.23	.32
180	79	211.0	15.1	.0	5,110	20.1	28.4	56.2	.23	.31
INITIAL BASAL AREA 140 AT AGE 60										
60	51	140.0	--	--	3,092	--	51.5	30.9	--	.52
70	56	144.1	4.0	.0	3,252	16.0	46.4	33.2	.23	.47
80	60	148.6	5.3	.0	3,408	15.6	42.6	35.3	.21	.44
90	64	153.5	6.2	.0	3,563	15.5	39.6	37.4	.21	.42
100	67	158.6	7.0	.0	3,716	15.3	37.2	39.4	.20	.39
110	69	163.9	8.0	.0	3,870	15.4	35.2	41.3	.19	.38
120	71	169.6	8.8	.0	4,028	15.8	33.6	43.3	.20	.36
130	73	175.6	9.8	.0	4,192	16.4	32.2	45.3	.20	.35
140	74	181.9	10.7	.0	4,360	16.8	31.0	47.4	.21	.34
150	76	188.6	11.7	.0	4,536	17.6	30.2	49.5	.21	.33
160	77	195.6	12.6	.0	4,717	18.1	29.5	51.6	.21	.32
170	78	203.2	13.9	.0	4,912	19.5	28.9	53.9	.23	.32
180	79	211.2	15.1	.0	5,115	20.3	28.4	56.3	.24	.31

Table 9.--Continued

Total age (years)	Height of dominants and codominants	Basal area			Volume			Volume		
		Accumulated	10-year mortality	10-year ingrowth	Accumulated	Current annual increment	Mean annual increment	Accumulated	Current annual increment	Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
INITIAL BASAL AREA 30 AT AGE 80										
80	60	30.0	--	--	723	--	9.0	7.7	--	.10
90	64	54.0	1.0	14.1	1,295	57.2	14.4	13.8	.61	.15
100	67	82.8	2.1	15.1	1,980	68.5	19.8	21.2	.74	.21
110	69	110.9	3.5	11.8	2,650	67.0	24.1	28.5	.73	.26
120	71	134.3	5.5	6.4	3,213	56.3	26.8	34.7	.62	.29
130	73	152.6	7.2	1.4	3,659	44.6	28.1	39.6	.49	.30
140	74	166.8	9.0	.0	4,009	35.0	28.6	43.6	.40	.31
150	76	178.6	10.4	.0	4,303	29.4	28.7	47.0	.34	.31
160	77	188.9	11.8	.0	4,561	25.8	28.5	49.9	.29	.31
170	78	198.4	13.2	.0	4,799	23.8	28.2	52.7	.28	.31
180	79	207.8	14.5	.0	5,035	23.6	28.0	55.4	.27	.31
INITIAL BASAL AREA 40 AT AGE 100										
100	67	40	--	--	979	--	9.8	10.6	--	.11
110	69	63.1	1.5	12.3	1,535	55.6	14.0	16.6	.62	.15
120	71	89.2	2.7	12.2	2,162	62.7	18.0	23.4	.68	.20
130	73	115.0	4.2	9.8	2,782	62.0	21.4	30.2	.68	.23
140	74	137.9	6.1	6.0	3,334	55.2	23.8	36.4	.62	.26
150	76	157.2	8.1	2.2	3,802	46.8	25.3	41.6	.52	.28
160	77	173.4	9.9	.0	4,198	39.6	26.2	46.0	.44	.29
170	78	187.3	11.7	.0	4,539	34.1	26.7	49.9	.39	.29
180	79	199.6	13.5	.0	4,842	30.3	26.9	53.3	.34	.30
INITIAL BASAL AREA 50 AT AGE 120										
120	71	50	--	--	1,234	--	10.3	13.5	--	.11
130	73	72.4	2.1	10.8	1,777	54.3	13.7	19.4	.59	.15
140	74	97.0	3.2	10.3	2,371	59.4	16.9	26.0	.66	.18
150	76	121.4	5.0	8.4	2,960	58.9	19.7	32.5	.65	.22
160	77	143.9	7.0	5.6	3,504	54.5	21.9	38.5	.60	.24
170	78	164.0	9.0	1.8	3,991	48.7	23.5	43.9	.54	.26
180	79	181.6	11.0	.5	4,419	42.8	24.6	48.7	.48	.27
INITIAL BASAL AREA 60 AT AGE 140										
140	74	60	--	--	1,489	--	10.6	16.4	--	.12
150	76	82.0	2.6	9.6	2,024	53.5	13.5	22.3	.59	.15
160	77	105.6	4.0	8.9	2,596	57.2	16.2	28.6	.63	.18
170	78	129.3	5.8	7.4	3,170	57.4	18.6	35.0	.64	.20
180	79	151.8	7.9	5.3	3,714	54.4	20.6	41.0	.60	.23
INITIAL BASAL AREA 70 AT AGE 160										
160	77	70	--	--	1,744	--	10.9	19.3	--	.12
170	78	91.8	3.3	8.6	2,275	53.1	13.4	25.2	.59	.15
180	79	115.0	4.8	8.0	2,839	56.3	15.8	31.5	.63	.18

Table 10.—Projected yield table for site index [illegible] black spruce in Minnesota by various initial densities and ages (all data are per acre for trees 3.6 inches d.b.h. and larger)

Total age (years)	Height of dominants and codominants	Basal area: Accumulated	Basal area: 10-year mortality	Basal area: 10-year ingrowth	Volume: Accumulated	Volume: Current annual increment	Volume: Mean annual increment	Volume: Accumulated	Volume: Current annual increment	Volume: Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
INITIAL BASAL AREA 20 AT AGE 60										
60	40	20.0	--	--	402	--	6.7	3.6	--	0.06
70	43	45.1	0.5	16.2	905	50.3	12.9	8.3	0.47	.12
80	46	78.6	1.5	19.4	1,576	67.1	19.7	14.6	.63	.18
90	49	110.3	3.1	14.7	2,218	64.2	24.6	20.7	.61	.23
100	51	133.8	4.9	6.2	2,702	48.4	27.0	25.4	.47	.25
110	53	149.9	6.6	.4	3,042	34.0	27.6	28.8	.34	.26
120	55	161.5	7.9	.0	3,294	25.2	27.4	31.4	.26	.26
130	56	170.7	9.1	.0	3,496	20.2	26.9	33.5	.21	.26
140	58	178.8	10.4	.0	3,676	18.0	26.2	35.3	.18	.25
150	59	186.6	11.4	.0	3,848	17.2	25.6	37.1	.18	.25
160	60	194.3	12.6	.0	4,018	17.0	25.1	38.9	.18	.24
170	60	202.2	13.7	.0	4,191	17.3	24.6	40.7	.18	.24
180	61	210.5	14.9	.0	4,371	18.0	24.3	42.6	.19	.24
INITIAL BASAL AREA 60 AT AGE 60										
60	40	60.0	--	--	1,167	--	19.4	10.4	--	.17
70	43	99.9	1.9	22.4	1,955	78.8	27.9	17.7	.73	.25
80	46	127.7	3.6	9.7	2,522	56.7	31.5	23.2	.55	.29
90	49	143.7	5.2	.5	2,865	34.3	31.8	26.6	.34	.30
100	51	153.8	6.5	.0	3,092	22.7	30.9	29.0	.24	.29
110	53	161.4	7.7	.0	3,268	17.6	29.7	30.9	.19	.28
120	55	168.2	8.7	.0	3,426	15.8	28.6	32.6	.17	.27
130	56	174.7	9.7	.0	3,576	15.0	27.5	34.2	.16	.26
140	58	181.4	10.6	.0	3,728	15.2	26.6	35.8	.16	.26
150	59	188.2	11.7	.0	3,880	15.2	25.9	37.4	.16	.25
160	60	195.4	12.6	.0	4,040	16.0	25.2	39.1	.17	.24
170	60	203.0	13.8	.0	4,207	16.7	24.7	40.8	.17	.24
180	61	211.0	15.0	.0	4,381	17.4	24.3	42.6	.18	.24
INITIAL BASAL AREA 100 AT AGE 60										
60	40	100.0	--	--	1,914	--	31.9	17.0	--	.28
70	43	128.6	3.1	10.0	2,497	58.3	35.7	22.6	.56	.32
80	46	142.6	4.7	.0	2,807	31.0	35.1	25.8	.32	.32
90	49	150.8	6.0	.0	3,002	19.5	33.4	27.9	.21	.31
100	51	157.3	6.9	.0	3,160	15.8	31.6	29.6	.17	.30
110	53	163.2	7.9	.0	3,304	14.4	30.0	31.2	.16	.28
120	55	169.2	8.8	.0	3,446	14.2	28.7	32.8	.16	.27
130	56	175.3	9.8	.0	3,588	14.2	27.6	34.3	.15	.26
140	58	181.7	10.7	.0	3,734	14.6	26.7	35.9	.16	.26
150	59	188.4	11.7	.0	3,884	15.0	25.9	37.5	.16	.25
160	60	195.6	12.6	.0	4,044	16.0	25.3	39.2	.17	.24
170	60	203.1	13.9	.0	4,209	16.5	24.8	40.9	.17	.24
180	61	212.3	15.1	.0	4,381	17.2	24.5	42.9	.17	.24
INITIAL BASAL AREA 140 AT AGE 60										
60	40	140.0	--	--	2,651	--	44.2	23.4	--	.39
70	43	144.1	4.0	.0	2,788	13.7	39.8	25.2	.18	.36
80	46	148.6	5.3	.0	2,921	13.3	36.5	26.8	.16	.34
90	49	153.5	6.2	.0	3,054	13.3	33.9	28.4	.16	.32
100	51	158.6	7.0	.0	3,186	13.2	31.9	29.9	.15	.30
110	53	163.9	8.0	.0	3,317	13.1	30.2	31.4	.15	.28
120	55	169.6	8.8	.0	3,454	13.7	28.8	32.9	.15	.27
130	56	175.6	9.8	.0	3,594	14.0	27.6	34.4	.15	.26
140	58	181.9	10.7	.0	3,738	14.4	26.7	35.9	.15	.26
150	59	188.6	11.7	.0	3,888	15.0	25.9	37.5	.16	.25
160	60	195.6	12.6	.0	4,044	15.6	25.3	39.2	.17	.24
170	60	203.2	13.9	.0	4,211	16.7	24.8	40.9	.17	.24
180	61	211.2	15.1	.0	4,385	17.4	24.4	42.7	.18	.24

Table 10.--Continued

INITIAL BASAL AREA 30 AT AGE 80

Total age (years)	Height of dominants and codominants	Basal area			Volume			Volume		
		Accumulated	10-year mortality	10-year ingrowth	Accumulated	Current annual increment	Mean annual increment	Accumulated	Current annual increment	Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
80	46	30.0	--	--	620	--	7.8	5.8	--	.07
90	49	54.0	1.0	14.1	1,110	49.0	12.3	10.4	.46	.12
100	51	82.8	2.1	15.1	1,698	58.8	17.0	16.0	.56	.16
110	53	110.9	3.5	11.8	2,272	57.4	20.6	21.6	.56	.20
120	55	134.3	5.5	6.4	2,755	48.3	23.0	26.3	.47	.22
130	56	152.6	7.2	1.4	3,137	38.2	24.1	30.1	.38	.23
140	58	166.8	9.0	.0	3,437	30.0	24.6	33.1	.30	.24
150	59	178.6	10.4	.0	3,687	25.0	24.6	35.6	.25	.24
160	60	188.9	11.8	.0	3,910	22.3	24.4	37.9	.23	.24
170	60	198.4	13.2	.0	4,114	20.4	24.2	40.0	.21	.24
180	61	207.8	14.5	.0	4,316	20.2	24.0	42.0	.20	.23
INITIAL BASAL AREA 40 AT AGE 100										
100	51	40.0	--	--	839	--	8.4	8.0	--	0.08
110	53	63.1	1.5	12.3	1,316	47.7	12.0	12.6	0.46	.11
120	55	89.2	2.7	12.2	1,853	53.7	15.4	17.8	.52	.15
130	56	115.0	4.2	9.8	2,385	53.2	18.3	22.9	.51	.18
140	58	137.9	6.1	6.0	2,858	47.3	20.4	27.6	.47	.20
150	59	157.2	8.1	2.2	3,260	40.2	21.7	31.5	.39	.21
160	60	173.4	9.9	.0	3,599	33.9	22.5	34.9	.34	.22
170	60	187.3	11.7	.0	3,891	29.2	22.9	37.8	.29	.22
180	61	199.6	13.5	.0	4,151	26.0	23.1	40.4	.26	.22
INITIAL BASAL AREA 50 AT AGE 120										
120	55	50.0	--	--	1,058	--	8.8	10.2	--	.08
130	56	72.4	2.1	10.8	1,523	46.5	11.7	14.8	.46	.11
140	58	97.0	3.2	10.3	2,033	51.0	14.5	19.7	.49	.14
150	59	121.4	5.0	8.4	2,538	50.5	16.9	24.6	.49	.16
160	60	143.9	7.0	5.6	3,004	46.6	18.8	29.2	.46	.18
170	60	164.0	9.0	1.8	3,421	41.7	20.1	33.3	.41	.20
180	61	181.6	11.0	.5	3,788	36.7	21.0	37.0	.37	.20
INITIAL BASAL AREA 60 AT AGE 140										
140	58	60.0	--	--	1,276	--	9.1	12.4	--	.09
150	59	82.0	2.6	9.6	1,735	45.9	11.6	16.9	.45	.11
160	60	105.6	4.0	8.9	2,226	49.1	13.9	21.7	.48	.14
170	60	129.3	5.8	7.4	2,718	49.2	16.0	26.6	.49	.16
180	61	151.8	7.9	5.3	3,184	46.6	17.7	31.1	.45	.17
INITIAL BASAL AREA 70 AT AGE 160										
160	60	70.0	--	--	1,495	--	9.3	14.7	--	.09
170	60	91.8	3.3	8.6	1,950	45.5	11.5	19.1	.44	.11
180	61	115.0	4.8	8.0	2,434	48.4	13.5	23.9	.48	.13

Table 11. – Projected yield table for site index 25 black spruce in Minnesota by various initial densities and ages (all data are per acre for trees 3.6 inches d.b.h. and larger)

Total age (years)	Height of dominants and codominants	Basal area			Volume			Volume		
		Accumulated	10-year mortality	10-year ingrowth	Accumulated	Current annual increment	Mean annual increment	Accumulated	Current annual increment	Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
INITIAL BASAL AREA 20 AT AGE 60										
60	28	20.0	--	--	328	--	5.5	2.5	--	0.04
70	31	45.1	0.5	16.2	736	40.8	10.5	5.7	0.32	.08
80	33	78.6	1.5	19.4	1,283	54.7	16.0	10.1	.44	.13
90	35	110.3	3.1	14.7	1,804	52.1	20.0	14.3	.42	.16
100	36	133.8	4.9	6.2	2,199	39.5	22.0	17.5	.32	.18
110	37	149.9	6.6	.4	2,476	27.7	22.5	19.9	.24	.18
120	38	161.5	7.9	.0	2,680	20.4	22.3	21.7	.18	.18
130	39	170.7	9.1	.0	2,845	16.5	21.9	23.1	.14	.18
140	40	178.8	10.4	.0	2,991	14.6	21.4	24.4	.13	.17
150	41	186.8	11.4	.0	3,132	14.1	20.9	25.6	.12	.17
160	42	194.3	12.6	.0	3,270	13.8	20.4	26.9	.13	.17
170	42	202.2	13.7	.0	3,410	14.0	20.0	28.1	.12	.16
180	43	210.5	14.9	.0	3,556	14.6	19.8	29.4	.13	.16
INITIAL BASAL AREA 60 AT AGE 60										
60	28	60.0	--	--	949	--	15.8	7.2	--	.12
70	31	99.9	1.9	22.4	1,591	64.2	22.7	12.2	.50	.17
80	33	127.7	3.6	9.7	2,052	46.1	25.6	16.0	.38	.20
90	35	143.7	5.2	.5	2,332	28.0	25.9	18.4	.24	.20
100	36	153.8	6.5	.0	2,516	18.4	25.2	20.0	.16	.20
110	37	161.4	7.7	.0	2,659	14.3	24.2	21.3	.13	.19
120	38	168.2	8.7	.0	2,788	12.9	23.2	22.5	.12	.19
130	39	174.7	9.7	.0	2,910	12.2	22.4	23.6	.11	.18
140	40	181.4	10.6	.0	3,033	12.3	21.7	24.8	.12	.18
150	41	188.2	11.7	.0	3,158	12.5	21.0	25.9	.11	.17
160	42	195.4	12.6	.0	3,288	13.0	20.6	27.0	.11	.17
170	42	203.0	13.8	.0	3,423	13.5	20.1	28.2	.12	.16
180	43	211.0	15.0	.0	3,565	14.2	19.8	29.4	.12	.16
INITIAL BASAL AREA 100 AT AGE 60										
60	28	100.0	--	--	1,557	--	26.0	11.7	--	.20
70	31	128.6	3.1	10.0	2,032	47.5	29.0	15.6	.39	.22
80	33	142.6	4.7	.0	2,284	25.2	28.6	17.8	.22	.22
90	35	150.8	6.0	.0	2,443	15.9	27.1	19.3	.15	.21
100	36	157.3	6.9	.0	2,572	12.9	25.7	20.5	.12	.20
110	37	163.2	7.9	.0	2,688	11.6	24.4	21.6	.11	.20
120	38	169.2	8.8	.0	2,804	11.6	23.4	22.6	.10	.19
130	39	175.3	9.8	.0	2,919	11.5	22.4	23.7	.11	.18
140	40	181.7	10.7	.0	3,038	11.9	21.7	24.8	.11	.18
150	41	188.4	11.7	.0	3,161	12.3	21.1	25.9	.11	.17
160	42	195.6	12.6	.0	3,291	13.0	20.6	27.0	.11	.17
170	42	203.1	13.9	.0	3,425	13.4	20.1	28.2	.12	.16
180	43	211.0	15.1	.0	3,565	14.0	19.8	29.4	.12	.16
INITIAL BASAL AREA 140 AT AGE 60										
60	28	140.0	--	--	2,157	--	36.0	16.2	--	.27
70	31	144.1	4.0	.0	2,269	11.2	32.4	17.4	.12	.25
80	33	148.6	5.3	.0	2,377	10.8	29.7	18.5	.11	.23
90	35	153.5	6.2	.0	2,485	10.8	27.6	19.6	.11	.22
100	36	158.6	7.0	.0	2,592	10.7	25.9	20.6	.10	.21
110	37	163.9	8.0	.0	2,699	10.7	24.5	21.7	.11	.20
120	38	169.6	8.8	.0	2,809	11.0	23.4	22.7	.10	.19
130	39	175.6	9.8	.0	2,924	11.5	22.5	23.7	.10	.18
140	40	181.9	10.7	.0	3,042	11.8	21.7	24.8	.11	.18
150	41	188.6	11.7	.0	3,164	12.2	21.1	25.9	.11	.17
160	42	195.6	12.6	.0	3,291	12.7	20.6	27.0	.11	.17
170	42	203.2	13.9	.0	3,426	13.5	20.2	28.2	.12	.16
180	43	211.2	15.1	.0	3,568	14.2	19.8	29.5	.13	.16

Table 11.--Continued

INITIAL BASAL AREA 30 AT AGE 80

Total age (years)	Height of dominants and codominants	Basal area			Volume			Volume		
		Accumulated	10-year mortality	10-year ingrowth	Accumulated	Current annual increment	Mean annual increment	Accumulated	Current annual increment	Mean annual increment
	Feet	Square feet	Square feet	Square feet	Cubic feet	Cubic feet	Cubic feet	Cords	Cords	Cords
80	33	30.0	--	--	505	--	6.3	4.0	--	.05
90	35	54.0	1.0	14.1	903	39.8	10.0	7.2	.32	.08
100	36	82.8	2.1	15.1	1,381	47.8	13.8	11.1	.39	.11
110	37	110.9	3.5	11.8	1,849	46.8	16.8	14.9	.38	.14
120	38	134.3	5.5	6.4	2,242	39.3	18.7	18.2	.33	.15
130	39	152.6	7.2	1.4	2,552	31.0	19.6	20.8	.26	.16
140	40	166.8	9.0	.0	2,797	24.5	20.0	22.8	.20	.16
150	41	178.6	10.4	.0	3,002	20.5	20.0	24.6	.18	.16
160	42	188.9	11.8	.0	3,182	18.0	20.0	26.2	.16	.16
170	42	198.4	13.2	.0	3,348	16.6	19.7	27.6	.14	.16
180	43	207.8	14.5	.0	3,512	16.4	19.5	29.0	.14	.16
INITIAL BASAL AREA 40 AT AGE 100										
100	36	40.0	--	--	683	--	6.8	5.5	--	0.06
110	37	63.1	1.5	12.3	1,071	38.8	9.7	8.7	0.32	.08
120	38	89.2	2.7	12.2	1,508	43.7	12.6	12.3	.36	.10
130	39	115.0	4.2	9.8	1,941	43.3	14.9	15.8	.35	.12
140	40	137.9	6.1	6.0	2,326	38.5	16.6	19.0	.32	.14
150	41	157.2	8.1	2.2	2,652	32.6	17.7	21.8	.28	.14
160	42	173.4	9.9	.0	2,928	27.6	18.3	24.1	.23	.15
170	42	187.3	11.7	.0	3,166	23.8	18.6	26.1	.20	.15
180	43	199.6	13.5	.0	3,378	21.2	18.8	27.9	.18	.16
INITIAL BASAL AREA 50 AT AGE 120										
120	38	50.0	--	--	861	--	7.2	7.1	--	.06
130	39	72.4	2.1	10.8	1,240	37.9	9.5	10.2	.31	.08
140	40	97.0	3.2	10.3	1,654	41.4	11.8	13.6	.34	.10
150	41	121.4	5.0	8.4	2,065	41.1	13.8	17.0	.34	.11
160	42	143.9	7.0	5.6	2,444	37.9	15.3	20.2	.32	.13
170	42	164.0	9.0	1.8	2,784	34.0	16.4	23.0	.28	.14
180	43	181.6	11.0	.5	3,082	29.8	17.1	25.5	.25	.14
INITIAL BASAL AREA 60 AT AGE 140										
140	40	60.0	--	--	1,039	--	7.4	8.6	--	.06
150	41	82.0	2.6	9.6	1,412	37.3	9.4	11.7	.31	.08
160	42	150.6	4.0	8.9	1,811	39.9	11.3	15.0	.33	.09
170	42	129.3	5.8	7.4	2,211	40.0	13.0	18.3	.33	.11
180	43	151.8	7.9	5.3	2,591	38.0	14.4	21.5	.32	.12
INITIAL BASAL AREA 70 AT AGE 160										
160	42	70.0	--	--	1,216	--	7.6	10.1	--	.06
170	42	91.8	3.3	8.6	1,587	37.1	9.3	13.2	.31	.08
180	43	115.0	4.8	8.0	1,980	39.3	11.0	16.5	.33	.09

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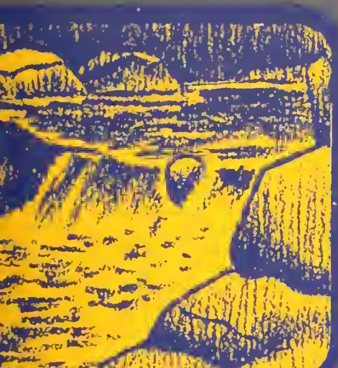
MPACT OF INSECTS ON MULTIPLE-USE VALUES OF NORTH CENTRAL FORESTS:
N EXPERIMENTAL RATING SCHEME



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CONTENTS

The authors thank the following colleagues who aided at various stages of scheme development: Arnold J. Ostrom, Herbert M. Kulman, Roger D. Price, Robert B. Brander, Richard S. Sartz, Roger R. Bay, David W. Lime, and especially Dean H. Urie.

Common names of trees used in this publication follow Little, Elbert L., Jr., 1953. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dep. Agr., Agr. Handb. 41, 472 p.

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IMPACT OF INSECTS ON MULTIPLE-USE VALUES OF NORTH-CENTRAL FORESTS: AN EXPERIMENTAL RATING SCHEME

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To establish priorities for research requires that problems be ranked according to their importance. Up to now, no rigorous basis for ranking forest insect problems has been available. We thought more accurate and precise ranking might result if a scheme were devised to systematize the use of many inputs that otherwise enter subjectively or not at all into ranking decisions. The scheme we introduce and demonstrate here numerically evaluates the importance of different insects to the multiple uses of forests on a regionwide, historical scale. It is not a formula for assessing current impact in a local situation, nor is it adequate for gauging the enormously important roles of purely beneficial insects like pollinators and scavengers. It has undergone several revisions and can no doubt be improved further. We offer it now for wider discussion and testing.

The traditional concept of forest insects emphasizes those that hinder wood production. The scheme enlarges this concept by considering more fully the role insects play in the forest. It recognizes that insects have positive as well as negative effects and that processes basic to the function and use of the forest as a whole are involved. The result is an ecosystem view of forest insects and a clear implication that the importance of insects cannot be evaluated adequately unless they are considered in an ecosystem context.

For evaluation purposes, problem units may be either single insect species or groups of taxonomically or ecologically similar species. Each unit to be rated is moved through the four parts of the scheme: one part each for timber, recreation, wildlife, and water. Each part consists of statements requiring a response based on factual information about the unit being evaluated. Responses have a corresponding score value. Where a unit does not fit well into any response category, a score midway between two categories may be assigned. All statements are understood to refer to the entire north-central region — the States of Minnesota, Wisconsin, Michigan, Iowa, Missouri, Illinois, and Indiana. Similar schemes for other areas could be developed.

Total score for each part is an arithmetic function of the various individual scores. Score computations were built in according to the additive or multiplicative character of the factors considered as well as overall scaling. The highest total score for any one part is 10. The score for the four multiple-use elements is obtained by adding score totals from the four parts. This amounts to equal weighting of the parts. If the user wishes, he can weight the multiple-use elements differently by simply multiplying part score totals by factors of his choosing before summing to get the grand total.

As an example of the system described, we illustrate our scoring for the forest tent caterpillar by circling individual scores and showing resulting arithmetic in bold face type.

PART I: TIMBER

Insects may kill trees, retard growth, or mar wood and tree form. These are mainly consequences of direct attacks that consist of foliage consumption, bud mining, wood boring, root destruction, and others. Indirect effects, such as seed eating, which might affect natural regeneration, are less understood. Part 1 of the scheme is concerned chiefly with direct effects on timber crops.

	Score
1. Value of standing timber affected (in millions of dollars, see table 1):	
a. Less than 50	1
b. 51 to 100	2
c. 101 to 200	(3)
d. 201 to 500	4
e. Over 500	5

2. Percent of growing stock attacked during an outbreak or other typical infestation period:

a. Less than 1	1
b. 1 to 5	2
c. 6 to 10	3
d. 11 to 20	4
e. Over 20	(5)

3a. If characterized by outbreaks, the number per century is:

	Score
a. 1	1
b. 2	2
c. 3 to 5	3
d. 6 to 9	(4)
e. Over 9	5

3b. If characterized as continuous, with no definite outbreak periods, the number of problem years during a crop rotation is:

a. Less than 6	1
b. 6 to 15	2
c. 16 to 30	3
d. 31 to 50	4
e. Over 50	5

4. Usual percentage of the stand affected (mortality or reduction in growth or quality) during an outbreak or other typical infestation period is:

a. Less than 6	1
b. 6 to 15	(2)
c. 16 to 30	3
d. 31 to 50	4
e. Over 50	5

Multiply scores of items 1 and 2. Multipl scores of items 3 (a or b) and 4. Add the tw products and divide sum by 5. Record quotien as score for Part 1 and go to Part 2: Recreation

$3\times5=15$. $4\times2=8$. $15+8=23$. $23\div5=4.6$.

Table 1.—Approximate value of standing timbe by species and species groups, North Centra States

Species or group	Volume[1]	Stumpage value: Per cubic foot[2]	Stumpage value: Total
	Million cubic feet	Dollars	Million dollars
Eastern cottonwood, quaking aspen, and similar species	8,377.8	0.023	192.7
Sugar maple	3,723.9	.166	618.2
White oak and similar species	3,447.5	.139	479.2
White spruce and balsam fir	3,296.4	.070	230.7
Black and northern red oaks	3,166.1	.125	395.8
Red and silver maples and boxelder	2,291.7	.100	229.2
White and black ashes	1,971.9	.113	222.8
Red and eastern white pines	1,726.1	.134	231.3
Jack pine	1,494.9	.053	79.2
American basswood	1,482.9	.156	231.3
Shagbark, pignut, and other hickories	1,428.1	.089	127.1
Eastern hemlock	897.3	.057	51.1
Yellow birch	731.2	.256	187.2
American beech	622.3	.093	57.9
Black walnut	294.9	.484	142.7

[1] Net volume of growing stock on commercial forest land, January 1, 1968.

[2] Stumpage value calculated from early 1968 prices in north-central region. Stumpage value per million board feet/160 = cubic foot value.

PART 2: RECREATION

Insects may affect forest recreation directly in two ways: by annoying recreationists and damaging vegetation important to recreational activities. In the first category, insects may bite, contaminate food or habitations, or offend in other ways. Some are capable of transmitting disease if other epidemiological requisites are present. As damagers of vegetation, insects mar the utility, quality, and beauty of sites such as campgrounds, vistas, and trails. Through their effects on wildlife, they are also indirectly related to forest recreation in such activities as hunting and bird study. This interaction of multiple-use elements is not taken into account, however. Insect effects on wildlife are evaluated separately in Part 3 of the scheme.

In Part 2 of the scheme, an insect unit can be evaluated in either or both categories A and B, depending on its habits. One that primarily affects vegetation must be evaluated under category B either as an outbreak or continuous type, not both.

A. Direct Annoyance

	Score
1. Degree of annoyance:	
a. Rarely offensive to humans in any way.	0
b. Offensive only because present incidentally where not wanted, as during an outbreak.	(1)
c. Contaminates food, habitations; may breed in filth; may be repugnant for reasons other than direct attack.	2
d. Irritates skin by biting, stinging, or other physico-chemical attack.	4
2. Disease vector potential:	
a. Absent	(0)
b. Present	2
3. Time of year active:	
a. Before June 15 or after September 1.	1
b. Less than half of period between June 15 and September 1.	(2)
c. More than half of period between June 15 and September 1.	3
4. Acres of forest affected:	
a. Less than 100,000	1
b. 100,000 to 500,000	2
c. 500,000 to 1 million	3
d. 1 to 10 million	(4)
e. Over 10 million	5

Multiply scores of items 1 and 3, 1 and 4, 2 and 3, and 2 and 4. Add the four products. If insect feeds primarily on man and animals, divide score by 4.8. Quotient is final score for recreation. If insect feeds primarily on vegetation, do not divide by 4.8; instead, hold sum as partial score and go to category B.

$1 \times 2 = 2$. $1 \times 4 = 4$. $0 \times 2 = 0$. $0 \times 4 = 0$. $2 + 4 + 0 + 0 = 6$.

B. Damage to Vegetation Basic to Pursuit of Recreation

Score

If characterized by outbreaks, go to item 1. If characterized as continuous, with no definite outbreak periods, go to item 6.

OUTBREAK INSECTS

	Score
1. Usual percentage of stand killed:	
a. Less than 2	1
b. 2 to 9	(2)
c. 10 to 25	3
d. Over 25	4

	Score
2. Usual forest area affected (acres):	
a. Less than 100,000	1
b. 100,000 to 500,000	2
c. 500,000 to 1 million	3
d. Over 1 million	(4)
3. Number of outbreaks per century:	
a. 1	1
b. 2	2
c. 3 to 5	3
d. 6 to 9	(4)
e. Over 9	5
4. Number of outbreak years per century (number of outbreaks x typical duration of outbreaks in years):	
a. Less than 10	1
b. 10 to 19	2
c. 20 to 30	3
d. Over 30	(4)
5. Time of growth season when injury culminates:	
a. Last 1/3	1
b. Middle 1/3	(2)
c. First 1/3 (if refoliation occurs same growth season, use score for *b*)	3

Multiply scores of items 1, 2 and 3. Multiply scores of items 4 and 5. Add the two products. Now add score from category A. Divide new sum by 14. Record quotient as score for Part 2 and go to Part 3: Wildlife.

2×4×4=32. 4×2=8. 32+8=40. 40+6=46. 46÷14=3.3.

CONTINUOUSLY DAMAGING INSECTS

	Score
6. Usual effect (immediate and residual) on individual host:	
a. Negligible	0
b. Branch mortality or breakage	1
c. Decline: higher than normal probability of death and breakage	2
7. Percent of host species in cover type:	
a. Less than 1	1
b. 1 to 5	2
c. 6 to 20	3
d. Over 20	4
8. Valuation of host species (see table 2):	
a. Low	1
b. High	2

Table 2.—Relative value of some common native tree species in a recreation context [1]

High	Low	High	Low
American beech	American basswood	Pin oak	Silver maple
Black walnut	American elm	Red maple	
Bur oak	American sycamore	Red pine	
Eastern hemlock	Bigtooth aspen	Scarlet oak	
Eastern white pine	Black cherry	Sugar maple	
Flowering dogwood	Boxelder	White ash	
Green ash	Eastern cottonwood	White oak	
Northern red oak	Jack pine	Yellow-poplar	
Paper birch	Quaking aspen		

1/Compiled mostly from: National Shade Tree Conference. Shade tree evaluation. 14 p. 1957.

Score

9. Percentage of forested area affect-
d:

a.	Less than 10	1
b.	10 to 30	2
c.	Over 30	3

Multiply scores of items 6 through 9. Divide roduct by 4.8. Record quotient as score for ecreation and go to Part 3: Wildlife. (Normally, egetation damagers of the continuous type have ero score from category A.)

PART 3: WILDLIFE

Insects influence wildlife in three major vays: as parasites, wildlife food, and disruptors f wildlife habitat. The parasite and food roles re obvious, but modification and disruption of he habitat are more complex. For example, the ffect of severe defoliation can be beneficial for ome animals while detrimental to others. The cheme attempts to quantify the modification r disruption rather than evaluate the effect on ny specific animal.

This part of the scheme requires that an nsect unit be evaluated in two of three cate- ories. Insects parasitic on animals, such as nosquitoes, would be evaluated in categories A nd B. Insect units such as defoliators would be valuated in categories B and C.

A. Parasitic Insects

Score

1. Degree of annoyance:

a.	Low	1
b.	Medium	2
c.	High	4

Score

2. Usual number of weeks per year active:

a.	Less than 5	1
b.	5 to 9	2
c.	10 to 14	3
d.	Over 14	4

3. Insect potential to vector pathogens:

a.	Negligible	1
b.	Low	2
c.	Moderate	4

4. Percent forest area affected:

a.	Less than 25	1
b.	26 to 50	2
c.	51 to 75	3
d.	Over 75	4

Multiply scores of items 1 and 2. Multiply scores of items 3 and 4. Add products. Hold sum as partial score. Further scoring instructions appear at end of Part 3.

B. Wildlife Food

Score

1. Mature feeding stage less than ¼ inch long; or possesses protective mechanism such as undesirable taste or odor:

a.	Yes	1
b.	Maybe	2
c.	No	(4)

2. Usual number of weeks available as food (period when it is more than ¼ inch long; or, if less than ¼ inch, is aggregated into conspicuous colonies or masses):

a.	Less than 5	1
b.	5 to 10	(2)
c.	11 to 20	3
d.	Over 20	4

Score

3. Vertical distribution during stages susceptible to predation:

a. Canopy of dominant and codominant trees	One of these	1
b. Canopy of subdominants	Two of these	2
c. Shrubs or boles of trees	Three of these	3
d. Herbaceous vegetation, ground, or water	All of these	(4)

4. Usual number of years present per decade in at least moderate numbers (more than 10,000 per acre):

a.	Less than 3	½
b.	3 to 5	(1)
c.	6 to 8	1½
d.	Over 8	2

5. Forest area occupied by at least moderate numbers in any one year (acres):

a.	Less than 500,000	½
b.	500,000 to 2 million	(1)
c.	2 to 4 million	1½
d.	Over 4 million	2

Multiply scores of items 1 and 2. Add scores of 4 and 5. Multiply score of item 3 by sum of scores for items 4 and 5. Add products. Hold sum as partial score. Further scoring instructions appear at end of Part 3.

4×2=8. 1+1=2. 4×2=8. 8+2+8=18.

C. Disruption of Habitat

Score

1. Position of host plants in habitat:

a.	Subdominant	1
b.	Codominant	2
c.	Dominant	3
d.	More than one of above	(4)

Sco

2. Percent recovery of host plants from outbreaks or other infestation periods:

a.	Over 90	(1
b.	75 to 90	2
c.	50 to 74	3
d.	Less than 50	4

3. Number of outbreak years per century (number of outbreaks x typical duration of outbreaks in years):

a.	Less than 10	1
b.	11 to 20	2
c.	21 to 30	3
d.	Over 30	(4

4. Usual size of outbreak area, or area otherwise occupied (acres):

a.	Less than 500,000	1
b.	500,000 to 1 million	2
c.	1 to 3 million	(3
d.	Over 3 million	4

Multiply scores of items 1 and 2. Multip scores of items 3 and 4. Add products. Ho sum as partial score. Go to final scoring instru tions below.

4×1=4. 4×3=12. 4+12=16.

Final score for Part 3: If insect unit bei evaluated is parasitic, add scores from categor A and B and divide by 6. If not parasitic, a scores from B and C and divide by 6. Rec sum as score for Part 3 and go to Part 4: Wat

18+16=34. 34÷6=5.7.

PART 4: WATER

Insects may alter conditions that affect run-off, nutrient concentration, and evapotranspiration in forests. Frequency of floods resulting from rainfall during the growing season is a key hydrologic factor in evaluating insect impact on forest watersheds. This part is therefore divided into two categories: one for low flood frequency zones and one for high flood frequency zones (fig. 1). Each insect unit is to be evaluated in both categories on the basis of its geographic distribution in each zone.

	Score High flood frequency	*Score* Low flood frequency
1. Size of area affected during outbreak or other infestation period (acres):		
a. Less than 100,000	**1**	1
b. 100,000 to 500,000	3	3
c. 500,000 to 1 million	5	5
d. More than 1 million	10	**10**
2. Recovery of host plants from defoliation or other damage:		
a. Refoliates same year	**½**	**1**
b. Does not refoliate same year	1	½
3. Usual percent of host defoliation during outbreaks or other periods:		
a. Less than 20	2	10
b. 20 to 39	4	8
c. 40 to 59	6	6
d. 60 to 80	8	4
e. More than 80	**10**	**2**
4. Typical duration of outbreak or other infestation period (years):		
a. Less than 2	1	1
b. 2 to 4	**3**	**3**
c. Over 4	5	5

(Bold values are circled on the page.)

Figure 1.—Zones of the north-central region having frequent severe floods. The shaded portions represent 10-year frequency flood twice normal annual flood. Generalized by D. H. Urie after U. S. Geological Survey Water Supply Papers 1675-1678 and 1680.

Make the following computations separately for each flood frequency: Multiply scores of items 2 and 3. Multiply scores of items 2 and 4. Add the two products. Multiply sum by score of item 1. Divide this product by 15. Add the quotients thus obtained for each flood frequency. The sum is the total score for Part 4.

High: $\frac{1}{2} \times 10 = 5$. $\frac{1}{2} \times 3 = 1\frac{1}{2}$. $5 + 1\frac{1}{2} = 6\frac{1}{2}$. $6\frac{1}{2} \times 1 = 6\frac{1}{2}$. $6\frac{1}{2} \div 15 = 0.4$.

Low: $1 \times 2 = 2$. $1 \times 3 = 3$. $2 + 3 = 5$. $5 \times 10 = 50$. $50 \div 15 = 3.3$. $0.4 + 3.3 = 3.7$.

Compute grand score for the unit by adding the total scores from each of the four parts of the scheme.

$$4.6 + 3.3 + 5.7 + 3.7 = 17.3$$

We have scored and ranked some prominent insects of north-central forests (table 3). Final scores have meaning only relative to other insects. The user may temper his evaluation of the scores with additional knowledge not considered in the scheme. Also, a particula mulitple-use value may be weighted accordin to the user's choosing. We believe that the sys tem results in a better perspective of insects a important elements of forest ecosystems.

Table 3.—Some insects of north-central forests in descending order of their scores on the evaluation scheme [1]

Insect unit	Score				
	Timber	Recreation	Wildlife	Water	Total
Forest tent caterpillar (*Malacosoma disstria*)	4.6	3.3	5.7	3.7	17.3
Spruce budworm (*Choristoneura fumiferana*)	5.8	3.2	4.7	1.5	15.2
Aedes mosquitoes (*Aedes* spp.)	0	7.5	5.1	0	12.6
Larch sawfly (*Pristiphora erichsonii*)	3.4	2.4	4.9	.8	11.5
Maple bud miners (*Proteoteras moffatiana* & *Obrussa ochrefasciella*)	7.4	1.3	1.9	0	10.6
Poplar borer (*Saperda calcarata*)	4.2	3.3	2.5	.6	10.6
Deerflies (*Chrysops* spp.)	0	7.5	3.0	0	10.5
Jack-pine budworm (*Choristoneura pinus*)	3.2	2.3	4.0	.7	10.2
Pine tussock moth (*Dasychira plagiata*)	4.8	1.6	3.0	.2	9.6
Large aspen tortrix (*Choristoneura conflictana*)	2.0	1.7	2.5	.6	6.8
Pine engraver (*Ips pini*)	1.4	3.3	1.3	.2	6.2
Hemlock looper (*Lambdina fiscellaria*)	1.2	.6	3.6	.7	6.1
Walkingstick (*Diapheromera femorata*)	1.6	.7	3.3	.4	6.0
Red-pine cone beetle (*Conophthorus resinosae*)	2.0	0	.9	0	2.9

[1] Much basic information used for evaluating some of these insects is assembled in the following unpublished file report: Batzer, H. O. A problem analysis for research on the ecology of defoliating insects of natural forest stands in the north-central States. 40 p. 1967.

SOME RECENT RESEARCH PAPERS
OF THE
NORTH CENTRAL FOREST EXPERIMENT STATION

Relation Between the National Fire Danger Spread Component and Fire Activity in the Lake States, by Donald A. Haines, William A. Main, and Von J. Johnson. USDA Forest Serv. Res. Pap. NC-41, 8 p., illus. 1970.

Thinning and Fertilizing Red Pine to Increase Growth and Cone Production, by John H. Cooley. USDA Forest Serv. Res. Pap. NC-42, 8 p., illus. 1970.

The Impact of Estimation Errors on Evaluations of Timber Production Opportunities, by Dennis L. Schweitzer. USDA Forest Serv. Res. Pap. NC-43, 18 p., illus. 1970.

User Evaluation of Campgrounds on Two Michigan National Forests, by Robert C. Lucas. USDA Forest Serv. Res. Pap. NC-44, 15 p., illus. 1970.

System Identifiication Principles in Studies of Forest Dynamics, by Rolfe A. Leary. USDA Forest Serv. Res. Pap. NC-45, 38 p., illus. 1970.

Skiing in the Great Lake States: The Industry and the Skier, by William A. Leuschner. USDA Forest Serv. Res. Pap. NC-46, 42 p., illus. 1970.

Proceedings of the Ninth Lake States Forest Tree Improvement Conference, August 22-23, 1969. USDA Forest Serv. Res. Pap. NC-47, 34 p. 1970.

A Water Curtain for Controlling Experimental Forest Fires, by Von J. Johnson. USDA Forest Serv. Res. Pap. NC-48, 7 p., illus. 1970.

Wilderness Ecology: A Method of Sampling and Summarizing Data for Plant Community Classification, by Lewis F. Ohmann and Robert R. Ream. USDA Forest Serv. Res. Pap. NC-49, 14 p., illus. 1970.

Predicting Lumber Grade Yields for Standing Hardwood Trees, by Charles L. Stayton, Richard M. Marden, and Glenn L. Gammon, USDA Forest Serv. Res. Pap. NC-50, 8 p. 1971.

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CH PAPER NC-58

GROWTH and YIELD of QUAKING ASPEN

IN NORTH-CENTRAL MINNESOTA

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FOREST SERVICE
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GROWTH AND YIELD OF QUAKING ASPEN IN NORTH-CENTRAL MINNESOTA

Bryce E. Schlaegel

Quaking aspen (*Populus tremuloides*) (Michx.) is the predominant tree of the largest timber type in the Lake States, the aspen-birch type. This type occupies 6¼ million acres in Minnesota alone (Stone 1966), and 15½ million acres in the Lake States (Findell *et al.* 1960, Stone and Thorne 1961, Stone 1966). Growth and yield estimates of quaking aspen are an integral part of managing the aspen-birch type.

Yield information for Minnesota aspen is presently available in Gevorkiantz and Duerr's (1938) normal yield tables and Buckman's (1961) stand volume equations. Neither source, however, is fully adequate as an estimator of aspen growth and yield; Gevorkiantz and Duerr do not include stand basal area as a yield variable, and Buckman's equations are a composite for red and jack pine as well as aspen. Thus, new variable density growth and yield information is needed for aspen.

This paper presents recent growth and yield information from permanent sample plots in Minnesota. A total cubic-foot yield table for representative densities and heights is presented. Also included are merchantable yields to 3- and 5-inch top diameters as well as equations for predicting future stand basal area, diameter, and height.

METHODS AND PROCEDURES

The data, from three stand density studies in north-central Minnesota, include 34 permanent sample plots that were established in pure aspen stands 10, 20, and 30 years old. The stands were thinned initially to various basal area densities and were not thinned again. The trees range from 10 to 57 years of age, the stands from 20 to 140 square feet of basal area, and the site indexes from 66 to 90. The study area is relatively flat with medium-textured soils.

On each plot, all trees 0.6 inch d.b.h. and larger were measured and classified by crown class. In addition, sample trees were measured for total height. Total tree volumes were estimated from tables prepared by Gevorkiantz and Olsen (1955). Merchantable height was measured on an additional sample of 85 trees[1]. The plot data were then summarized and regression equations derived for total yield, merchantable yield, basal area growth, height growth, and diameter growth.

PREDICTING PRESENT YIELD

All volume yields were estimated in cubic feet inside bark. Total cubic-foot yield includes the entire stem volume of all trees over 0.5 inch d.b.h. A number of yield models reported in the literature were fitted to the data and the regression model finally chosen was:

$$Y = 0.41898\ (BH) \tag{1}$$

where Y = the total stand cubic-foot yield per acre, inside bark,

B = total stand basal area in square feet per acre, and

H = average total height, in feet, of dominants and codominants.

The standard error of this ratio estimate is 0.00068. This equation, along with the site index curves of figure 1, was used to prepare table 1 (total cubic-foot yield).

Merchantable volume is expressed as a ratio of merchantable stand volume to total stand volume. The assumption is that as the average stand diameter increases, the proportion of merchantable volume will asymptotically approach some constant, the constant being less than 1 but approaching 1 as merchantability limits become smaller. The equations used to predict the merchantable volume ratios, derived by techniques suggested by Stevens (1951), are:

---

[1] *I would like to thank Boise Cascade Corporation of Minnesota for supplying data from 37 trees.*

Table 1.—Total yield per acre in tens of cubic feet, excluding bark, by total stand age, site index, and basal area density (all trees 0.6 inch d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	35	70	105	140	176	211	246	281
30	45	90	134	179	224	269	314	359
40	51	101	152	202	253	304	354	405
50	54	109	163	218	272	327	381	436
60	57	114	172	229	286	343	401	458
SITE INDEX 70								
20	38	76	113	151	189	227	265	302
30	48	97	145	193	241	290	338	386
40	55	109	164	218	273	327	382	436
50	59	117	176	235	293	352	411	469
60	62	123	185	246	308	370	431	493
SITE INDEX 75								
20	40	81	121	162	202	243	283	324
30	52	103	155	207	259	310	362	414
40	58	117	175	234	292	350	409	467
50	63	126	189	251	314	377	440	503
60	66	132	198	264	330	396	462	528
SITE INDEX 80								
20	43	86	130	173	216	259	303	346
30	55	110	165	221	276	331	386	441
40	62	125	187	249	312	374	436	499
50	67	134	201	268	335	402	469	536
60	70	141	211	282	352	422	493	563
SITE INDEX 85								
20	46	92	138	184	230	276	321	367
30	59	117	176	235	293	352	411	469
40	66	132	199	265	331	397	463	530
50	71	142	214	285	356	427	499	570
60	75	150	224	299	374	449	524	599
SITE INDEX 90								
20	49	97	146	194	243	292	340	389
30	62	124	186	248	310	373	435	497
40	70	140	210	281	351	421	491	561
50	75	151	226	302	377	452	528	603
60	79	158	238	317	396	475	554	633

$$V3/VT = 0.9858 - 5.4737\ (0.4876)^{D} \quad (2)$$
$$V5/VT = 0.9804 - 12.3277\ (0.57)^{D} \quad (3)$$

where V3/VT = ratio of merchantable stand volume (3-inch top) to total stand volume (merchantable volume above a 6-inch stump for all trees 3.6 inches d.b.h. and larger),

V5/VT = ratio of merchantable stand volume (5-inch top) to total stand volume (merchantable volume above a 6-inch stump for all trees 5.6 inches d.b.h. and larger), and

D = average stand diameter of all stems 0.6 inch d.b.h. and larger; i.e., the diameter of the tree of average basal area.

The first coefficient given in Equation 2 is the asymptotic constant that V3/VT approaches. Or, as the average stand diameter increases, the merchantable volume to a 3-inch top approaches 98.6 percent of the total volume. The same analogy is also true for Equation 3.

Tables 3 to 8, presented at the end of this paper, were prepared by substituting several stand diameters into Equations 2 and 3 and applying the resulting ratios to table 1.

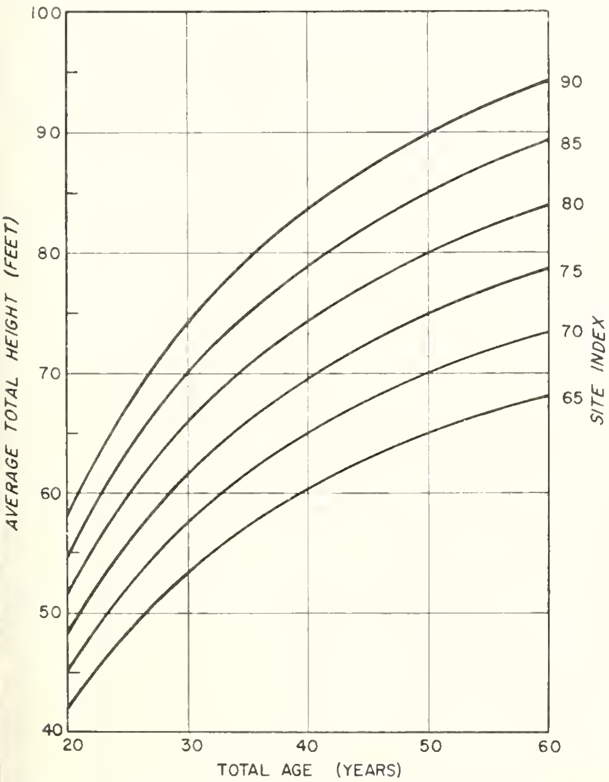

Figure 1.—Site index curves for quaking aspen in north-central Minnesota.

PREDICTING FUTURE YIELD

To predict future stand volume, future values of the stand basal area, average total height, and average diameter must be estimated. Ways of predicting these parameters were developed from the growth data.

Stand Basal Area

Total stand basal area for each measurement period was calculated by summing the basal areas of all trees 0.6 inch d.b.h. and larger. Net periodic annual growth is the difference between two successive basal area measurements divided by the number of years in the period. These growth values were then fitted to a model by Clutter (1963) and the resulting equation is:

$$BAG = B\ (5.3903 - LnB)\ A^{-1} \quad (4)$$

where BAG = net periodic annual basal area growth in square feet per acre (table 2),

B = total stand basal area in square feet per acre,

A = total stand age in years, and

Ln = natural logarithm.

This equation accounts for 45.34 percent of the variation in BAG; the standard error is 1.01 about a mean of 2.72 square feet per acre per year. By using Equation 4, annual basal area increments can be obtained and summed to give periodic growth.

Future basal areas can be obtained by adding summations from Equation 4 to the present basal area. Or, considering future basal area as a projection in time of present basal area, integrating Equation 4 from initial stand age (A_i) to future stand age (A_f) gives:

$$B_f = \exp\left[5.3903 - A_i\ (5.3903 - LnB_i)\ A_f^{-1}\right] \quad (5)$$

where exp = e — the base of the natural logarithms, and

B_i, B_f = initial and future stand basal area.

Table 2.—Net periodic annual basal area growth per acre per year by age and basal area

Total stand age (years)	Basal area per acre						
	20	40	60	80	100	120	140
	Square feet						
20	2.39	3.40	3.89	4.03	3.92	3.62	3.14
25	1.92	2.72	3.11	3.23	3.04	2.89	2.51
30	1.60	2.27	2.59	2.69	2.62	2.41	2.09
35	1.37	1.94	2.22	2.30	2.24	2.07	1.79
40	1.20	1.70	1.94	2.02	1.96	1.81	1.57
45	1.06	1.51	1.73	1.79	1.74	1.61	1.40
50	0.96	1.36	1.56	1.61	1.57	1.45	1.26
55	0.87	1.24	1.41	1.47	1.43	1.32	1.14

Stand Height

Future stand height is commonly estimated from a set of site index curves. Gevorkiantz' (1956) harmonized site index curves developed from temporary plot data were inadequate to show the actual height growth of trees in this study. Therefore, a new set of site index curves were developed (fig. 1) from the measured height growth on the permanent sample plots. Although the data are from a restricted area, the curves represent height growth from repeated measurements and are therefore believed to be more reliable than those prepared from single tree measurements. Additional testing is required to determine their reliability in other areas.

Bruce and Schumacher's (1950) technique was used to construct the curves. The guide equation is:

$$\mathrm{Ln}H = 4.5338 - 14.6111\ (A^{-1}) \qquad (6)$$

where H = total tree height in feet, dominants and codominants only, and

A = total tree age in years.

Bruce and Schumacher suggest that if the coefficient of variation of tree height increases with age, then the site index curves should be adjusted to take this into account. Plotting coefficient of variation over age showed that no trend existed and that the coefficient of varia tion could be considered constant over ag Thus, no adjustment in the curves is necessar

Because site curves represent height growtl future height can be found by following th curve to the desired age and reading the corre ponding height. Future stand height can also b computed by the equation:

$$H_f = H_i \cdot \exp\left[14.6111\ (A_i^{-1} - A_f^{-1})\right] \qquad (7$$

where H_i, H_f = initial and future total stan height, and

A_i, A_f = intial and future total stand age.

Stand Diameter

The preceding methods of predicting futu stand basal area and height will enable th user to estimate future stand volume usi Equation 1. In order for Equations 2 and 3 to used for estimating future merchantable volum the method of projecting average stand diamet will also be needed.

The relationship between average stand di meter and age was found, by means of a scatt diagram, to be linear. This relationship can estimated by the equation:

$$\text{Average DBH} = 0.5305 + 0.1841\ (\text{Age}), \ ($$

which gives the average stand diameter that can be expected for the average site index and stand density. However, Equation 8 is not to be used to estimate average stand diameter from a given stand age, but is presented as a basis for predicting future stand diameter, given an initial value. From equation 8 the average stand diameter is increasing at a rate of 0.1841 inch per year. Therefore, future stand diameter (DBH_f) can be estimated from Equation 9 if the initial stand diameter (DBH_i) is known:

$$DBH_f = 0.1841\ (A_f - A_i) + DBH_i. \qquad (9)$$

ACCURACY OF EQUATIONS

Accuracy of the total stand volume estimate from table 1 for a known stand age, stand basal area, and site index, is dependent upon the accuracy of Equation 1. The standard error of Equation 1 is 0.00068 or $\pm$ 0.317 percent at the 95-percent confidence level.

Predicting future stand volume is more variable because it is dependent on predicting stand basal area and height growth. The standard error of the annual basal area growth equation is 1.01, or 37 percent of the mean. Additional error in predicting height growth also influences the accuracy. The errors involved in projecting stand volume ahead for long periods of time should be easily recognized.

DISCUSSION

The preceding sections have presented equations for predicting present and future stand volumes. The user should keep the following things in mind when extrapolating values presented in this paper.

First, all of the data are from pure, thinned aspen stands. Second, the study area is geographically limited. The plots are located on or near the Pike Bay Experimental Forest in north-central Minnesota, thus the range of site conditions is small. Third, aspen has large genetic variability. This means that growth patterns may differ greatly from stand to stand. No attempt was made to quantify clonal differences in this study, although some clonal variation was noted.

The question now arises as to the applicability of the information in this paper to natural stands of either pure or mixed aspen. Tests have indicated there should be no problem utilizing this information in pure, natural stands. However, when projecting basal area over long periods (over 15 years), it should be realized that longer projections result in greater estimation errors. The yield information presented here should have utility for the aspen component of mixed stands. However, use of the growth equations in mixed stands is not recommended.

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Table 3.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 6 inches (all trees 3.6 inches d.b.h. and larger)

SITE INDEX 65

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
20	32	64	96	128	161	192	224	256
30	41	82	122	163	204	245	286	327
40	47	92	139	184	231	277	323	369
50	49	99	149	199	248	298	347	398
60	52	104	157	209	261	313	366	418
SITE INDEX 70								
20	35	69	103	138	172	207	242	275
30	44	88	132	176	220	264	308	352
40	50	99	150	199	249	298	348	398
50	54	107	161	214	267	321	375	428
60	57	112	169	224	281	337	393	450
SITE INDEX 75								
20	36	74	110	148	184	222	258	295
30	47	94	141	189	236	283	330	378
40	53	107	160	213	266	319	373	426
50	57	115	172	229	286	344	401	459
60	60	120	181	241	301	361	421	482
SITE INDEX 80								
20	39	78	119	158	197	236	276	316
30	50	100	150	202	252	302	352	402
40	57	114	171	227	285	341	398	455
50	61	122	183	244	306	367	428	489
60	64	129	192	257	321	385	450	513
SITE INDEX 85								
20	42	84	126	168	210	252	293	335
30	54	107	161	214	267	321	375	428
40	60	120	181	242	302	362	422	483
50	65	130	195	260	325	389	455	520
60	68	137	204	273	341	409	478	546
SITE INDEX 90								
20	45	88	133	177	222	266	310	355
30	57	113	170	226	283	340	397	453
40	64	128	192	256	320	384	448	512
50	68	138	206	275	344	412	482	550
60	72	144	217	289	361	433	505	577

Table 4.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 8 inches (all trees 3.6 inches d.b.h. and larger)

SITE INDEX 65

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
20	34	68	102	136	170	204	238	272
30	44	87	130	173	217	260	304	348
40	49	98	147	196	245	294	343	392
50	52	106	158	211	263	317	369	422
60	55	110	166	222	277	332	388	443
SITE INDEX 70								
20	37	74	109	146	183	220	257	292
30	46	94	140	187	233	281	327	374
40	53	106	159	211	264	317	370	422
50	57	113	170	227	284	341	398	454
60	60	119	179	238	298	358	417	477
SITE INDEX 75								
20	39	78	117	157	196	235	274	314
30	50	100	150	200	251	300	350	401
40	56	113	169	227	283	339	396	452
50	61	122	183	243	304	365	426	487
60	64	128	192	256	319	383	447	511
SITE INDEX 80								
20	42	83	126	167	209	251	293	335
30	53	106	160	214	267	320	374	427
40	60	121	181	241	302	362	422	483
50	65	130	195	259	324	389	454	519
60	68	136	204	273	341	408	477	545
SITE INDEX 85								
20	45	89	134	178	223	267	311	355
30	57	113	170	227	284	341	398	454
40	64	128	193	257	320	384	448	513
50	69	137	207	276	345	413	483	552
60	73	145	217	289	362	435	507	580
SITE INDEX 90								
20	47	94	141	188	235	283	329	377
30	60	120	180	240	300	361	421	481
40	68	136	203	272	340	408	475	543
50	73	146	219	292	365	438	511	584
60	76	153	230	307	383	460	536	613

Table 5.—Merchantable yield in tens of cubic feet, excluding bark, to a 3-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 10+ inches
(all trees 3.6 inches d.b.h. and larger)

SITE INDEX 65

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
20	34	69	103	137	173	207	242	276
30	44	88	132	176	220	264	308	353
40	50	99	149	198	248	299	348	398
50	53	107	160	214	267	321	374	428
60	56	112	169	225	281	337	394	450
SITE INDEX 70								
20	37	75	111	148	186	223	260	297
30	47	95	142	190	237	285	332	379
40	54	107	161	214	268	321	375	428
50	58	115	173	231	288	346	404	461
60	61	121	182	242	302	363	423	484
SITE INDEX 75								
20	39	80	119	159	198	239	278	318
30	51	101	152	203	254	304	355	407
40	57	115	172	230	287	344	402	459
50	62	124	186	246	308	370	432	494
60	65	130	194	259	324	389	454	518
SITE INDEX 80								
20	42	84	128	170	212	254	298	340
30	54	108	162	217	271	325	379	433
40	61	123	184	245	306	367	428	490
50	66	132	197	263	329	395	461	526
60	69	138	207	277	346	414	484	553
SITE INDEX 85								
20	45	90	136	181	226	271	315	360
30	58	115	173	231	288	346	404	461
40	65	130	195	260	325	390	455	520
50	70	139	210	280	350	419	490	560
60	74	147	220	294	367	441	515	588
SITE INDEX 90								
20	48	95	143	191	239	287	334	382
30	61	122	183	244	304	366	427	488
40	69	137	206	276	345	413	482	551
50	74	148	222	297	370	444	518	592
60	78	155	234	311	389	466	544	622

Table 6.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 6 inches (all trees 5.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	20	39	59	78	98	118	137	157
30	25	50	75	100	125	150	175	200
40	28	56	85	113	141	170	198	226
50	30	61	91	122	152	182	213	243
60	32	64	96	128	160	191	224	256
SITE INDEX 70								
20	21	42	63	84	105	127	148	169
30	27	54	81	108	134	162	189	215
40	31	61	92	122	152	182	213	243
50	33	65	98	131	163	196	229	262
60	35	69	103	137	172	206	240	275
SITE INDEX 75								
20	22	45	68	90	113	136	158	181
30	29	57	86	116	145	173	202	231
40	32	65	98	131	163	195	228	261
50	35	70	105	140	175	210	246	281
60	37	74	110	147	184	221	258	295
SITE INDEX 80								
20	24	48	73	97	121	145	169	193
30	31	61	92	123	154	185	215	246
40	35	70	104	139	174	209	243	278
50	37	75	112	150	187	224	262	299
60	39	79	118	157	196	235	275	314
SITE INDEX 85								
20	26	51	77	103	128	154	179	205
30	33	65	98	131	163	196	229	262
40	37	74	111	148	185	222	258	296
50	40	79	119	159	199	238	278	318
60	42	84	125	167	209	251	292	334
SITE INDEX 90								
20	27	54	81	108	136	163	190	217
30	35	70	104	138	173	208	243	277
40	39	78	117	157	196	235	274	313
50	42	84	126	169	210	252	295	336
60	44	88	133	177	221	265	309	353

Table 7.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 8 inches (all trees 5.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	30	59	89	118	148	178	207	237
30	38	76	113	151	189	227	265	303
40	43	85	128	170	213	256	298	341
50	46	92	137	184	229	276	321	368
60	48	96	145	193	241	289	338	386
SITE INDEX 70								
20	32	64	95	127	159	191	223	255
30	40	82	122	163	203	244	285	325
40	46	92	138	184	230	276	322	368
50	50	99	148	198	247	297	346	395
60	52	104	156	207	260	312	363	416
SITE INDEX 75								
20	34	68	102	137	170	205	239	273
30	44	87	131	175	218	261	305	349
40	49	99	148	197	246	295	345	394
50	53	106	159	212	265	318	371	424
60	56	111	167	223	278	334	389	445
SITE INDEX 80								
20	36	72	110	146	182	218	255	292
30	46	93	139	186	233	279	325	372
40	52	105	158	210	263	315	368	421
50	56	113	169	226	282	339	395	452
60	59	119	178	238	297	356	416	475
SITE INDEX 85								
20	39	78	116	155	194	233	271	309
30	50	99	148	198	247	297	346	395
40	56	111	168	223	279	335	390	447
50	60	120	180	240	300	360	421	481
60	63	126	189	252	315	379	442	505
SITE INDEX 90								
20	41	82	123	164	205	246	287	328
30	52	105	157	209	261	314	367	419
40	59	118	177	237	296	355	414	473
50	63	127	191	255	318	381	445	508
60	67	133	201	267	334	400	467	534

Table 8.—Merchantable yield in tens of cubic feet, excluding bark, to a 5-inch top inside bark, by age, site index, and basal area density, when average stand diameter is 10+ inches

(all trees 5.6 inches d.b.h. and larger)

Total stand age (years)	Basal area per acre							
	20	40	60	80	100	120	140	160
SITE INDEX 65								
20	33	66	98	131	165	197	230	263
30	42	84	125	168	210	252	294	336
40	48	95	142	189	237	285	331	379
50	51	102	153	204	255	306	357	408
60	53	107	161	214	268	321	375	429
SITE INDEX 70								
20	36	71	106	141	177	212	248	283
30	45	91	136	181	226	271	316	361
40	51	102	154	204	256	306	358	408
50	55	110	165	220	274	329	385	439
60	58	115	173	230	288	346	403	461
SITE INDEX 75								
20	37	76	113	152	189	227	265	303
30	49	96	145	194	242	290	339	388
40	54	110	164	219	273	328	383	437
50	59	118	177	235	294	353	412	471
60	62	124	185	247	309	371	432	494
SITE INDEX 80								
20	40	80	122	162	202	242	284	324
30	51	103	154	207	258	310	361	413
40	58	117	175	233	292	350	408	467
50	63	125	188	251	314	376	439	502
60	66	132	197	264	329	395	461	527
SITE INDEX 85								
20	43	86	129	172	215	258	300	344
30	55	110	165	220	274	329	385	439
40	62	124	186	248	310	372	433	496
50	66	133	200	267	333	400	467	534
60	70	140	210	280	350	420	490	561
SITE INDEX 90								
20	46	91	137	182	227	273	318	364
30	58	116	174	232	290	349	407	465
40	66	131	197	263	329	394	460	525
50	70	141	212	283	353	423	494	564
60	74	148	223	297	371	445	519	592

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sediment in a michigan trout stream its source, movement & some effects on fish habitat

EDWARD A. HANSEN

NORTH CENTRAL FOREST EXPERIMENT STATION
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Special acknowledgment is due to Paul E. Nelson and Carl L. Nichols, deceased employees, who contributed significantly to the study.

CONTENTS

SEDIMENT IN A MICHIGAN TROUT STREAM

Its Source, Movement, and Some Effects on Fish Habitat

Edward A. Hansen

A large area of the Lake States is covered by a deep nantle of sandy glacial drift. Streams in this area generally have lower sediment concentrations than other areas of the United States. Even so, stream ediments are slowly filling harbors and reservoirs and possibly damaging fish habitat.

Much stream improvement work, including bank tabilization, has been done to reduce the already low ediment concentration in these streams and, in turn, mprove the fish habitat. However, there is very little quantitative information on the sediment regime of treams in the Lake States, or the effects of bank rosion on sediment load (Striffler 1964). Also, the ew studies on the effect of stream improvement prorams on fish populations have not investigated the mpact of sediment reduction on the aquatic environment (Tarzwell 1937, Shetter *et al.* 1949, Hale 1969, Hunt 1969).

This paper gives the results of a study designed to etermine the sediment sources, the size and quantity f bank sediments, the timing of delivery, and the nethod of transport. The change in sediment load nd streambed composition, and some possible effects f streambank stabilization are also presented for a ection of stream with many eroding banks.

THE STUDY AREA

The study was made from 1967 through 1969 n the Pine River, tributary of the Manistee, in the orthwestern part of Michigan's Lower Peninsula fig. 1). The Pine River is a relatively high gradient ool and riffle stream with a long section of eroding anks. The river drains a 265-square mile watershed bove Stronach Dam. The 640-acre-foot capacity eservoir at Stronach Dam was completely filled with diment in 40 years (1912-1953) and power genation was terminated shortly thereafter. The Michian Department of Natural Resources built fish habit improvement devices and stabilized most of the oding banks in the upper part of the watershed in e mid-1950's. However, no work was done in the wer part of the watershed which includes the study ea.

The study section, which includes 204 eroding banks, is 26 miles in length measured along the meandering stream; the straight line distance is about half as much. The mean stream width is 55 feet and mean depth is 2.2 feet, with pools 4 to 8 feet in depth. Mean stream gradient is 0.00175, or about 9 feet per mile.

Stream discharge increases 80 percent as it passes through the study section. Only 14 percent of this increase comes from the three major tributaries; most of the remainder originates from springs, seeps, and ground water inflow through the streambed.

The discharge at a relatively long-term U.S. Geological Survey gaging station situated 5 miles upstream from Stronach Dam has averaged 282 c.f.s. during the 17 years of record. The minimum discharge was 161 c.f.s., and the two largest peaks were 1,430 c.f.s. and 2,440 c.f.s. The mean discharge 5 miles downstream at Stronach Dam is about 30 percent greater. However, peak discharges are about the same due to the storage capacity of a broad flood plain above Stronach Dam and a lack of surface runoff between the two stations.

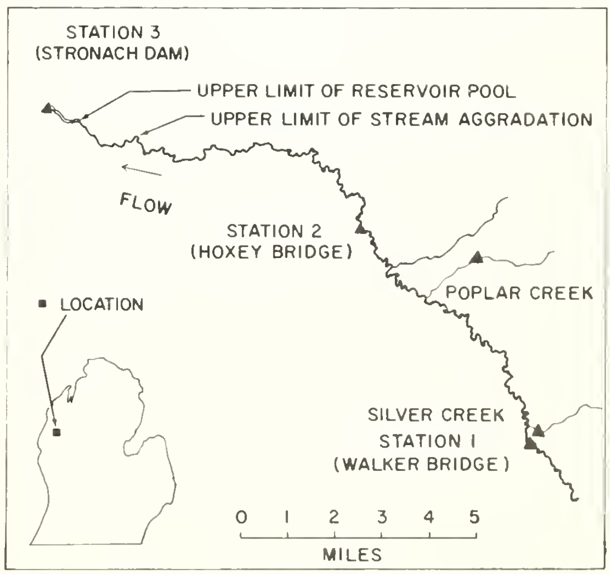

Figure 1. — *Pine River study area.*

F-520630

Figure 2. — *River terraces 11, 17, and 40 feet above the present water surface. Arrow shows location of photo in figure 3.*

The Pine is a geologically youthful stream — entrenched about 100 feet into sandy glacial outwash and moraines. Large inclusions of consolidated clays occur that are highly resistant to erosion. However, because the ground surface of the entire area is covered with sand, the presence and extent of the clay masses can only be inferred by their exposure in eroding streambanks and by the occurrence of swamps on the uplands. The stream has gradually eroded away the loose sand, consolidating the small amounts of gravel and leaving the more resistant clay masses exposed. The clay acts as a control for many, if not most, of the rapids on the river. These clay controls often have a thin veneer of cobbles and boulders which may add to their durability.

Evidence of past meandering is present in river terraces at levels high above the stream (fig. 2). Eroding banks that intersect the old elevated stream channels often expose bands of stream-laid gravels (fig. 3). These deposits, like the present streambed gravels, are rarely more than 12 to 18 inches thick. Underneath the gravel is the glacially deposited sand or sometimes a clay inclusion.

As the Pine meanders across the valley, it moves laterally off its gravel pavement. However, at the same time it erodes into the old terraces with their alluvial gravel deposits. Thus, it is likely that the amounts of gravel gained and lost to the stream channel by lateral erosion are nearly equal.

METHODS

Definitions

Bedload. — sediment that moves in essentially continuous contact with the streambed by rolling, sliding, or saltation.

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Figure 3. — *Ancient gravel streambed deposits now exposed by streambank erosion. Gravel lies on top of uncohesive sand glacial drift, a situation common with many present-day streambed gravel areas.*

Bedload discharge. — the quantity of bedload passing a given stream cross section in a unit time.

Bed material. — sediment composing the bed of the stream.

Suspended sediment. — sediment that is moved in suspension in water and is maintained in suspension by the upward components of the stream turbulence, or by colloidal suspension.

Suspended sediment discharge (or load). — the quantity of suspended sediment passing a given stream cross section in a unit time.

Total sediment discharge (or load). — the quantity of total sediment (suspended sediment plus bedload) passing a given stream cross section in a unit time.

Unsampled zone. — the distance between the streambed and the lowest point in the vertical profile of a stream at which suspended sediment can be sampled with a U.S. series sediment sampler; usually about 0.3 foot.

Study Design

Three sediment sampling stations were located on the main channel of the Pine River and will hereafter be referred to as Stations 1, 2, and 3 (fig. 1). These stations were in operation for a 3-year period. Station 1, the uppermost station, was located at Walker Bridge several miles below the last stream improvement work done by the Michigan Department of Natural Resources. Station 3, the lowermost station, was 26 miles downstream at Stronach Dam. Station 2 was located at Hoxey Bridge, midway between Stations 1 and 3. Two other sampling stations were on Poplar and Silver Creeks, tributaries of the Pine between Stations 1 and 2. These tributary sampling sites were in continuous operation only during the last year of the study, although intermittent sampling was done prior to that.

Total sediment load was meaured at Station 1, above which there was relatively little sediment contribution, and again at Station 3, 26 miles downstream. The data collected on Poplar and Silver Creeks, two of the three main tributaries, permitted an approximation of the total tributary sediment contribution. Observation of the three road crossings on the main stream between Stations 1 and 3 indicated that their contribution could be safely assumed as zero. Overland flow to the main channel almost never occurred. Therefore, most of the measured sediment increase between Stations 1 and 3 would be attributable to bank erosion or tributary input. Since tributary input was being measured, the bank contribution could be estimated by the difference.

Even though Stronach reservoir above Station 3 is filled with sediment, deposition will theoretically continue until the stream gradient through the reservoir approaches that of the original channel; or in the case of a pool and riffle stream, deposition will continue until the increased slope is great enough to transport the available sediment load. Changes in stream morphology indicate that deposition has occurred up to 2.8 miles upstream from the dam and .8 miles upstream from the original reservoir limit (fig. 1). Significant deposition would reduce the measured sediment load at the dam, which would result in an underestimate of both the total sediment load and the eroding bank contribution. Consequently, five permanent profiles were established across the valley to detect any appreciable current flood plain building. These profiles were surveyed annually.

Sediment Sampling Techniques

Sediment samples were collected weekly at each sediment sampling station, except during floods when up to three samples a day were collected. Hand operated DH-48 and DH-59 sediment samplers utilizing a 1-pint sample container were used. Samples were collected by the "equal transit rate" technique, which consists of sampling at several equally spaced points across the stream (Inter-Agency Committee on Water Resources 1963). At each point the sampler is traversed at a constant rate throughout the complete vertical profile of flow. The number of sampling points per station ranged from five to 17, depending upon stream width and discharge.

Because the samplers could not operate closer than 0.3 foot from the streambed, wooden sills were constructed to force all bedload off the streambed as it passed over the sill. The sills were made of 2-inch lumber placed on edge so that they protruded about 3 inches above the original bed of the stream and extended completely across the streambed perpendicular to the flow. A sill was not required at Station 3 where the sampling was done over the metal control gates at the dam, which effectively eliminated any unsampled zone. The sediment samples were collected by lowering the sampler down through the vertical profile of flow until the sampler intake touched the sill or metal control gate, and then raising it back to the surface (fig. 4). A metal guide was used for positioning the sampler when high turbidity obscured the sill or gate.

Since the samplers collect sediments adequately only up through the sand size range (2.0 mm.), a "screen" sampler was devised to sample the gravel size sediment. This is a 44 by 305 mm. rectangular open box with a 1 mm. mesh screen sack attached to the downstream end to trap the sediments. The

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Figure 4. — *Sampling the sediment load at a wooden sill.*

Table 1. — *Eroding streambanks by size, percent of waterline eroded, and texture (In number of banks)*

Soil class	Small banks (100-200 sq. ft. soil exposed)				Medium banks (201-2,000 sq. ft. soil exposed)				Large banks (>2,000 sq. ft. soil exposed)			
	Percent of waterline eroded				Percent of waterline eroded				Percent of waterline eroded			
	1-10	11-30	31-70	71-100	1-10	11-30	31-70	71-100	1-10	11-30	31-70	71-100
90+ percent sand[1/]	2	7	3	13	11	11	2	10	2	2	2	5
90+ percent clay	3	4	2	8	4	2	7	3	4	0	2	12
10+ percent sand and 10+ percent clay	0	1	2	4	3	3	1	4	5	1	5	18
5+ percent gravel and sand or clay	0	3	5	6	1	2	7	8	1	0	2	1

1/ Percent of exposed bank face covered by given soil class.

metal sides are flared 10° to compensate for head loss. The sampler was hooked on to the sill at different points for a constant timed interval.

Several checks indicated that the data collected with the instruments and techniques outlined above adequately represented the total sediment load (Hansen 1970).

All sediment samples were analyzed for total sediment concentration and for the percent of material greater than 0.062 mm. (sand size and larger). In addition, a particle size distribution of material greater than 0.062 mm. was made on selected DH-48 and DH-59 samples and on all of the "screen" samples.[1]

Channel Survey

Stream cross sections were mapped at 1/3-mile intervals along the upper 23 miles of stream channel to determine the relationship between changes in sediment load and stream channel characteristics. Stream width, depth, and gradient measurements were made at all of the 70 cross sections. Stream bottom composition was mapped by size classes, and the material was probed to a maximum depth of 18 inches to determine the thickness of deposits. Bed material samples were collected in sand-bed areas at the same 70 locations to determine: (1) The size relationship between bed material and total load in those areas having an erodible bed, (2) the minimum particle size present and hence the minimum size moved as bedload in sand-bed areas, and (3) whether large changes in water discharge, sediment discharge, and gradient along the stream had any effect on the particle-size distribution in sand-bed areas. Bed material samples were also collected from six coho salmon (*Oncorhynchus kisutch* (Walbaun)) spawning beds located in gravel areas. The samples were collected on November 24, 1967, shortly after spawning and 3 months later on February 25 before egg hatching.

Streambank Survey

The 204 eroding banks were tentatively stratified into classes that were believed to be related to erosion rates. These classes were based on area of exposed soil (bank size), soil texture, and evidence of recent waterline erosion; i.e., devoid of vegetation (table 1). A 24-percent sample was randomly selected from each class or, when few banks were present, a group of closely related classes. Thus, 48 banks were selected for annual surveys to determine the volume of erosion.

Permanent bench marks placed along the top of the surveyed banks were used as reference points from which to measure the recession rate of the bank crest. Also, they were used to establish points along the crest so that profiles could be surveyed down the bank face at 10-foot intervals. The volume of eroded material was obtained graphically by plotting the annual profiles and measuring the cross-sectional area between them. The eroded area multiplied by the width of the bank gave the volume eroded from that section. The volumes eroded from all sections were then summed to obtain the total erosion for the bank. The volume of material eroded from the unsurveyed banks was estimated from these data.

Soil samples were collected by textural class from each bank for particle-size analysis.

RESULTS

Flood Frequency

The interpretation of data must be done within the limitations imposed by the storm events and the resultant hydrologic conditions that were encountered. Therefore, a brief comparison was made between the study period and the previous 14 years of record on

[1] *Most of the basic sediment load data used in this paper are published (USDI Geological Survey 1967, 1968, 1969).*

the Pine River. The three factors selected for comparison, because of their importance and the availability of records, were the maximum annual flood peak, the frequency of summer floods, and the mean annual water discharge.

The annual peak discharges in 1967 and 1969 were fourth and fifth highest out of the 17 years of record for the Pine River. Also, four of the nine summer floods over 650 c.f.s. occurred during the same 2 years, with three unusually large summer floods occurring in 1969. Twenty-five percent of all flood peaks greater than 650 c.f.s. (regardless of season) during the 17 years of record occurred in 1967 and 1969. Also, the two largest total annual stream discharges were experienced in 1967 and 1969. In contrast, 1968 was average or below average in its stream discharge characteristics.

It was concluded that mean sediment discharge, which is closely related to stream discharge, was probably greater during the 3-year study than during the previous 14 years of record. There was no good basis for speculating whether eroding streambanks contributed proportionately more or less sediment during the 3-year study.

Sediment Budget

MAIN CHANNEL SEDIMENT LOAD

The annual stream sediment load averaged 9,000 tons[2] at Station 1 compared with 50,000 tons at Station 3 (table 2). The relatively consistent increase between these two stations ranged from a low of 490 percent in 1969 to a high of 700 percent in 1970 and averaged 560 percent for the 4-year period.[3] The sediment load increase along the channel was quite consistent on a monthly basis also (fig. 5).

Sediment concentration and consequently sediment load increased with stream discharge. Sediment concentration ranged generally between 0 and 400 mg./liter at Station 1 (depending upon stream discharge) and during low flows was typically less than 50 mg./liter. Downstream at Station 3, concentrations averaged three times greater, with a maximum of around 800 mg./liter.

Table 2. — *Annual sediment discharge (In tons)*

Water year	Sampling station				
	Station 1	Station 2	Station 3	Silver Creek	Poplar Creek
1967	13,000	--	70,000	--	--
1968	6,600	17,000	39,000	--	--
1969	9,900	24,000	48,000	550	770
1970	6,300	17,000	44,000	280	680
Average	9,000		50,000		

TRIBUTARY SEDIMENT LOAD

Sediment measurements on the larger two of the three major tributaries entering between Stations 1 and 3 showed a combined sediment discharge of 1,320 tons in water year 1969 and 960 tons in 1970 (table 2). This represents 3.4 and 2.2 percent of the sediment discharge *increase* from Stations 1 to 3 for the two years respectively.

Allowing for the third tributary, and several smaller ones, it seems probable that the total tributary sediment contribution would be less than 10 percent of the sediment increase between Stations 1 and 3, and possibly as little as 5 percent. Sediment contributed directly to the main stream from the few road crossings and other man-induced causes is negligible. Therefore, about 90 percent of the sediment increase from Stations 1 to 3 comes from other sources — with streambank and channel erosion the most probable contributors.

FLOOD PLAIN SEDIMENTATION

Five profiles were surveyed across the valley on the reservoir fill and on the adjacent upstream valley fill in order to check for permanent sediment deposition on the flood plains. The present rate of flood plain sedimentation had no significant effect on the sediment budget during the 3-year period.[4]

[2] *Conversion of units from tons to cubic yards and vice versa were made with the assumptions, based on extensive field data, that 70 percent (by weight) of the sediment load and of the eroding bank material was sand and 30 percent was silt and clay (see fig.), and the specific gravity of undisturbed eroding bank sediments was 1.49 for sand and 2.15 for the silt-clay fraction. The resulting conversion factor was cubic yard = 1.39 tons. This conversion permitted convenient comparisons between tonages of sediment load and cubic yards of eroding bank sediments.*

[3] *Data obtained during water year 1970 after completion of the formal study are included in these values and in table 2.*

[4] *Considering sampling variation, 0.014 foot deposition would have been the minimum detectable change at a 95-percent confidence level. Such an increase, if assumed to have occurred over the 500-foot average width of the flood plain along the 2 miles of stream channel influenced by the dam, would have been the equivalent of 2,600 cubic yards (3,600 tons) of sediment, or only 2 percent of the 3-year total sediment discharge of 157,000 tons at Station 3. The actual measured change was —0.006 foot. It was concluded that the present reservoir filling rate and flood plain building had no significant effect on the sediment budget.*

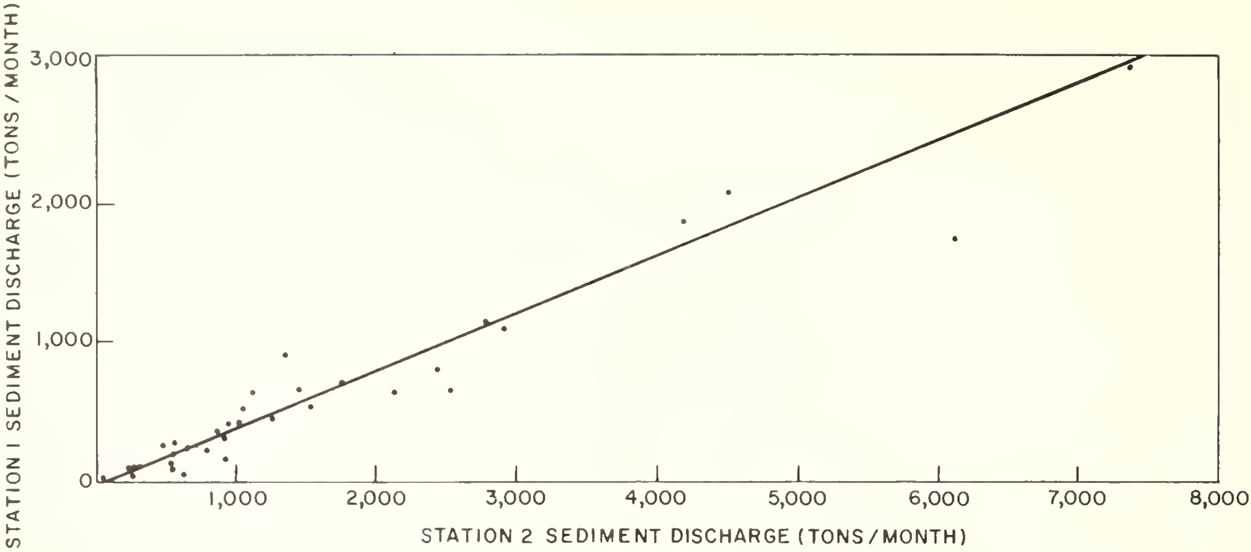


Figure 5.—*Monthly sediment discharge at Station 1 plotted against that for Station 2.*

STREAMBANK SEDIMENT CONTRIBUTION

Streambank surveys indicated that 70,000 tons of material eroded from all the banks during the 3-year study. This accounted for 55 percent of the sediment load increase in the study section of stream.

The quantity of eroding bank sediments ranged from a high of 50,000 tons in 1967 to no measurable erosion in 1968 (table 3). The volume of eroding bank sediments was related generally to the total mean annual discharge and the magnitude of the flood peak.

Table 3. — *Annual eroding bank contribution (In tons)*

Water year	Total sediment load	Sediment load increase in study section	Eroding bank contribution
1967	70,000	57,000	50,000
1968	39,000	32,000	1/0
1969	48,000	38,000	20,000
Total	157,000	127,000	70,000

1/Only a partial survey was made in 1968. Therefore, the zero estimate may have a considerable error. Any erosion that might have occurred is included in the 1969 data.

The method of selection and survey of the banks probably underestimated the volume of erosion. It was first assumed that only eroding streambanks with raw, unvegetated faces contributed sediment. However, vegetated portions of streambanks were apparently also undergoing moderate sheet and rill erosion, and yet were maintaining at least a semblance of plant cover with pioneer herbaceous species. Since only a small number of the vegetated streambanks were included in the survey, the volume of material eroded from that source was underestimated.

Another source of measurement error was due to subsidence of the entire bank together with the surveyed control points. This resulted in an underestimate of the volume of eroded material. Also, several new points of erosion started during the summer of the third year. These banks were not surveyed, resulting in a further, though slight, underestimate of bank erosion.

TOTAL SEDIMENT BUDGET

As stated previously, about 55 percent of the sediment load *increase* was attributable to measured bank erosion. An additional small amount, estimated to be less than 10 percent, came from tributaries. The remaining 35 percent was believed to have come primarily from slow and unobtrusive but widespread sheet erosion, and in some cases gradual subsidence and slumping of long sections of the bank.

The total sediment budget for the three years is shown in figure 6. Also shown are the individual annual sediment budgets, which give an indication

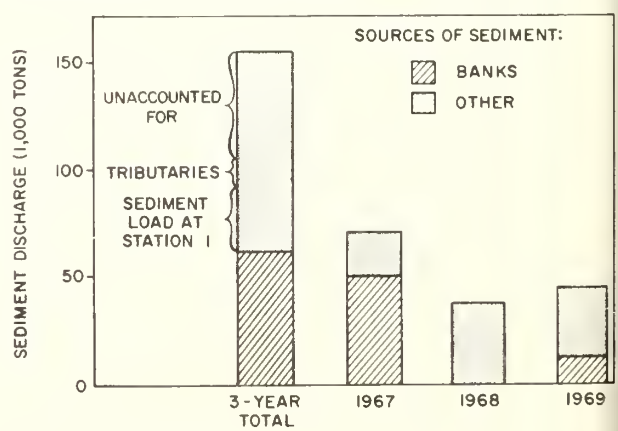


Figure 6. — *Pine River sediment budget at Station 3.*

of the year-to-year variation in bank erosion and sediment discharge rates.

Sediment Size

TOTAL LOAD SEDIMENT SIZE

Seventy to seventy-five percent of the Pine River sediment load was sand size (0.062 to 2.0 mm.). Stream discharge rate had no effect on the proportion of the sediment in sand size (fig. 7). Apparently, even at the lowest discharges, the stream can move some sand-size material.

The particle-size distribution of the total sediment load was essentially unchanged as it moved down the section of stream channel from Station 1 to Station 3, despite the large increase in both stream discharge and sediment load (fig. 8).

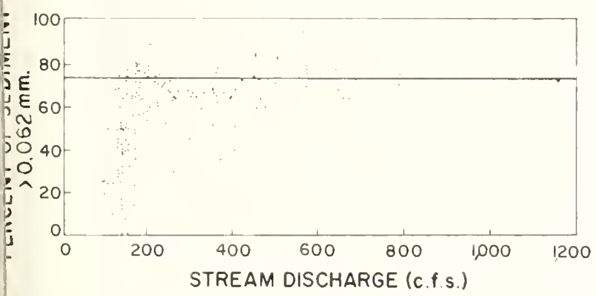


Figure 7. — *Variation of sand (0.062 to 2.0 mm.) content of sediment load with stream discharge at Station 1.(The large variation in the proportion of sand at discharges less than 200 c.f.s. was due to concentrations less than 20 mg./liter, where a fluctuation of a few sand grains could result in a large percentage change.)*

ERODING BANK SEDIMENT SIZE

The particle-size distribution of eroding bank sediments, except for the coarse material greater than 1.0 mm., was almost the same as the sediment already in transport in the stream at Station 1 (fig. 8). Since the eroding banks are a major sediment source and since the bank sediments have a similar size distribution to that already in transport at Station 1, the little change noted in the size of sediments discharged downstream at Station 3 would be expected.

There were, however, more coarse particles in the eroding bank sediments than were moving in the stream. This gravel-size material, primarily larger than 4 mm., constitutes about 5 percent of the eroding bank sediments (fig. 8). Much of the gravel is from old stream deposits in river terraces. The small amount of gravel measured in transport, even at high stream discharges, indicates that most of the eroded streambank gravels are again being redeposited on the streambed.

BED-MATERIAL SIZE

Except for small areas of silt deposits, sand streambed areas constitute the sole area where significant interchange between streambed sediments and the sediments in transport is possible. Bed-material samples from sand-bed areas indicated that about 88 percent was between 0.125 to 0.5 mm. in size (fig. 8). This is the same size group that constitutes 60 percent of both the eroding bank sediments and the sediment in transport. Less than 2 percent of the bed material in the sand-bed areas was finer than 0.125 mm. Since sand-bed areas were in the sections of the stream with minimum gradient, the smallest particles that move as bedload would be traveling there. In more turbulent sections of the stream, more sands would be in suspension and the minimum bedload particle size would likely be greater than 0.125 mm. Therefore, the smallest particle commonly moved as bedload on the Pine River was 0.125 mm.

There was no significant change in the sand bed material size distribution along the channel from the mean distribution shown in figure 8. Evidently there was little sorting of sand sizes, even in those high gradient sections where sand comprised a minor portion of the streambed.

DEPOSITS ON FISH SPAWNING BEDS

From 23 to 36 percent by weight of all the spawning-bed material was less than 8.0 mm. The size distribution of sediment finer than 8.0 mm. deposited between the November and February sampling dates is plotted in figure 8. Proportionately more of the coarse sands from eroding banks and bed-material sediments were deposited on the spawning beds, probably as a result of the higher velocity and greater turbulence associated with the gravel streambed areas used for spawning. Almost no deposited sediment was finer than 0.125 mm., and 58 percent of the deposited material was between 0.125 and 1.0 mm. This latter size group also constitutes 55 percent of the eroding bank sediments and is in the size group that has been shown to be associated with large reductions in spawning-bed gravel permeability (Cooper 1965, Terhune 1958).

The eroding bank sediments were of the same size as the bulk of the sediments deposited on spawning beds. Therefore, there is a possibility that reduction of the stream sediment load through streambank stabilization would result in an improved spawning environment.

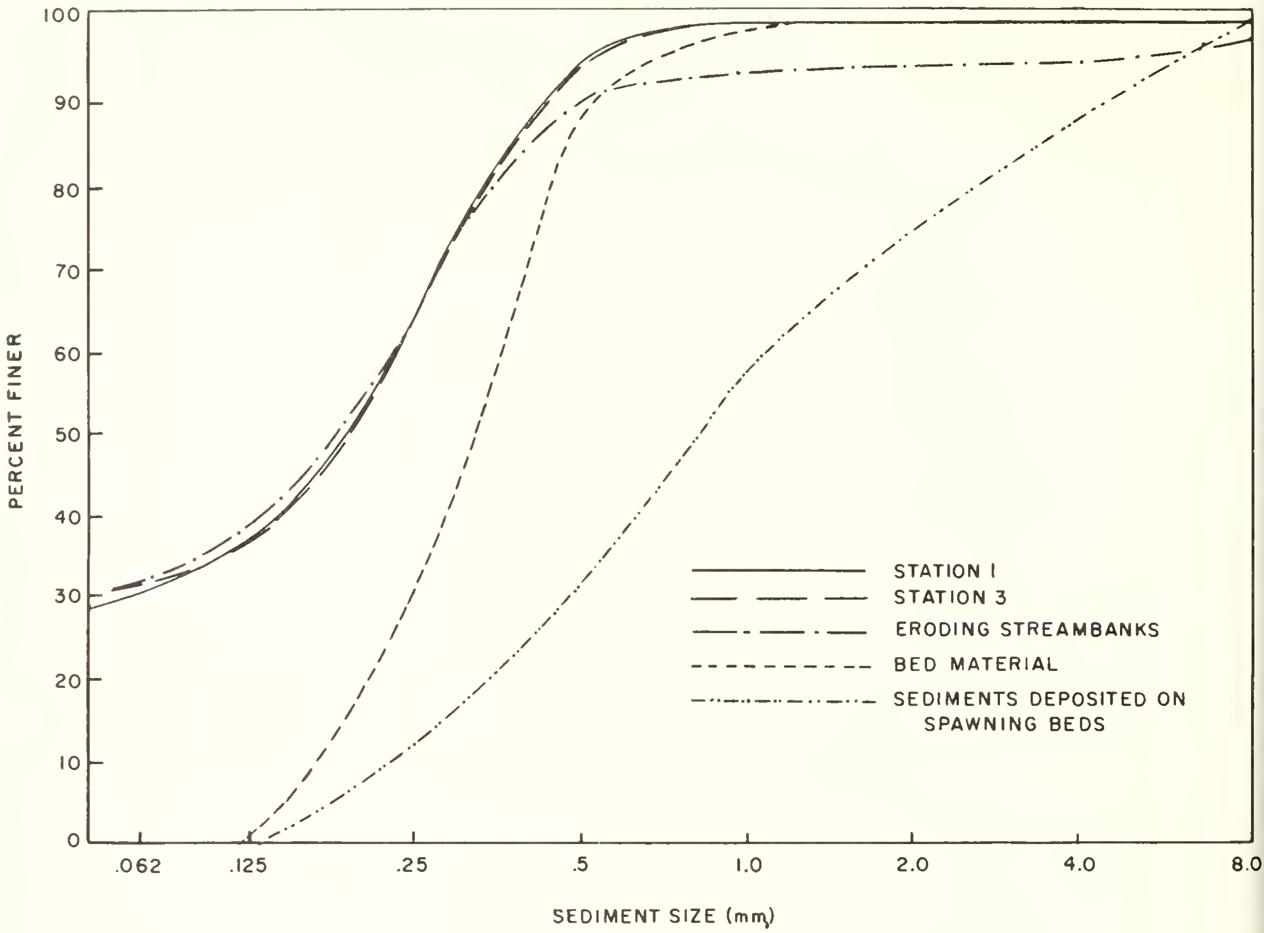


Figure 8.—*Particle-size distribution of sediment at its source, in transport, and in areas of deposition.*

STREAMBED COMPOSITION

Areas of erodible sand constituted 22 percent of the total streambed area of which more than half (12 percent) was covering gravel. Areas of essentially nonerodible material were: boulder 7 percent, cobble 17 percent, gravel 32 percent, and residual clay 12 percent. Silt deposits were present on 10 percent of the area, primarily in narrow bands along the stream's edges.

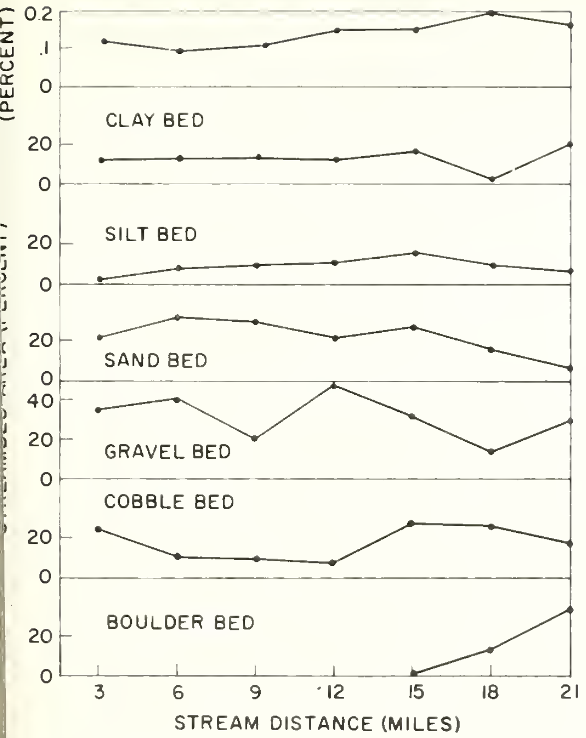
The major classes of sediment on the streambed were closely related to the water surface slope, which increased gradually toward the lower end of the study section. As slope increased, the percentage of the streambed covered by cobbles and boulders increased and the percentage covered by sand and gravel decreased (fig. 9). Silt areas increased downstream except in the last 6 miles with the steepest gradient, where the area of silt decreased. The proportion of the streambed occupied by exposed, consolidated clay remained about the same along the stream.

Streambank Erosion

STREAMBANK EROSION RELATIONS

The volume of sediment eroded from individu streambanks ranged from 0 to a total of 2,400 cub yards for the 3-year study period. A partial breal down of the volumes of eroded sediments from the 4 surveyed streambanks is as follows:

Three-year total of eroded sediments Cubic yards	*Number of banks*
0	6
0-100	21
100-1,000	19
>1,000	2



igure 9. — *Relation of water surface slope to percent of various bed types along 23 miles of stream channel. Each point is the mean of 10 cross sections equally spaced along 3 miles of stream.*

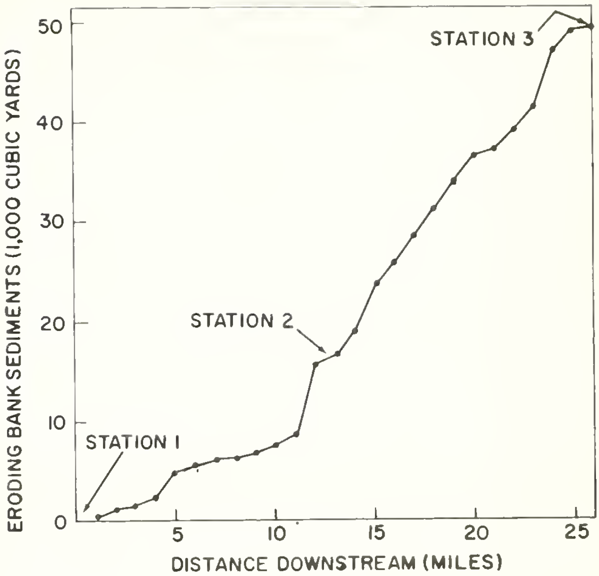


Figure 10. — *1966-69 cumulative sediment yield from eroding streambanks.*

.e 50,000 cubic yards (70,000 tons, table 3) of ›ding bank sediments came from 16,300 linear feet › eroding waterline. The maximum lateral recession › any streambank was 13 feet during the 3-year riod, although 1 to 5 feet was most typical.

Eroding bank sediment contribution was much eater in the lower two-thirds of the study area (fig.). This was due to the higher banks and, possibly, the greater stream discharge and gradient. Volume eroding bank sediments increased in direct proporin to bank height. Even though high banks had re sediment entering the channel per foot of waterie, the banks did not recede more slowly. This indies that the stream's sediment transport capability n excess of the sediment supply to the stream. Sand iments temporarily accumulated at the base of iks during dry weather were always removed dur high flows. Slumped clay sediments sometimes nained at the base of banks for years. However, this latter case, the durability of the slumped sedint was due to the erosion resistance of the cohesive iments rather than the lack of transport capability the stream.

Detailed eroding bank data would be useful in designing a stabilization program to: minimize cost, given a required level of sediment reduction; or, maximize sediment reduction, given a fixed input of funds. The following data from the Pine River illustrate some of the many relationships that can be developed for that stream using the streambank stratifications described earlier. Similar relations could be developed on other streams in the glacial drift region.

There is a large difference in the annual volume of sediment loss from streambanks of various sizes and erosion classes (fig. 11A). The greatest erosion rates were from the large banks in the "severe" and "moderate" erosion classes. There was no measurable sediment loss from banks in the "light" erosion class, regardless of bank size. The average length of eroding bank waterline also varied with bank size and erosion class (fig. 11B).

The data in figures 11A and 11B permit the calculation of the number of cubic yards of material eroded per linear foot of waterline for different types of eroding banks. This identifies the banks that would have the greatest volume of sediments stabilized per linear foot of bank treatment, or the highest "efficiency of stabilization." Stabilization of large banks in the "severe" and "moderate" erosion classes would produce the greatest efficiency (fig. 11C).

Large banks in the "severe" erosion class have by far the greatest total volume of sediment yields and

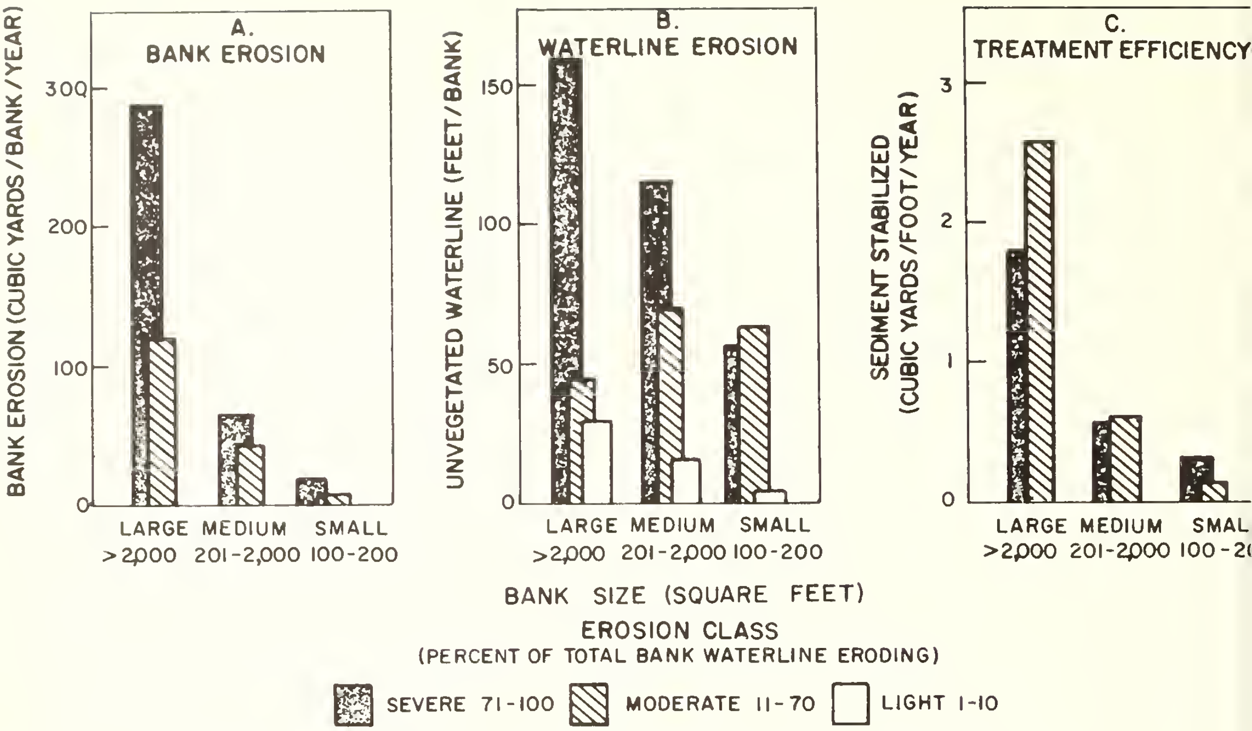


Figure 11. — *Variation of selected bank characteristics by erosion and size class.*

the greatest length of eroding waterline (figs. 12A and 12B). Stabilization of all the large banks in the "severe" and "moderate" erosion classes (the two strata with highest treatment efficiency shown in figure 11C) would result in a 74 percent reduction in eroding bank sediments from treatment of only 40 percent of the total eroding waterline. Banks in other strata could be treated to get further reduction in eroding bank sediments, but only with a reduced efficiency.

INDICATORS OF RAPID EROSION

Several additional factors, although subjective, may aid in identifying areas of rapid erosion when no other data are available.

Islands, bars, and fallen trees are all indicators of rapid erosion caused by a lateral shift in the stream course. As the stream cuts into a rapidly eroding bank, the stream becomes wider and shallower with gravel bars, islands, and a flood plain building up on the inside of the bend. These deposited sediments are rapidly vegetated with pioneer species such as willow and alder (fig. 13). Trees eroded from the bank lodge in the shallow water and catch additional debris. This debris sometimes helps stabilize the bank, but often it accelerates local scour.

Debris cones are an indication of past rapid strea erosion at the waterline and an oversteepening the bank (fig. 14). Subsequent wind erosion of t bank face during dry periods and water erosion du ing short, high-intensity summer rainstorms contribu to the buildup of debris cones at the toe of the bar The loose material is usually washed away during t next flood.

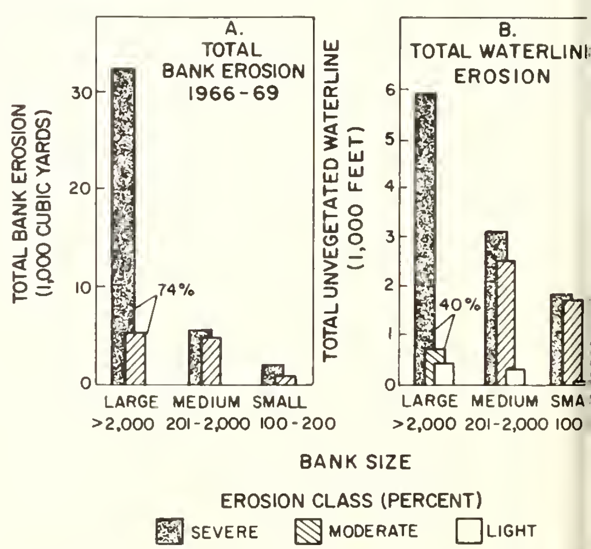


Figure 12. — *Total erosion of all banks by erosi and size class.*

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gure 13. — *A rapidly eroding bank associated with a lateral shift in the stream has resulted in the stream becoming wider and shallower. Features commonly associated with such a situation are: (1) islands, (2) pioneer vegetation, and (3) debris at the base of the bank.*

Clay banks sometimes sheer considerable distances 00+ feet) from the stream (fig. 15). The toe of h a slump narrows the stream with resultant her stream velocities and greater erosive potential g. 16). The toe of the slump often contains sub-rged vegetation that originally grew above the ter surface. The rate at which the slump erodes greatly dependent upon the resistance of the clay, actor for which there is no accurate measurement present.

Banks containing wet clay areas with seeps or ings are prone to slumps and mud flows during t seasons (fig. 17). Measurements indicated that h wet bank failures occurred at infrequent inter-s, but the volume of material was large enough t wet banks had the highest erosion rates. In con-st, dry clay banks had the lowest erosion rates, and nks with sand or separate areas of both sand and ly were intermediate as shown below:

mber banks	*Soil texture*	*Moisture status*	*Erosion rate Cubic yards/ bank/year*
7	Clay	Dry	27
17	Sand	Dry	57
15	Clay & sand	Dry	88
9	Clay & sand	Wet	207

F-520637

Figure 14. — *Debris cones at the base of a mixed sand and clay bank. These cones were formed by wind erosion of sand bank faces steeper than the angle of repose.*

F-520634

Figure 15. — *A near-vertical shear zone in a clay bank. The shear is at a distance of 80 feet horizontally and 40 feet vertically from the stream, and occurred sometime during a 1-year period between visits. Such slumps may occur relatively quickly, perhaps in minutes or less.*

F-520635

Figure 16. — *Submerged vegetation is an indicator of obvious slumping as shown above, and of less obtrusive subsidence of large sections of streambank.*

Some of the apparent difference in erosion rates was due to an interaction between soil texture, the presence of springs, and bank size. As bank size increased, the probability increased that more than one major soil textural class would be exposed and also that the bank would intersect areas of ground water inflow to the stream. Therefore, banks containing mixed soil textures and classified as "wet" were to some extent the same large banks that produced more sediment. However, bank size explained only a small part of the above variation. Some of the remaining variation was no doubt due to the influence of soil texture and the moisture status on the erosion rate.

Eroding banks that are adjacent to recreational areas or at stream access points almost always have high erosion rates. Three such banks along the Pine River had an average sediment yield of 105 cubic yards/bank/year, higher than any of the erosion rates tabulated above for similar "dry" banks. Only the "wet" banks exceeded the banks receiving recreational usage in the severity of erosion rate.

DISCUSSION AND SUMMARY

The theory of sediment transport and the interactions between sediment load and the stream channel is incomplete. However, some apparent relationships and the trends in sediment dynamics following streambank stabilization can be mentioned.

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Figure 17. — *A mud flow on a wet clay bank.*

There was less sand on the streambed in the dow stream section despite the 560-percent increase sand sediment load. This is due to the greater energ gradient and more generally the high transport capa city of a pool and riffle stream. It implies that th capability of the stream to transport sands and fin material is in excess of the sediment supply. Cons quently, an erosion reduction program designed reduce total sediment load for the purpose of im proving stream esthetics and fish habitat, or for r ducing reservoir or harbor siltation rates, should resu in a relatively rapid decrease in moving sediment ar associated changes in streambed composition.

A hypothetical program stabilizing all of the ide tifiable eroding banks in the study section wou reduce the total sediment load 45 percent at Station (table 3), with a possibility of a wide error in eith direction from the estimate. If the 53 eroding strear banks upstream from the study section were also st bilized, the total sediment load reduction would be percent. In any event, a complete bank stabilizati program would not result in complete elimination the sediment load. The problem therefore becom one of exploring possible effects of a partial reducti in sediment load on the stream channel.

Because the particle size distribution of streamba sediments was nearly the same as sediments alrea in transport, stabilization of all eroding banks wou not produce much change on the particle size d tribution of the sediment load. However, there is st some latitude in designing a program to change pa ticle size. For example, a change in streambed co position and a maximum reduction in bedload cou be attained by stabilizing only the banks with lar nounts of sand. This is possible because the mini-um particle size present on the streambed and rried as bedload is between 0.125 and 0.25 mm. ine sand). Since deposited silts and clays constitute ly a small fraction of the streambed area and were t present in gravel, stabilization of such banks ould have little effect on the stream bottom.

In contrast, if the objective were to lower turbidities iring floods, banks containing clays and silts should stabilized. However, since clays and silts constitute ly 25 percent of the total sediment load, with con-ntrations rarely exceeding 100 mg./liter, the oppor-nities for producing dramatic changes in turbidities e limited. Also, stabilizing these banks would not ticeably affect low flow turbidities because there almost a complete absence of movement of clays d silts during low flow.

A reduction in sediment load might result in the ouring of sand off buried gravels and also affect the iount of sand intermixed in gravel areas of the eambed. However, bedload movement in a pool d riffle stream is commonly concentrated in nar-w bands parallel to the direction of flow and is not tributed over the entire width of the streambed ove and Benedict 1948). Consequently, a reduction sediment load in a pool and riffle stream might ve its primary effects concentrated in the relatively all portion of the streambed experiencing moving dload. The effects of this in terms of streambed nposition changes and in cleaning sand from gravel as with an already low bedload movement is not edictable.

These changes are all in the direction generally epted as an improvement in fish habitat (Cordone d Kelley 1961). However, it has yet to be demon-ated that sediment changes of the above predicted gnitudes are large enough to have any measurable ect upon either fish or fish habitat.

The results of this study were highly dependent on its duration and the prevailing climatic condi-ns. Results range from "verifiable relationships" ich remained fairly constant throughout the course the study, to "best estimates" of highly variable a which may be both climatically and time de-dent, to "hypotheses" which attempt to formulate e order from the incomplete results. The main lings are summarized generally in that order.

. Sediment load increased five to six times within 6-mile-long section of the Pine River. Sediment centration increased three times and stream dis-rge increased 1.8 times within the same section.

2. Seventy percent of the total sediment load was sand-size material (0.062 to 2.0 mm.).

3. Particle-size distribution of the sediment load did not change through the 26-mile reach even though there was a large increase in sediment load.

4. The mean particle-size distribution of eroding bank sediments (the major sediment source) was essentially the same as that of the sediment already in transport.

5. Fifty-eight percent of the material deposited on fish spawning beds was between 0.125 and 1.0 mm., the same size group that constituted 55 percent of the eroding bank sediments.

6. The minimum particle size present in any spawn-ing gravels and in bed material samples was 0.125 mm.

7. Bank sediments greater than 1 to 2 mm. are not readily transported by the stream and probably aid in forming areas of stable bed.

8. Even though the sand sediment load increased five times along the channel reach, there was a de-crease downstream in the proportion of the streambed covered with sand and an increase in cobbles and boulders. This was probably a result of the increased gradient.

9. Twelve percent of the streambed area was com-posed of gravels buried by sand. Therefore, this is the upper limit of any conversion of sand to gravel bot-tom type following a sediment load reduction.

10. During the 3-year study the eroding bank sediments contributed 55 percent of the total sedi-ment load increase that occurred within the study section.

11. Most of the streambank sediment came from large banks in the most severe erosion class. A 74-percent reduction in eroding bank sediments could be achieved by stabilizing only 40 percent of the eroding waterline.

12. Tributaries and road crossings contributed less than 10 percent and possibly as little as 5 percent of the sediment load increase along the 26-mile chan-nel reach.

13. It was hypothesized that the remaining 35-percent sediment contribution came from vegetated streambanks through sheet erosion and gradual bank subsidence.

14. The best estimate of the reduction of the Pine River sediment load following complete streambank stabilization along the 26-mile study section was 45 percent.

15. A complete streambank stabilization program would significantly reduce the sediment load but would not affect the particle-size distribution of the moving sediment.

16. It was hypothesized that a reduction in sediment load following bank stabilization would tend to increase the area of streambed covered with gravel, decrease the area of sand, and decrease the sand content in existing exposed gravels. However, the extent of such changes is not yet predictable.

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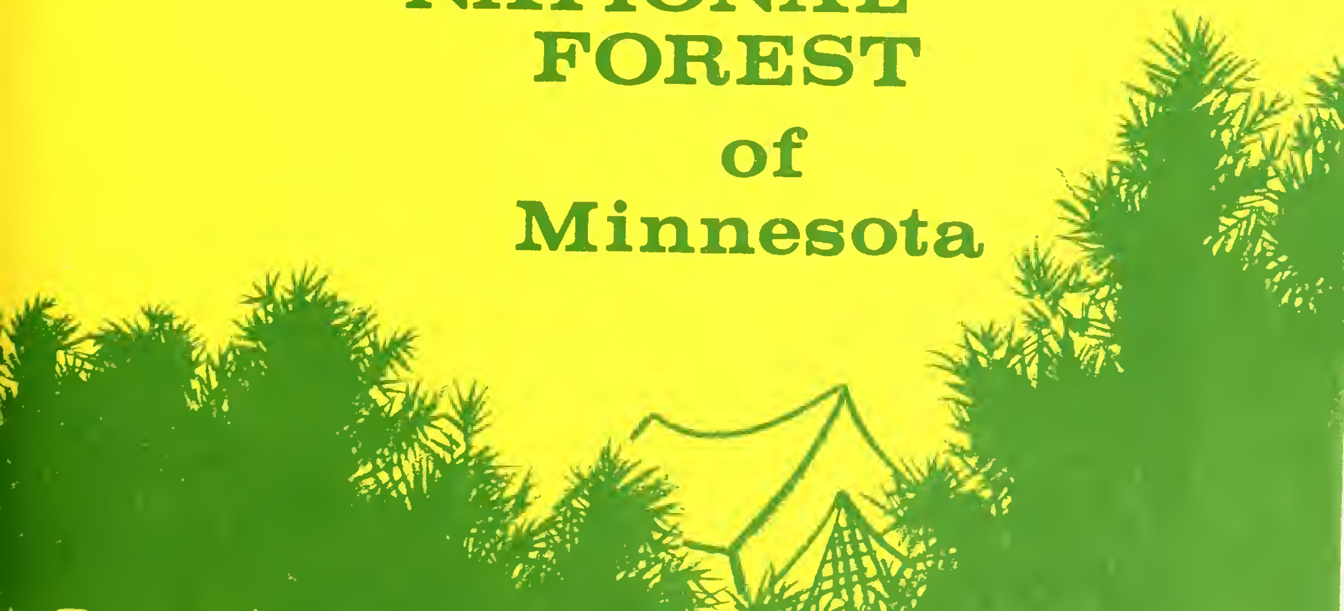
DAVID W. LIME

Factors Influencing Campground Use in the SUPERIOR NATIONAL FOREST of Minnesota



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The author gratefully acknowledges the guidance and encouragement of Dr. David G. Arey, University of Pittsburgh, and Dr. Robert C. Lucas, Intermountain Forest and Range Experiment Station, Missoula, Montana.

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CONTENTS

Factors Influencing Campground Use In The Superior National Forest Of Minnesota

David W. Lime

Managers of public recreation lands must eet the persistent demands of an ever-increasing ecreating public during the coming decades. ecisions, once made, will be irreversible for the ost part. It is therefore essential that decisions e made with a clear understanding of the conse- uences to future visitors. Understanding these nsequences in terms of their effect on environ- ental quality and recreational land use calls for keen comprehension and interpretation of the terrelations of people, resources, location, and sign.

Auto campgrounds vary greatly in amount use. While some are frequently full, others ceive only light use. Reasons for this uneven stribution of users are not well understood.

The objective of the study was to identify ctors which influenced the distribution of sitors among auto campgrounds of the Superior ational Forest during the peak of the camping ason.

Meeting this objective required: (1) deter- ning how intensity of use varied among camp- ounds; (2) correlating the distribution of users th attributes of the campgrounds; (3) inter- wing campers to learn what factors influenced eir choice of a particular camping area; and) ascertaining if these factors were the same a the campground attributes under (2) above (ime 1969b).

STUDY AREA: THE SUPERIOR NATIONAL FOREST

The Superior National Forest is located in n theastern Minnesota and is bounded by On- tio on the north and Lake Superior to the s theast. Composed of about 3 million acres, o which approximately one-third is the Boun- dy Waters Canoe Area (BWCA), the Forest stetches about 130 miles from east to west and 7 miles from north to south (see map, pages 8 nd 9).

Recreational use of the campgrounds is primarily vacation-oriented rather than weekend or transient. The auto campgrounds are not located near the major through-travel arteries of northeastern Minnesota. Route 61, a through route between Duluth and Ontario following the shoreline of Lake Superior, passes along the eastern portion of the Forest, but this route is served by several State park campgrounds. State highway routes 1 and 169 probably serve as the major artery for camping traffic in and out of the Forest (see map). Few other auto campgrounds (State, municipal, or private) exist in northeastern Minnesota to compete with facilities in the Superior National Forest.

A primary recreational attribute of the study area is its water. In 1968, 30 percent of the Forest's use (in visitor-days) was water activities.[1] More than 10 percent of the gross acreage is water. This represents over 2,000 lakes 10 acres or larger in size, and totals nearly 315,000 acres of water. The streams, which are characteristically short with an abundance of falls and rapids, total more than 1,500 miles in length.

There are 36 auto campgrounds in the Superior National Forest; all but two (because of isolation from the others) were included in this study (see map). The evolution of the campgrounds dates to the 1920's. Several facilities were developed from parking lots used by fishermen. Increased development took place in the 1930's by the Civilian Conservation Corps but was meager until the late 1950's when the Forest Service began rehabilitating older campgrounds and developing new ones.

These programs have not been completed and differences in the degree of development

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[1] *Canoeing, boating, fishing, and swimming. Recreation files, Superior National Forest, Duluth, Minnesota.*

between some campgrounds are extreme. Site and location conditions also vary widely: 15 of the campgrounds have no source of water except lake or stream; the number of campsites per campground ranges from one to 69 with 15 campgrounds containing more than 18 sites; 29 are located adjacent to lakes and the remaining seven are on streams; some have been utilized for more than 40 years, the newest only 4; 18 require overnight camping fees; only one has flush-toilet facilities; several are located adjacent to a paved main State route while the most remote is more than 30 miles from the nearest paved road; some have striking vegetation and scenery such as cliffs, falls, and rapids, while others exhibit sparse and trampled vegetation, low relief, and quiet water; and one campground is 5 miles from a town, the most remote more than 28 miles.

METHODS

Sampling Campground Use

In 1967 the 34 campgrounds were sampled during a 35-day period between August 1 and Labor Day. Campground occupancy was tallied for 16 randomly selected dates — 10 weekday nights (Sunday through Thursday) and six weekend nights (Friday and Saturday) — after 7 p.m. in the evening on the assumption that most campers would be within their respective campgrounds at this time. A check made on a particular night was a record of use for the following day.

Estimates of the total number of group-nights[2] of use at each campground during the survey period were derived from the sample. For each campground each "weekday day" was checked twice during the 5-week period. Two Mondays were checked, two Tuesdays were checked, and so on. Similarly, each weekend day was checked three times during the 5-week period. An estimate of total use was determined by multiplying the total number of group-nights by the inverse of the respective sampling rate — 1.67 for weekend values and 2.50 for weekday figures.

Total group-nights of use at each campground was then converted to percent occupancy by dividing the total number of group-nights by the total number of possible group-nights during the sample period. Possible group-nights was the number of designated campsites times the length of the survey period — 35 days.

The survey was repeated in six of the campgrounds during the same time period in 1968 to determine if there were differences between years.

Interviewing Campers

The time period for interviewing campers during 1968 closely paralleled the inventory of use in 1967. Interviews were conducted between July 23 and Labor Day, 1968. Each campground was visited three times — twice on weekdays (Monday through Friday) and once on weekends.

The sample size at each camping area was determined onsite by selecting at random a portion of all occupied units. Campgrounds with many sites occupied were sampled at a lower rate than those with few sites occupied. All questioning and recording was conducted by the author. The group spokesman was self-selected. On questions involving opinions, other interested members of the party also were probed. Approximately 25 minutes were required to conduct each interview; 248 interviews were completed. There were no refusals. If the people in the sample site were gone when the interviewer called, he made several return trips to the site to interview them. If these campers were not interviewed another randomly selected occupied unit was sampled. The substitution rate was under 1 percent.

A weighting procedure was devised to control bias for different sampling rates on weekends and weekdays, and variability in onsite sampling. These adjustments were found to have little effect on the summation of responses. Thus data are presented in the unweighted form.

Although the length-of-stay bias was recognized (Lucas 1963, Wagar and Thalheim 1968), questionnaire responses deliberately were not corrected on this basis. A decision to occupy a campground unit 10 days was felt to be twice as important as one to occupy a campsite for only 5 days. Thus, the analyses of campers' responses were left in visitor-days (or group-days

[2] *A group-night represents the use of one campsite for one night.*

RESULTS

Campground Use in 1967

Campground use was sampled for compara-
ve purposes during the peak of the camping
ason rather than to measure total summer
isitation. The data revealed considerable
ariation in use among camping areas for
ie three time periods (table 1). For the overall
irvey period some places were used more than
ve times as much as others, the same ratio
ported in a study of a few camping areas near
ie BWCA in 1961 (Lucas 1964).

For ease of comparison campgrounds were
rbitrarily grouped into four size classes. Striking
ariations existed in the intensity of use both
etween and within these groups.

For the entire survey period, occupancy
veraged 42 percent of capacity, but individual
ampgrounds ranged from 19 to 104 percent
fig. 1). Smaller campgrouunds (fewer than 11
ampsites) were generally more intensively used.
Some campgrounds were used more than three times as intensively as others in the same size class.

On weekends occupancy averaged 52 percent of capacity (fig. 2). Individual campgrounds varied from 23 to 123 percent. Again small campgrounds received more intensive use, but exceptions are readily apparent. As before, there was a large range within size classes and some camping areas were used more than three times as much as others.

Predictably, weekday occupancy averaged below weekend occupancy, or 36 percent of capacity (fig. 3). Variations in the intensity of use between individual campgrounds was extreme, from 12 to 96 percent. Occupancy by size classes varied most during the weekday period. Some campgrounds averaged over six times as much occupancy as others in the same size class.

The following tabulation gives another view of the wide variation in use between camp-

Table 1.—Rankings of the intensity of auto campground use for the overall survey period, weekends, weekdays (Aug. 1 to Sept. 5, 1967)

Overall survey period			Weekends		Weekdays	
Campground name	Campsites	Occupancy	Campground name	Occupancy	Campground name	Occupancy
	Number	Percent		Percent		Percent
Moose Lake	8	104	Moose Lake	123	Moose Lake	96
Lake Jeanette	9	88	Lake Jeanette	109	Lake Jeanette	79
Hogback Lake	5	80	Kawishiwi Lake	104	Hogback Lake	72
Devil Track Lake	18	72	Hogback Lake	100	Devil Track Lake	71
Kimball Lake	9	72	Kimball Lake	91	Trails End	66
Kawishiwi Lake	5	70	Temperance River	85	Kimball Lake	64
Lake One	6	68	Lake One	83	Dumbell Lake	64
Trails End	33	67	Devil Track Lake	77	Ox-Bow	63
Dumbell Lake	5	67	Bouder Lake	75	Lake One	62
Bouder Lake	2	64	Poplar River	75	Bouder Lake	60
Ox-Bow	3	64	Stony Point	74	Stony Point	60
Stony Point	5	64	Dumbell Lake	73	Sawbill Lake	59
Sawbill Lake	50	62	Cascade River	72	Iron Lake	58
Temperance River	8	59	Trails End	70	Kawishiwi Lake	56
Fall Lake	48	58	Whiteface Reservoir	69	Fall Lake	55
Iron Lake	6	57	Sawbill Lake	68	Temperance River	49
Poplar River	4	55	Lichen Lake	67	Poplar River	48
Fenske Lake	14	49	Ox-Bow	67	Isabella River	42
Cascade River	3	44	Fall Lake	64	Fenske Lake	42
Isabella River	11	44	Fenske Lake	61	Baker Lake	40
Baker Lake	4	42	Iron Lake	53	South Kawishiwi River	38
South Kawishiwi River	34	37	Portage River	50	Cascade River	33
Lichen Lake	1	33	Isabella River	49	Crescent Lake	30
Portage River	3	33	Baker Lake	46	Flour Lake	29
Crescent Lake	40	32	Cadotte Lake	41	Portage River	27
Flour Lake	43	30	Crescent Lake	38	East Bearskin Lake	27
Whiteface Reservoir	57	30	South Kawishiwi River	35	Ninemile Lake	27
Ninemile Lake	19	29	Flour Lake	35	Birch Lake	23
East Bearskin Lake	44	27	Echo Lake	35	Two Island Lake	23
Birch Lake	38	24	Ninemile Lake	34	Echo Lake	17
Two Island Lake	36	23	East Bearskin Lake	28	Whiteface Reservoir	14
Echo Lake	29	22	McDougal Lake	27	Lichen Lake	14
Cadotte Lake	27	20	Birch Lake	25	McDougal Lake	12
McDougal Lake	20	19	Two Island Lake	23	Cadotte Lake	12

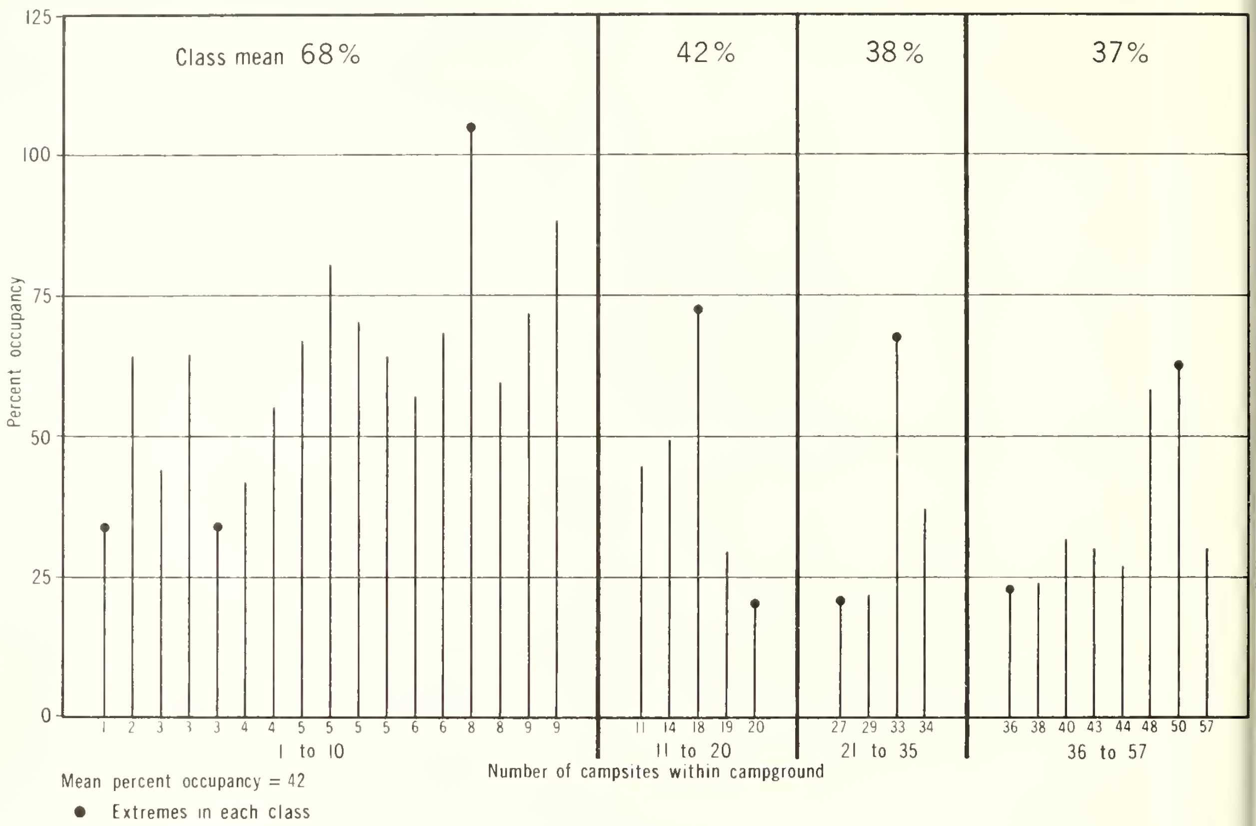

Figure 1.—Variation in campground occupancy: overall survey period, 1967 (Aug. 1-Sept. 5).

grounds.

Number of campgrounds	*Overall survey period*	*Weekends*	*Weekdays*
Over 2/3 full	9	18	5
1/3 to 2/3 full	13	12	16
Under 1/3 full	12	4	13

Of the 18 camping areas averaging over two-thirds full on weekends, four were filled beyond their designed capacity. Of those averaging over two-thirds full for the overall survey period, only one was full beyond capacity. On weekdays, none were overfilled.

Of the 647 individual campsites in the 34 campgrounds, 30 percent averaged fewer than three nights of use during the survey period. Twelve percent were never used even though the survey included the Labor Day weekend (fig. 4). On the other hand, 17 percent of the campsites averaged over 75 percent full, and 6 percent averaged over 90 percent full (fig. 5).

Although the intensity of use generally increased at each location on weekends, difference between weekends and weekdays were not great The difference in use between weekends an weekdays was less than 20 percent for 22 of th 34 campgrounds. This substantiated the assertion that use of the Forest's campgrounds wa primarily vacation-oriented. Furthermore, th relative rankings of percent occupancy for thes two time periods were nearly the same.

Campground Use in 1968 Compared to 1967

The six camping areas[3] as a whole experience about a 10-percent increase in total use betwee the two years. A comparison of the percentage of total use that each campground received for both years indicated that camp

[3] *Birch Lake, Fall Lake, Fenske Lake, Lak One, Moose Lake, and South Kawishiwi Riv Campgrounds.*

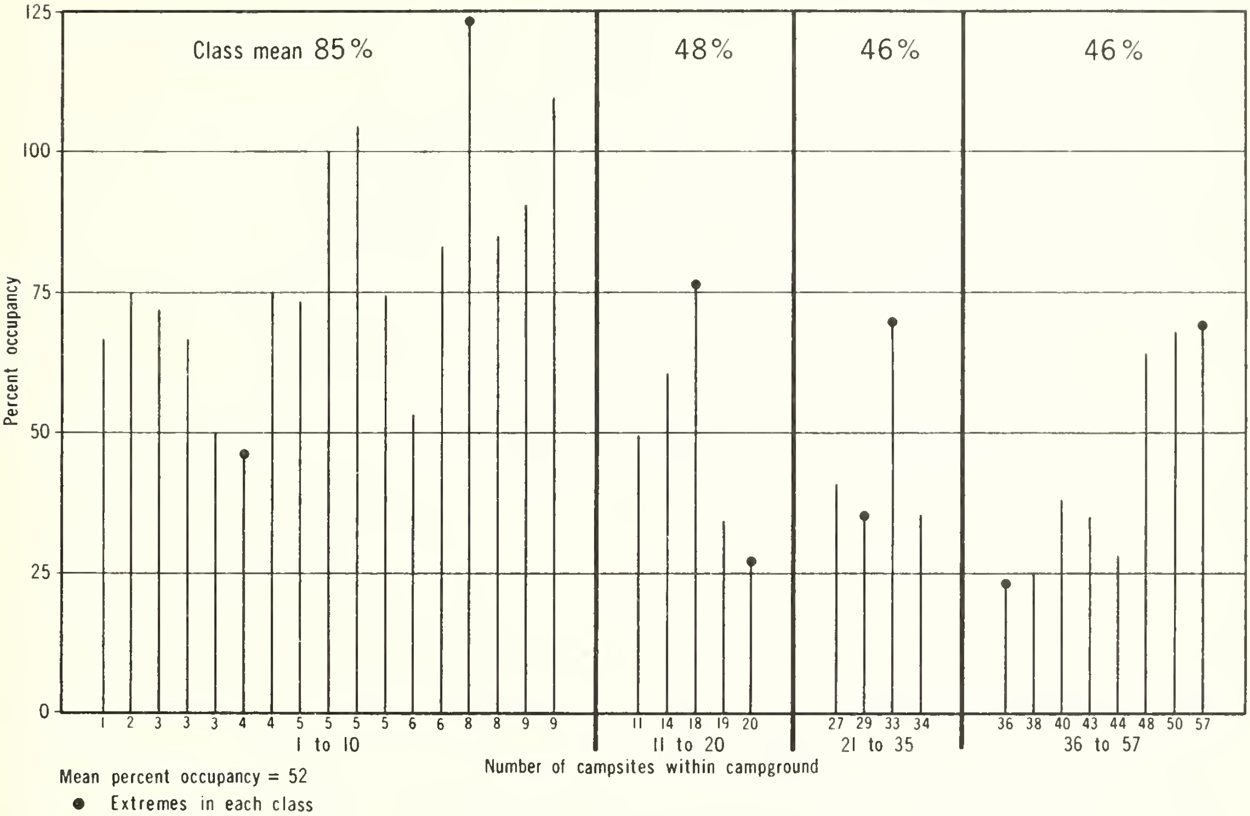

Figure 2.—Variation in campground occupancy: weekends, 1967 (Aug. 1-Sept. 5).

round use remained essentially stable. This neant that the percent occupancy observed in 967 was a reliable index of use for at least a -year period. This assumption gains additional upport from observations of similar use intenities at several of these same camping areas in 961 (Lucas 1964).

Factors Associated with the Intensity of Campground Use

ACTORS CONSIDERED

Relations were determined between the inensity of campground use (percent occupancy) nd 74 variables that the author felt might affect ntensity of use. These variables were divided nto three groups: locational, natural, and mannade environments of the campgrounds.

The location factors were the proximity of he campgrounds to: (1) travel routes, paved oads, (2) towns, (3) other recreation facilities, nd (4) their degree of "northness" within the uperior National Forest itself as well as their earness to Canada.

The natural environment factors included both land resources (vegetation and topography) and water resources (type and recreational quality) and their potential for outdoor activities.

Factors of the manmade environment included: (1) the facilities and services provided (including activity potentials, conveniences for comfort, and number of individual campsites), (2) the year of opening and whether an overnight fee was charged, (3) number of individual campsites on the waterfront, (4) the number of campsites suitable for trailers, and (5) the spacing and quality of the screening between campsites.

ANALYSIS OF VARIABLES SINGLY

Because of the wide variation in campground size, the statistical variance in percent occupancy during the sampling period was greater, hence, less reliable in camping areas with few campsites than in areas with many sites. As a result it was necessary to weight the raw occupancy data for each campgrouund on the basis of its size or number of individual campsites.

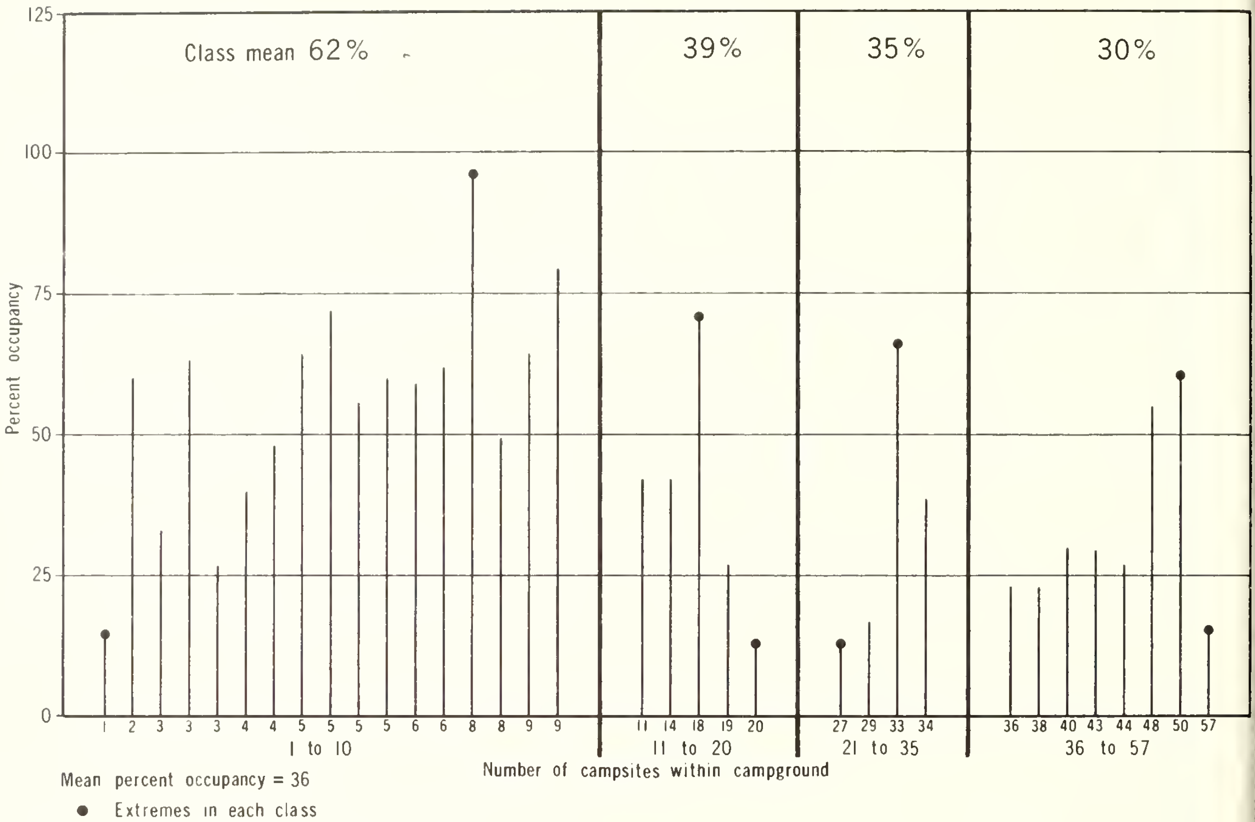

Figure 3.—Variation in campground occupancy: weekdays, 1967 (Aug. 1-Sept. 5).

Analysis was made using percent occupancy for the entire 1967 survey period as the dependent variable and the campground factors as independent variables. Only a few factors were significantly related (0.05 level) to percent occupancy.

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Figure 4.—About one-third of the Forest's individual campsites were seldom if ever used.

A map of campground use (see map) shows occupancy rates at the various locations. Two location factors were significantly related to use: (1) campgrounds "up north," especially at five places on major access points into the BWCA, and (2) camping areas somewhat removed or "remote" from general concentrations of people and main roads but relatively close to a few basic camper-needs (groceries, watercraft rentals, and bait shops). The location of the three camping areas which were filled beyond 80 percent of capacity shows no obvious reasons for their rates of use. One might also have expected that places closer to Duluth and the Iron Range cities would have received more intensified use because of their proximity to people and the force of convenience. This was not indicated however.

Five factors of the natural environment in and around the campground resulted in higher rates of occupancy — (1) a reputation for good fishing, (2) the presence of coniferous trees, (3) deep water offshore, (4) bedrock outcrops, and

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Figure 5.—About a quarter of the campsites were occupied at least three-fourths of the time.

) cliffs. Two attributes of the cultural environ-ent were significantly related to use: (1) mping areas with many waterfront campsites, d (2) older, well established campgrounds. he data (though statistically nonsignificant) ggested that higher rates of use were also lated to campgrounds with few campsites and ose not highly developed (without such facil-ies as a swimming beach, nature trail, picnic ound, and boat launching ramp).

ULTIPLE REGRESSION

Since many of the variables seemed inter-rrelated, they were analyzed in combination. A eighted, backward stepwise regression[4] employ-g 25 variables yielded only three which were atistically significant (0.05 level) in describing ercent occupancy: (1) the percentage of water-ont campsites, (2) the reputation of the lake stream adjacent to the campground for fish-g, and (3) the length of time the campground ad been open.

The resulting regression equations showed at these three variables accounted for 65 per-nt of the variation in occupancy among all 34 ampgrounds and 77 percent among 29 camp-grounds[5]. For the 29 campgrounds the final equation was:

$$Y = 26.82 + 6.61X_1 - 0.32X_2 + 0.47X_3{}^*$$

where,

Y = Percent occupancy for the entire survey period

X_1 = Number of fish species the water body adjacent to the campground was well known for

X_2 = Calendar year initially opened to public camping**

X_3 = Percentage of the individual campsites which were waterfront campsites.

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* *Regression was also run using an arc-sine transformation of percent occupancy with little difference in the final result.*

** *Only the last two digits of the calendar year were used in the analysis.*

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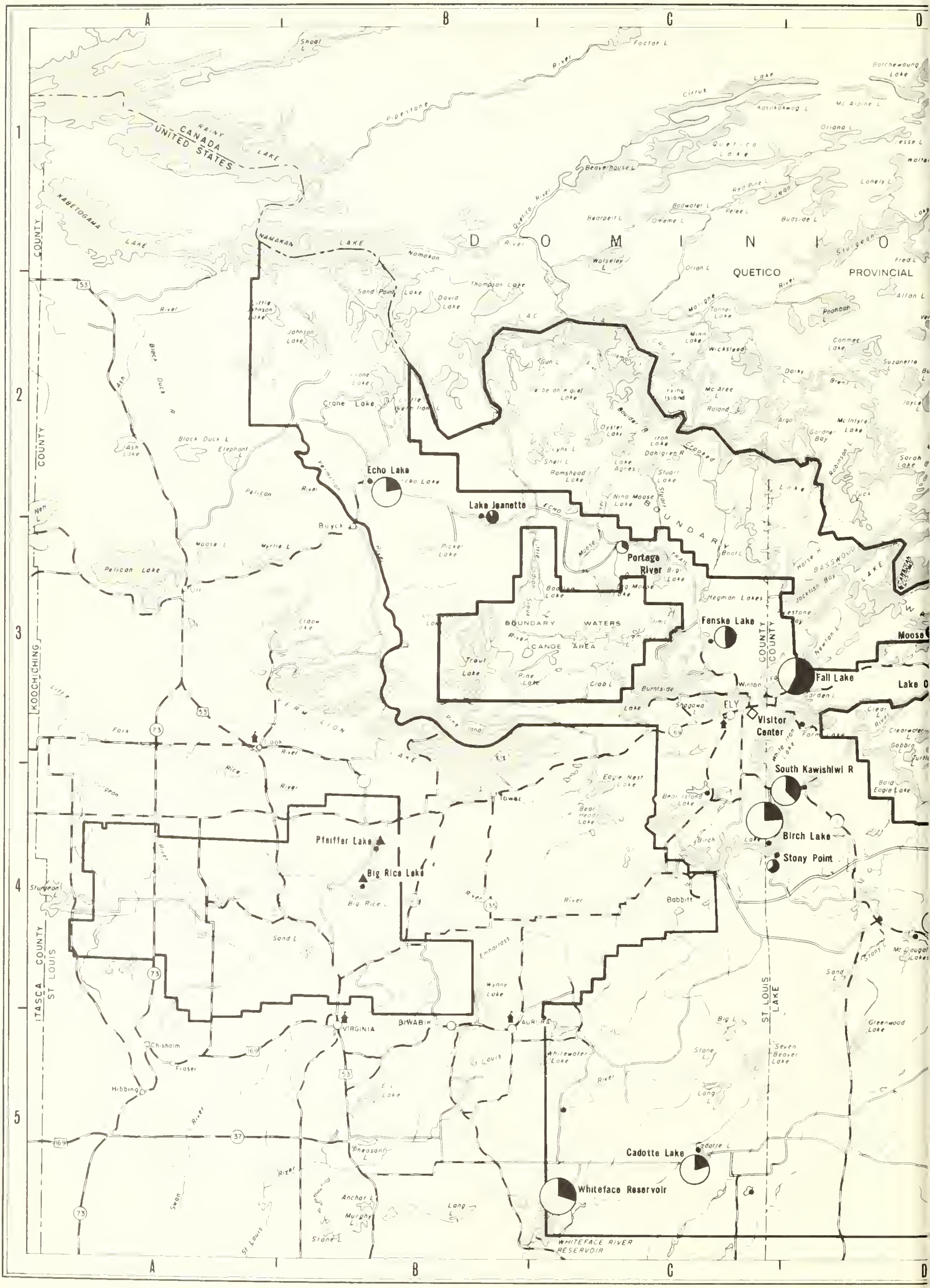
[4] *The program, UMST580 Stepwise Regres-on, deletes least significant variables one at a me based on a fixed probability level. The rogram was developed for the Control Data orporation 6600 Computer, University of Min-esota.*

[5] *Examination of scatter diagrams and simple correlations of variables suggesting possible relationships for all 34 campgrounds indicated that five of the camping areas seemed somewhat "different" in their relationships toward variables associated with greater percent occupancy. This group included those five campgrounds located on major access points into the BWCA — Moose Lake, Lake One, Trails End, Sawbill Lake, and Fall Lake. All received high use but generally did not possess many traits of other heavily used camping areas.*


A
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CANADA
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RAINY LAKE
KABETOGAMA LAKE
NAMAKAN LAKE
D O M I N I O
QUETICO
PROVINCIAL
BOUNDARY
BOUNDARY WATERS CANOE AREA
KOOCHICHING COUNTY
ITASCA COUNTY
ST LOUIS COUNTY
LAKE COUNTY
Echo Lake
Lake Jeanette
Portage River
Fenske Lake
Fall Lake
Visitor Center
ELY
South Kawishiwi R
Birch Lake
Stony Point
Pfeiffer Lake
Big Rice Lake
Cadotte Lake
Whiteface Reservoir
WHITEFACE RIVER RESERVOIR
Moose
VIRGINIA
BIWABIK
AURORA
Chisholm
Hibbing
Fraser
Babbitt
Winton
Tower
Cook
Buyck
Orr
Crane Lake
Pelican Lake
Burntside Lake
Shagawa L
Basswood Lake
Vermilion Lake
Quetico River
Pipestone River
Beaverhouse L
Thompson Lake
Sand Point Lake
Johnson Lake
Black Duck L
Elephant L
Trout Lake
Pine Lake
Crab L
Eagle Nest Lake
Bear Island Lake
Big L
Stone L
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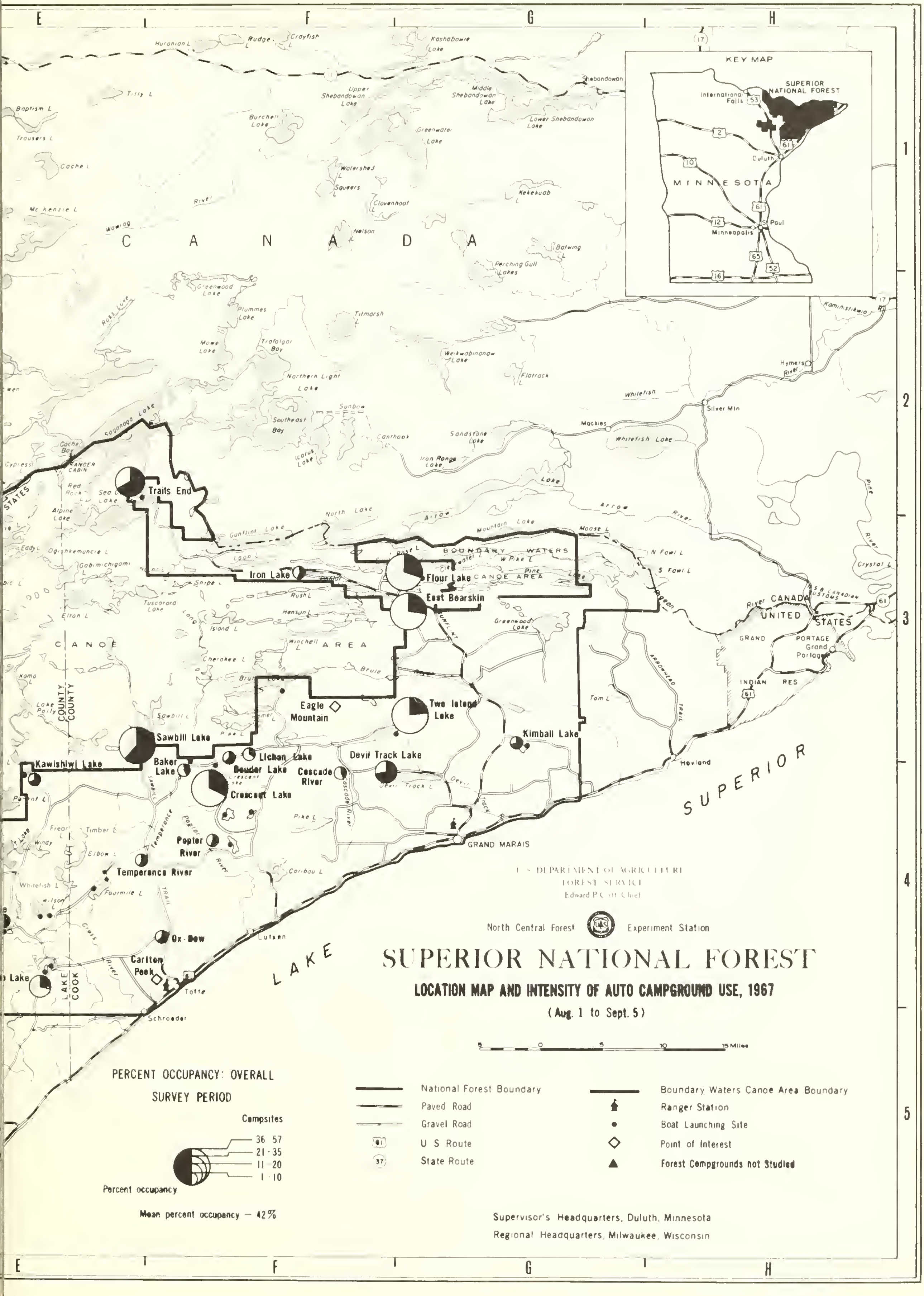
Wynne Lake
Embarrass
St Louis
Pheasant L
Anchor L
Murphy L
Stone L
Whitewater Lake


U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Edward P. Cliff, Chief
North Central Forest Experiment Station
SUPERIOR NATIONAL FOREST
LOCATION MAP AND INTENSITY OF AUTO CAMPGROUND USE, 1967
(Aug. 1 to Sept. 5)
5 0 5 10 15 Miles
PERCENT OCCUPANCY: OVERALL SURVEY PERIOD
Campsites
36-57
21-35
11-20
1-10
Percent occupancy
Mean percent occupancy — 42%
National Forest Boundary
Paved Road
Gravel Road
U S Route
State Route
Boundary Waters Canoe Area Boundary
Ranger Station
Boat Launching Site
Point of Interest
Forest Campgrounds not Studied
Supervisor's Headquarters, Duluth, Minnesota
Regional Headquarters, Milwaukee, Wisconsin
KEY MAP
SUPERIOR NATIONAL FOREST
International Falls
Duluth
MINNESOTA
St. Paul
Minneapolis
CANADA
UNITED STATES
BOUNDARY WATERS CANOE AREA
LAKE SUPERIOR
Traits End
Iron Lake
Flour Lake
East Bearskin
Two Island Lake
Eagle Mountain
Kimball Lake
Sawbill Lake
Kawishiwi Lake
Baker Lake
Lichen Lake
Bouder Lake
Crescent Lake
Cascade River
Devil Track Lake
Poplar River
Temperance River
Ox-Bow
Carlton Peak
GRAND MARAIS
Lutsen
Tofte
Schroeder
Hovland
Grand Portage
GRAND PORTAGE INDIAN RES
Silver Mtn
Hymers
Shebandowan
Gunflint Lake
Saganaga Lake
COOK COUNTY
LAKE COUNTY

The multiple correlation coefficient (R) was 0.88. Analysis of variance showed significance beyond the 0.01 level. The resulting $R^2 = 0.77$, indicated that 77 percent of the variance in percent occupancy of the 29 camping areas was predictable from these three campground attributes. Each independent variable was statistically significant at the 0.05 level with percentage of waterfront campsites also significant at the 0.01 level.

The percentage of waterfront campsites was by far the most useful predictor in the model. This is seen in the tabulation below of the percent contribution of each variable to the variance in percent occupancy (Harp 1967).

Variable	*Contribution Percent*
Percentage of waterfront campsites	84.16
Number of fish species water body was well known for	8.19
Calendar year initially opened to public camping	7.65
Total	100.00

Although the added effect of the other two attributes was statistically significant, their contribution was small. In fact, when the percentage of waterfront campsites was considered alone, it accounted for 65 percent of the variation in percent occupancy between campgrounds. The statistical significance of water as an attraction of campgrounds is consistent with other studies (Beardsley 1967, Shafer and Thompson 1968, Lucas 1970).

The pattern of residuals from the regression equation was examined to see if any other attributes could be identified which were associated with percent occupancy. Camping areas were thus pinpointed which had rates of usage not reasonably representative of campground characteristics employed in the model. No common attribute that was measured helped to explain why these places received unpredictable use.

Because most of the variables originally considered did not ultimately contribute to the prediction of occupancy does not mean that they might not have been useful if measured or scaled in other ways. Also, specific values for some of the variables had little range among campgrounds. Undoubtedly, there are esthetic and other elements of the environment which have been overlooked or cannot be readily measured or classified. Perhaps some scale of "campground remoteness" would have been useful in which various elements of distance and level of campground development could have been incorporated.

The Campground Selection Process

Although the previous analysis was a useful method for identifying campground attributes that were associated with rates of occupancy, it must be remembered that they may not be the cause of why people went where they did to camp. Many campers, for example, may select a place to camp because of other reasons. To better understand the processes of selection behavior, campers were asked to discuss why they chose one campground rather than another.

The basic question asked of campers was: Why did you choose to camp in this campground rather than some other campground in the Superior National Forest? Probing was directed to answering morespecific questions. Which factors, if any, of the site and its location affected your decision? What other factors are important? These may include haphazard search or chance, word-of-mouth communication, and habit – returning to the same place.

Additional questioning sought to identify visitors' previous camping experience, knowledge of alternative campgrounds, degree of trip planning, sources of information about campgrounds, place of residence, preferences for individual campsites in a campground, and preference for campground size.

BACKGROUND OF CAMPERS

The results showed that most visitors had planned their outing in advance and nearly all knew *where* they were going as well as *why*. Many campers had previous experience with the recreation opportunities of northeastern Minnesota. Eighty-nine percent of all campers had been in the area before; 65 percent had auto camped in the Superior National Forest before; and, 48 percent of all parties had previously visited the campground in which they were interviewed.

Visitors were fairly well informed about the ailability of other campgrounds in the Forest, t there were notable exceptions. The mean mber of campgrounds they were familiar with is eight. Twenty-nine percent of the campers re aware of more than 10 locations while 31 rcent were familiar with three or fewer places.

Perhaps surprising, 80 percent of all camps (97 and 78 percent, respectively, for weekders and vacationers[6]) selected a campground *fore* they left home. For 78 percent of all mpers, the particular camping area in which ey were interviewed was their main destinan.

Parties also were asked if they had considered y alternative destinations in the process of ecting a campground. Thirty-seven percent d, and most (74 percent) of this group had nsidered only one or two other locations.

Forest Service literature and personnel were t particularly influential in assisting people d a campground (table 2). As some other idies have shown, word-of-mouth advertising d "we just saw the sign and pulled in" were e principal ways campers found out about e camping area in which they were interewed.

able 2.—Response of campers to "How did you first learn about this campground?"

Answer	Respondents	
	Number	Percent
Interpersonal Communication		
Friends or acquaintances	93	38
Forest Service personnel	15	6
Local businessmen	20	8
Printed Literature		
Forest Service recreation map	30	12
Campground atlas or directory	18	7
Gasoline company road map	11	4
Local chamber of commerce map or county recreation map	4	2
Other Reasons		
Saw entrance sign and pulled in	42	17
Live or have lived nearby, familiar with the area	8	3
Don't remember	3	1
All other reasons	4	2
Total	248	100

[6] *Vacationers differed from weekenders in that ey were on extended trips of more than 2 ys.*

Home for most of the campers was not northeastern Minnesota. Sixty-six percent were from Minnesota (of this total, over 64 percent were from the Twin Cities metropolitan area), with Illinois the second most popular State (17 percent). Campers traveled an average of 382 miles from their places of residence — 420 miles and 140 miles respectively for vacationers and weekenders.

REASONS FOR CHOOSING A CAMPGROUND

Basic data were obtained from open-ended questions in which respondents were asked to explain why they had selected that particular campground. Campers were given ample time to state freely any factors which came to mind. They were then asked to identify the three most important reasons from among all those mentioned (table 3).

Reasons in the locational category were varied. The importance of being close to other recreation attractions largely reflected campers' desires for being near lakes and streams for fishing, boating, and canoeing. Accessibility reasons were equally divided between a desire for remoteness and easy access. On the whole, few campers chose a place because it was close to home or to stores.

Fishing was the element of the natural environment reported most often by campers (fig. 6). Campsites, both in sight of water (waterfront), and well screened from neighbors, were the most frequently noted cultural aspects. A recent onsite survey of Adirondack campers identified the importance of campsites near the water (Shafer 1969). Lucas' (1970) survey of National Forest campers in Michigan found that visitors prefer well-spaced campsites.

In the human-related category, the feeling of wilderness or uncrowdedness ranked first followed by interpersonal communication (advice from acquaintances or local businessmen). Although the type of outdoor environment that campers were seeking was classified as a human-related reason it also may involve each of the other three categories of reasons (locational, natural, and cultural). Wilderness and uncrowdedness could be applied to: places well removed from major highways and towns, camping areas farther "up north," especially scenic settings,

Table 3.—Response of campers to "Among all the reasons you mentioned, what are the three most important reasons you chose this campground?"

Type of reason	User category		
	Vacationers N = 214	Weekenders N = 34	All campers N = 248
	Percent	Percent	Percent
Locational			
Accessibility (either remoteness or proximity to roads or travel route)	18	6	16
Nearness to services 1/	10	0	8
Nearness to primary residence 2/	3	29	7
Nearness to other recreation attractions	19	26	20
Natural Environment			
Vegetation (tree cover)	1	0	1
Fishing quality 1/	40	62	42
Wildlife	1	9	2
Geography of surroundings (terrain, water body) 1/	16	3	14
General scenery	5	3	4
Cultural Environment			
Facilities--comfort-based (drinking water, toilets)	7	0	6
Facilities--activity-based (swimming beach, nature trail) 1/	7	18	9
Absence of a fee	2	0	2
Campsite design--view of water	14	12	13
Campsite design--campsite quality (privacy, size, parking space)	14	15	14
Number of campsites	9	0	8
Human-related			
Type of outdoor atmosphere sought (wilderness and/or uncrowdedness)	29	29	29
Interpersonal communication	20	15	19
Unplanned circumstances	10	6	9
Nearness to persons visiting in area	5	3	4
Habit	8	9	8
Lack of awareness of other campgrounds	8	3	7
All others	1	0	1

1/ Chi-square test indicates differences among vacationers and weekenders significant at 0.05 level.

2/ Vacationers differed significantly from weekenders at the 0.001 level.

F-520782

Figure 6.—The opportunity for fishing was the most frequently reported reason campers gave for choosing a particular campground.

locations with a low level of development, small campgrounds, and individual campsites were screened from neighbors.

WEEKENDERS ARE DIFFERENT FROM VACATIONERS

There were few interviews with weekenders (34 of 248 interviews) because most of the campground use was from vacationers. These few interviews with weekenders weaken statistical comparisons with vacationers but some trends are evident, however (table 3). As anticipated, weekenders more frequently reported the convenience of a campground's location to their home as important. They cared little for being near services but did indicate a greater concern for finding a camping area with a swimming beach. Fishing also rated higher with weekenders

Vacationers gave many of the same reasons weekenders, but differed in wanting to be ɔse to paved roads and stores. However, most mping parties on an extended stay came well pplied with the basic necessities for the dura- ɔn of their visit. Vacationers also more fre- ıently noted aspects of the geography of the rrounding area than did weekenders — par- :ularly lake characteristics and the potential r visiting a chain of lakes without portaging.

ɔUR TYPES OF SELECTION MONG VACATIONERS

Vacationers (214 interviews) were studied to tegorize campers on the basis of how they lected a campground. Campers were grouped / their awareness of the camping alternatives the Forest. Four groups were identified.

1. The *haphazard* group (19 percent) planned e least in selecting campgrounds, were familiar th only a few alternatives, and had only limited mping experience in the Forest. Selection of campground was attributed either to unplanned rcumstances, or a general lack of awareness of ternative campgrounds.

2. The *experienced* group (44 percent), ex- nsively planned their selection, displayed con- derable camping experience, and were the most miliar with alternative sites. In selecting a ımping area, they were the most discriminating the four groups. As such, they showed greater vareness of the campground resources and con- quently had the most definitive motives for ıeir selections.

3. The *inexperienced* group (27 percent) ere newcomers to the Forest. They had little ıowledge of other places, but many planned ıeir selection. Their campground choices were rongly affected by the knowledge and advice others. Because of this their reasons were milar to those of the experienced group.

4. The *habitual* group (10 percent) was ɔmewhat less familiar with other places than ıe experienced choosers. They had made the ost trips to the Forest of any group, however, ıd repeatedly came back to the same place. lthough they had thoroughly planned their se- ction and reported clearcut reasons for them, ıeir motives were less well defined compared ɔ the experienced group.

Validation by Campers of Factors From Distribution of Use Analysis

In this section an attempt is made to determine if the factors from the distribution of use analysis actually explained why recreationists went where they did. All 248 interviews were treated as a group since the distribution of use analysis in 1967 was based on aggregate use during the entire survey period.

WATERFRONT CAMPSITES

The importance of a waterfront campsite from the multiple regression analysis was borne out by the interviews. Campers emphatically supported a desire to camp within sight of a water body (waterfront) when asked, "If none of the sites had been occupied when you first arrived, which one would you have selected, and why?" Obtaining a waterfront campsite was by far the most common reason for selecting a campsite (table 4). Seventy-seven percent of all campers who selected some campsite mentioned this aspect of campground design. Only 14 parties had no preference for a campsite.

Table 4.—Response of campers who had a preference for a campsite to "If none of the sites had been occupied when you first arrived, what would be the reasons for your selection?"

Type of reason	Respondents
	Percent[1/]
Campsite design--near the waterfront	77
Campsite design--site-area quality (size, aspect, level)	31
Campsite design--screening (people, noise, prevailing winds, dust, shade)	24
Facilities--comfort-based (close to wood, toilets, drinking water)	15
Campsite design--spur quality (level, wide, long)	10
Facilities--activity-based (close to beach or launching ramp)	8
Habit, used this campsite more often in past than others	4
Bedrock, boulders, falls, or rapids present	3
Large trees present	2
Terrain characteristics	2
Shoreline characteristics	1
Type of trees predominating (pine or birch)	1
Potential for seeing wildlife	1

1/ Of the 234 respondents, many gave more than one reason.

Ninety-one percent of the campers who preferred a waterfront site did so because of the view (fig. 7). Many also wanted a watercraft

F-502645

Figure 7.—Many campers said they preferred to camp close to the water. Nearly all of them gave "the view" as the reason.

close to their camp for easy access. Others liked the openness of such campsites and indicated that this permitted breezes to act as a partial insect control.

It is interesting to speculate why so many campers noted the view of the water as a desirable feature in selecting a campsite. One answer might be that large differences in local relief are not common in northeastern Minnesota. Also, most of the area is heavily forested. Therefore, the visitor has few opportunities to obtain a sense of space or perceive distance, aside from those views afforded by the presence of water. Although considerable research has documented the lure of water as an attraction for water-based activities, little evidence is available to suggest what it is about the visual aspects of water that appeals to people.

Some parties rejected a campground eithe because all available waterfront campsites wer filled, or they had been to the camping are before and knew it had few such sites. Thirty seven percent of all campers rejected a camp ground on this trip. Of these, 24 percent reporte that the lack of a waterfront campsite was im portant in their decision.

Waterfront campsites may cease to be a effective indicator of occupancy if use in th Forest increases to the point where there are no enough of these campsites to fill the demand Less than half of the Forest's campsites ar classified as waterfront sites (301 of 647). I the 1967 use survey, waterfront sites average 60 percent occupancy compared to 25 percen for other sites.

SHING OPPORTUNITIES

Visitors to northeastern Minnesota placed eat emphasis on fishing as an attraction of the ea and its campgrounds. However, the impor- nce of fishing as found in the distribution of e analysis was not validated by camper inter- ews. Campers' reasons for choosing a camp- ound were compared for locations that were nown" for fishing versus those that were not. *both* instances, fishing was the most frequent- reported reason for picking that particular mpground among all reasons noted.

Although fishing quality was influential as reason why campers went to heavily used aces, it similarly was important to campers io went to lightly used places. The fact that th camper groups stressed the importance of hing in their selection is probably explained part by the fact that *all* of the water bodies jacent to the campgrounds had *some* fishing tential. Moreover, due to the relatively high vel of experience of campers, many of them obably knew of "hot spots" in some of the iters which had been classified as "not well iown for fishing."

MPGROUND AGE

The length of time that a camping area had en open to the public was significant in edicting the intensity of campground use, but e users themselves did not say that it was portant to them. The relationship between e year it was opened and the percentage of mpers who were familiar with each location is determined. Although there was a slight ndency for campers to be somewhat more miliar with older places, the relationship was t statistically significant. In other words, the ta did not support the contention that older mpgrounds generated greater word-of-mouth vertisement and subsequently produced a eater intensity of use.

As with the fishing variable, the age of the mpground (year opened) made a statistically gnificant contribution to the explained vari- ce; yet this contribution was relatively small. pparently, it was largely a chance occurrence chance in 20) that several older facilities ceived unusually intensive occupancy during e survey period.

NEARNESS OF CAMPGROUNDS TO THE BOUNDARY WATERS CANOE AREA

The use analysis indicated that camping areas farther north in the Forest received more intensive use, especially those on access points into the Boundary Waters Canoe Area. But interviews at 10 such locations showed that substantial numbers of the parties apparently had no great motivation to be there. Many felt that they had been in "the wilderness" some time before reaching its administrative boundary. For the most part they were day-users and their penetration into the BWCA was not deep. Many of these parties could have obtained a "wilder-ness" experience (for them) in developed camp-ing areas not adjacent to the BWCA. If recrea-tional opportunities in other parts of the Forest were better known to them, many of them could be satisfied elsewhere (Lime 1969a).

CONIFER TREES

Some researchers have hypothetized that the type of trees may influence where people go to recreate (Frissell and Duncan 1965, Klukas and Duncan 1967). Although conifer tree cover was significantly associated with a higher intensity of campground use, there was little evidence that this or any other type of vegetation actually influenced visitors' choices (table 4). Most campers were primarily concerned with being able to see the water, having a spacious and level site, and being well screened from neighbors.

CAMPGROUND SIZE

Generally, small campgrounds were more in-tensively used than large ones but the relation-ship was not strong. Of the campers who men-tioned size as a reason for selecting a particular camping area, most preferred a small one with fewer than 15 campsites (table 3).

Campers were asked how many camping spots would be ideal in a campground providing they did not have to worry about getting one. Only 10 percent felt that size was not important to them and that any size would be fine. A large proportion (43 percent) stated that size was not really important as long as the campsites were well spaced, screened, and reasonably pri-vate from one another. About an equal number (47 percent) felt that campgrounds should not have more than 20 or 25 campsites. Most of these campers also thought that campsites should be well spaced and reasonably private (fig. 8). This diversity of desires regarding campground size has been shown by others (Lucas 1970, Wagar 1963).

F-520785

Figure 8.—The majority of campers felt that individual campsites should be well spaced, screened and reasonably private from one another.

IMPLICATIONS FOR MANAGEMENT

Results from earlier studies indicate many similarities regarding the use of auto campgrounds) Burch 1964, Love 1964, Beardsley 1967, Shafer and Thompson 1968, Shafer 1969, Cordell and Sykes 1969, Lucas 1970). These include the wide disparity in use both among and within camping areas, the importance of scenery or landscape variability, the significance of water as an attraction, some caution in overexpanding campgrounds, the essential role of diversity in campground planning and development, the attraction of spacing and privacy between individual campsites, and the dominance of word-of-mouth advertising.

Although the Forest Service is apparentl satisfying most of their auto campground clien tele, several findings point out promising area for policy change or reevaluation of managemen goals.

At present it appears that simply locating campground adjacent to a lake or stream i northeastern Minnesota is not enough; visitors desires for a view of the water from their camp site are legitimate and real indeed. This call for a compromise in campground planning; t preserve and protect the lakeshore and at th same time provide users with a view of the wate This can be done by judicious placement o campsites in which topography and vegetatio thinning techniques are given adequate attentio in landscape design.

There is a definite need to provide a variety of different sized campgrounds. Although ther was acceptance by many visitors for large facilities, provided measures are taken to ensure reasonable degree of privacy between individua units, there also was support for small places a well (less than 20 or 25 campsites). It would appear to be a mistake not to include both type of campgrounds in management's overall pla for future development.

Forest Service literature has had only a mino influence on how campers found out about various campgrounds. More information in the campgrounds giving the location of other camping areas, policies and regulations, and the locatio of nearby services and recreation attractions probably would be appreciated by many visitors Maps of the Forest are provided in campgrounds where a fee is collected, for example, but othe distribution schemes could be devised.

Efforts might also be expanded to distribute more information through several communication media — the State of Minnesota, chambers of commerce, local businessmen, radio and television stations, and others. Such efforts might help distribute use more evenly among facilities and enhance satisfaction by making campers more aware of what was available elsewhere to meet their needs and desires.

The study showed that substantial numbers of campers in campgrounds on the periphery of the BWCA had no great motivation to enter the canoe country at all. As visitor numbers grow in this unique area, management may need to nit use. One way is to direct some visitors ay from its borders to other locations in the rest.

The desire to see this National Forest left d or wilderness-like was emphasized by many itors. Only a very few wanted to see these mpgrounds become modernized (flush toilets, nning water, or electricity) or highly developed vimming beaches, concessions, or play- ounds.)

DIRECTION OF FUTURE RESEARCH

These findings cannot adequately describe tterns of use or perceptions of visitors for all ner periods of use — the spring fishing season fall fishing and hunting seasons, for instance. e manner of use during other seasons is po- ntially very different from that observed during e summer. Generalizations concerning the year ound camping social system would be a mis- ke and should be reserved until additional ormation is forthcoming. The results are es- cially relevant for the summer, however, be- use the study period covered August, the *peak* the camping season. It is for this crucial heavy e period that planning and development of mpgrounds should be designed.

The findings of this study cannot necessarily applied to other National Forests. However, e methodology and some of the assumptions ployed could be tested in additional situa- ns. A logical next step would be to test these earch techniques and to compare the results this study with studies on the other seven tional Forests in the Lake States (Michigan, sconsin, and Minnesota).

Now that some insight has been obtained out how people select a camping area, all e campgrounds in the Forest could be studied more detail. This would permit an analysis campground use based on types of users ther than an aggregate use alone. In this y it would be possible to determine if certain egories of people go to certain kinds of camp- ounds and how this affects the distribution of e among campgrounds. For example, did camp- s who were influenced by the advice of other ople induce higher rates of use at some loca- ns?

Another important question is how stable are patterns of use from year to year? This research and Lucas' (1964) indicate that they are stable, but patterns of use could be updated at regular time intervals to see if present trends continue.

Analysis of trends could also be continued to determine the degree to which people's motives and attitudes change over time. Campers should be segregated into meaningful user groups — weekenders versus vacationers, by type of sleeping accommodations, by type of choosers, and perhaps others.

The influence of other peoples' advice on patterns of use and user satisfaction deserves more study. Is the flow of information between the informant and the potential user accurate and satisfying? What did the informant not tell him about the facility that he would like to have known? Was he informed about only one place or about several alternatives?

A better understanding of "habit" as an influence on leisure-time behavior would be desirable. It might have influenced action in some people more than they realized or would readily admit. Drawing this reason out of people might take more probing than simply asking them to explain why they went where they did to camp.

The influence of road signs on patterns of use is another topic which could be explored. Recent research has suggested that signs do make a difference in where people go to recreate but definitive conclusions are lacking (Brown and Hunt 1969).

Research designed to thoroughly evaluate the desirability and potential for establishing visitor information centers in selected metropolitan areas would also be beneficial. Urban information centers could assist visitors in more efficient trip planning and achieve more uniform use patterns among campgrounds.

Another unanswered question relates to the distribution of visitors *within* campgrounds. Why are some campsites in a campground much more intensively used than others? Obviously, the drawing power of a campground per se is closely related to the drawing power or attractiveness of its individual campsites. The importance of individual units on patterns of use has been paramount in this study, but additional probing would be desirable.

How prevalent is "noncampground" camping, and why do people camp in places other than the Forest's maintained campgrounds? Frequently they just pull off on the shoulder along a gravel road. Others congregate at the end of dead-end roads or in parking lots at boat launching sites. How do these visitors "fit" into the camping social system of the Superior National Forest?

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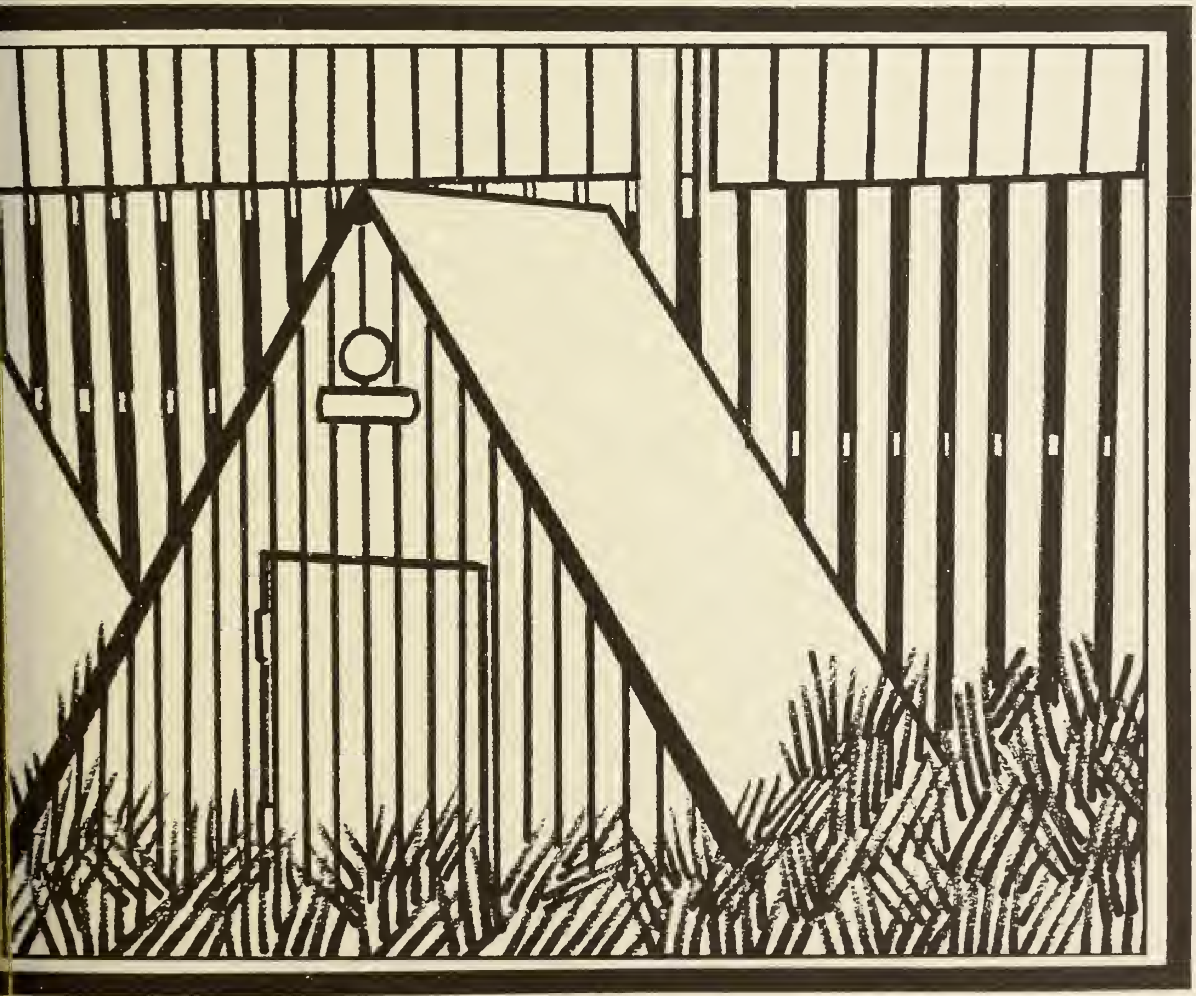
the CHANGING MARKET for wood materials used in farm structures

AVID C. BAUMGARTNER



ITH CENTRAL FOREST EXPERIMENT STATION
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CONTENTS

HE CHANGING MARKET FOR WOOD MATERIALS USED IN FARM STRUCTURES

David C. Baumgartner

The volume of lumber used in farm building nstruction declined from 4.5 billion board feet 1952 to 2 billion board in 1962.[1] This much ecline in a traditionally large market for lumber is been attributed to several factors, including reduction in the number of farm buildings nstructed annually, changes in building con-ruction types, and the substitution of other ood and nonwood products for lumber (table 1).

able 1.—Lumber, plywood, and veneer consumed in farm structures, 1952-1962[1]

ear	Lumber		Plywood and veneer	
	Volume	Use per dollar[2/] of expenditure	Volume used	Use per dollar of expenditure
	Million board-ft.	Board-ft.	Million sq. ft. 3/8-inch basis	Sq. ft. 3/8-inch basis
952	4,500	2.47	--	--
962	2,000	1.41	210	0.15

1/ Includes farm service buildings and structures; excludes wellings. Source: USDA Forest Serv., Forest Resource Rep. 17, 35 p. 1965.
2/ 1961 dollars.

In 1949 over 800,000 new farm service build-ngs were constructed (see footnote 1), whereas uring the agriculture census survey years 1958-160 about 194,000 were built annually, exclud-ng dwellings and silos. During the census survey years 1963-1965, the average number constructed had declined further to 160,666 per year. Although about 17 percent fewer buildings were built during the 1965 survey period than in the 1960 period, the average size of all new farm service buildings (excluding silos and grain storage buildings) increased from 1,590 square feet to 1,775, or about 11.5 percent.[2]

Changes in the type of structures needed on the larger, more specialized, modern farms have also contributed to the decline in lumber use. Examples are the increase in construction of pole type barns with metal roofs and siding and hog confinement buildings built primarily of metal and concrete.

The increasing subsitution of plywood, building board, and nonwood materials has also caused a decline in lumber consumption. The importance of this substitution effect can be emphasized by the fact that investment in farm buildings, expressed as a percentage of gross farm product, has been a fairly stable long-term function and is expected to continue as such (table 2).

Significant changes in farm building construction and materials use have taken place during the last two decades. To gain insight into the future use of wood in this sector of the construction industry, this farm structures study was undertaken.

[1] *U. S. Department of Agriculture, Forest Serv.e. Timber Trends in the United States. USDA Frest Ser., Forest Resource Rep. 17, 235 p. 1:65.*

[2] *U. S. Dep. of Commerce, Suppl. 1, 1964 Census of Agriculture, III, Part 3. Sample Survey of Agriculture 1969.*

Table 2.—Farm output and construction expenditures, 1920-1962[1] and projections, 1970-2000.

(1960 dollars)

Period or year	Gross farm product (GFP)	Construction expenditures[2/] Total	New structures	Repairs	Construction expenditures as a percent of GFP
	Million dollars	Million dollars	Million dollars	Million dollars	Percent
1920-29[3/]	14,800	920	480	440	6.2
1930-39[3/]	15,600	620	210	410	4.0
1940-49[3/]	17,800	1,060	620	440	6.0
1950-59[3/]	19,200	1,540	1,040	500	8.0
1960	20,900	1,310	890	420	6.3
1961	21,400	1,470	980	490	6.9
1962	21,600	1,420	950	470	6.6
1970	23,500	1,530	1,060	470	6.5
1980	25,800	1,680	1,160	520	6.5
1990	28,500	1,850	1,280	570	6.5
2000	31,500	2,050	1,420	630	6.5

1/ Source: USDA Forest Serv., Forest Resource Rep. 17, 235 p. 1965.

2/ Includes farm service buildings and structures; excludes dwellings.

3/ Data shown are annual averages for the decade.

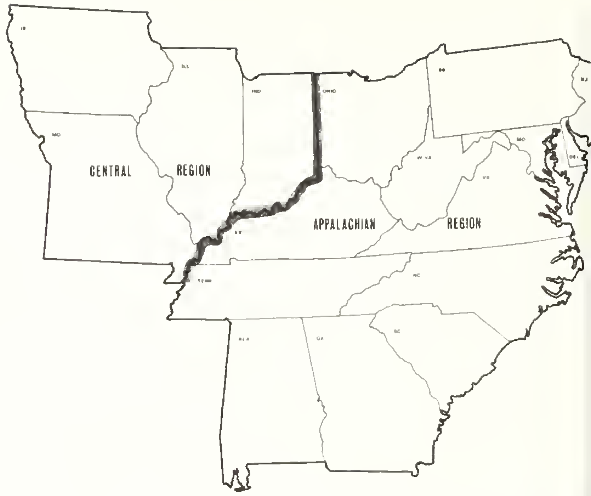


Figure 1.—Seventeen-State study area includir the Central and Appalachian Regions.

THE STUDY

During the summer of 1966, the Forest Service in cooperation with Doane Agriculture Service conducted a study of farm building construction activities for the years 1963 through 1965. The study included a sample of commercial farms[3] in the Central and Appalachian Regions of the United States (fig. 1). Questionnaires were mailed to all 1,600 members of the Doane Farm Panel, which is carefully selected by stratified sampling techniques to represent the commercial farm market. The panel is periodically checked and rebalanced on the basis of the Census of Agriculture. To insure that the panel is properly maintained, annual characteristic surveys are conducted and checks of reporting accuracy are made regularly.

Results from 1,348 usable questionnaires, obtained from farmers in the 17-State area, are presented in three general divisions: permanent buildings, farm building repair, and portable structures.

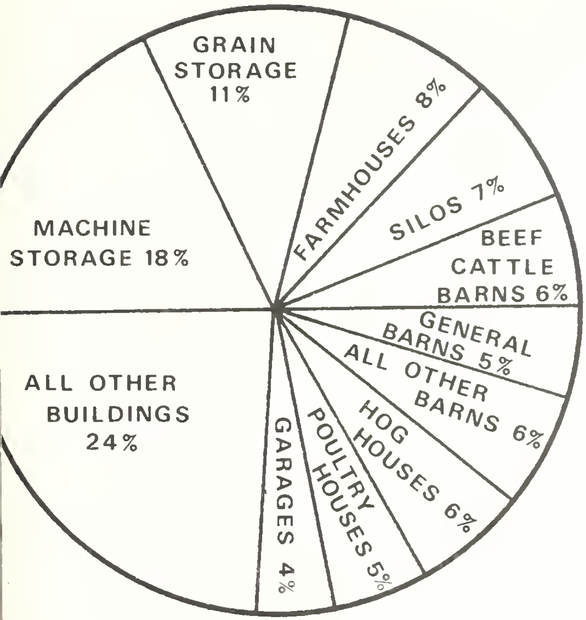
[3] *Commercial farms are defined for this study as farms having total farm products sales of $2,500 or more in 1964.*

PERMANENT BUILDINGS

Number and Type of Buildings

During the 3-year study period, 247,000 ne permanent farm buildings were constructed wit in the 17-State study area — 131,000 were bui in the Central Region and 116,000 in the App lachian Region. The survey classified 25 bas types of permanent farm buildings according 4 basic frame construction types. Under ea frame type, several types of exterior wall co struction materials were listed.

In the entire 17-State area, grain stora and machine storage buildings were the mo frequently constructed types, accounting f about 29 percent of all new buildings (fig. 2 Farmhouses were third, accounting for 8 pe cent of all new construction, but no other ty accounted for more than 7 percent of the tot buildings. Machine storage buildings account for high percentages in both the Central (percent) and Appalachian (16 percent) Regior Grain storage buildings, however, accounted f 17 percent in the Central Region, as opposed only 4 percent in the Appalachian Region. Th difference in the number of grain stora



ure 2.—Percentage of buildings in general categories.

ldings was offset by a much higher percent- of poultry houses in the Appalachian Re- ı, other types of structures accounting for ilar percentages in both regions. General ns, beef cattle barns, silos, and corn cribs each ounted for slightly more than 5 percent of total.

Poultry houses had the largest floor area of building types constructed. They averaged rly 2,700 square feet of floor area in the ıtral Region and over 4,800 square feet in the palachian. Broiler houses (all built in the Ap- ıchian Region) averaged over 12,000 square . General barns, beef cattle barns, and dairy ns were the next largest types, each averaging ween 2,000 and 2,500 square feet in both ons.

Frame and Wall Construction

In the 17-State area, six basic frame-exterior combinations predominate. They are shown ollows:

Frame type	*Exterior wall type*	*Percent of all buildings*
Lumber	Lumber	24
Wood pole	Metal	16
Metal	Metal	13
Masonry	Concrete block	13
Lumber	Metal	11
Wood pole	Lumber	9
Six most popular types		86
Thirteen other types		14
		100

Buildings with both frame and exterior walls made of lumber were still the most common type, but metal was the predominant exterior wall material when all frame types were considered – 41 percent of all new buildings had metal exterior walls. Of the two most popular building types, more than three-fourths of the grain storage buildings were made entirely of metal and another 10 percent had metal exterior walls. Machine storage buildings (fig. 3) were largely of lumber or wood pole frame, with exteriors evenly divided between wood and metal. The Central Region had more wood pole-metal, all metal, and lumber-metal buildings; the Appalachian Region had more all-lumber, masonry-concrete, and wood pole-lumber buildings.

Figure 3.—Machine storage building with wood-pole frame and metal exterior walls. (Photo courtesy of University of Illinois, Department of Agricultural Engineering)

Source of Building Plans

Fifty-eight percent of the new buildings were built from the farm operator's own plans. Building materials dealers supplied about 13 percent of the plans and university extension services supplied 9 percent. Manufacturers, professional architects, and local contractors provided 16 percent of the plans. This response may be misleading since it was impossible to tell where farmers acquired their ideas for their "own" plans, or where plans from dealers and contractors originated. Grain storage buildings and silos were the least likely to be built from the farm operator's own plans. Farmhouses, dairy cattle barns, milk parlors, poultry brooder and broiler houses, and hay storage buildings were also less likely to be designed by the farm operator himself.

Builders

Nearly 40 percent of the new buildings in the 17-State area were built by someone other than the farmer himself. Independent contractors constructed nearly one-fourth of all buildings and building materials dealers 13 percent. More recent estimates[4] suggest that the percentage built by persons other than the farm operator himself may be much higher now than during the survey years. About 10 percent more buildings were built by the farm operator in the Appalachian Region than in the Central Region. Poultry broiler and brooder houses, silos, milk parlors, farmhouses, and grain storage buildings were the least likely to be constructed by farm operators.

Form of Wood Materials Used

Nearly three-fourths of the wood materials used in new farm buildings were purchased in unassembled and uncut form. About 7 percent of the wood was purchased precut and only about 5 percent (mainly roof trusses) in prefabricated form. Regional differences in the form of woo used were not large. Poultry brooder and broile houses were the most frequent users of prefabri cated wood components. More than 23 percen of the brooder houses had prefabricated roo trusses and about 8 percent had both wall panel and roof panels prefabricated. About 39 percen of the broiler houses had prefabricated roo trusses. Farmhouses, sheep barns, hay storage machine storage, and utility buildings were th other major users of prefabricated wood com ponents.

[4] *Farm Building News*, p. 8, November 1969.

Sources of Wood Materials

Lumberyards provided the wood materials fo about 42 percent of all buildings constructed i the 17-State area, and sawmills for about 2 percent. In the Appalachian Region, about one third of the new buildings were constructed wit wood obtained from sawmills as compared t only 6 percent in the Central Region. This wa probably due to the availability of softwoo lumber at local mills in the Appalachian Regio Contractors supplied the wood materials for percent of the buildings and about 4 percen used wood cut on the farm. About one-fifth the new buildings contained no wood.

FARM BUILDING REPAIRS

In addition to the new buildings construct in the 17-State area, an estimated total of 19 000 existing buildings were repaired or remodel during the 3-year period. Only those repair jo involving a materials cost of $100 or more a included in this total. Nearly two-fifths of t buildings repaired were farmhouses. Gener barns accounted for 16 percent of buildings r paired and dairy barns for 7 percent. Poult laying houses and corn cribs were the only oth building types accounting for as much as 5 pe cent of all repair jobs. About 10 percent mo repair jobs were reported in the Appalachi Region, although the Central Region reported larger number of new buildings. The followi tabulation shows the combinations of materi used in repair jobs and their frequency of u in the 17-State area.

	Percent frequency
Lumber only	25
Metal and Lumber	24
Lumber and plywood	17
Metal only	7
Metal and plywood	5
All other combinations	22
	100

Regional differences in materials used in epairs were very minor.

PORTABLE STRUCTURES

Number and Type of Structures

Portable structures also represent an impor-ant segment of farm building construction. More than 1.3 million portable structures were dded in the 17 States during the 3-year study eriod. Approximately one-half of these struc-ures were purchased as ready-made units. Struc-ures used for hogs (473,000), and for poultry 468,000), accounted for over 70 percent of the otal (fig. 4). Most of the poultry structures, owever, were feeders and laying nests which are ery small. Among the hog structures, self feed-rs, troughs, "A" and shed-type houses (fig. 5), nd farrowing crates all accounted for large num-ers. Nearly twice as many hog structures were dded in the Central Region as in the Appala-hian, while the Appalacian Region had nearly all f the poultry portables. Other portable struc-ures included 123,000 cattle structures, 17,000 heep structures, and 221,000 miscellaneous tructures (mainly gates).

Materials Used in Portable Structures

Structures made entirely of metal or entirely of lumber occurred in equal numbers and ac-counted for over 80 percent of all the portables. Combinations of metal and lumber were used for 12 percent and lumber and plywood for 5 percent. Metal was the most popular material for hog feeders and farrowing crates, and poultry feeders and brooders. Nearly all (94 percent) of the metal structures were fabricated before pur-chase. Lumber was the predominate material used for hog houses, troughs, feeding stalls and loading chutes, sheep shelters, poultry laying nests, cattle feeders and loading chutes, and truck racks. About 87 percent of the "lumber only" structures were built on the farm.

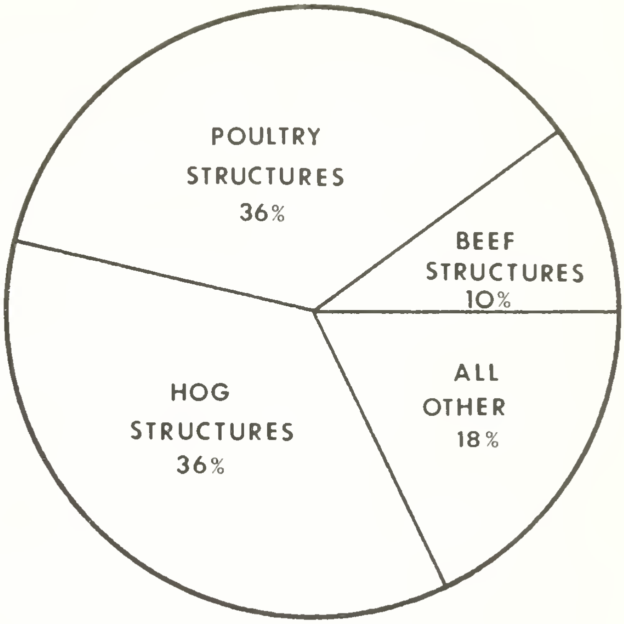


Figure 4.—Percentage of portable structures in general categories.

Source of Materials

Of the 643,000 portable structures built on the farm, about 65 percent were constructed with materials obtained from building materials deal-ers. Sawmills provided the materials for 27 per-cent and scrap materials were used for 5 percent.

Building materials dealers sold 50 percent of the 660,000 portable structures which were pur-chased complete and 40 percent were purchased from farm stores. About 8 percent were pur-chased secondhand from other farmers.

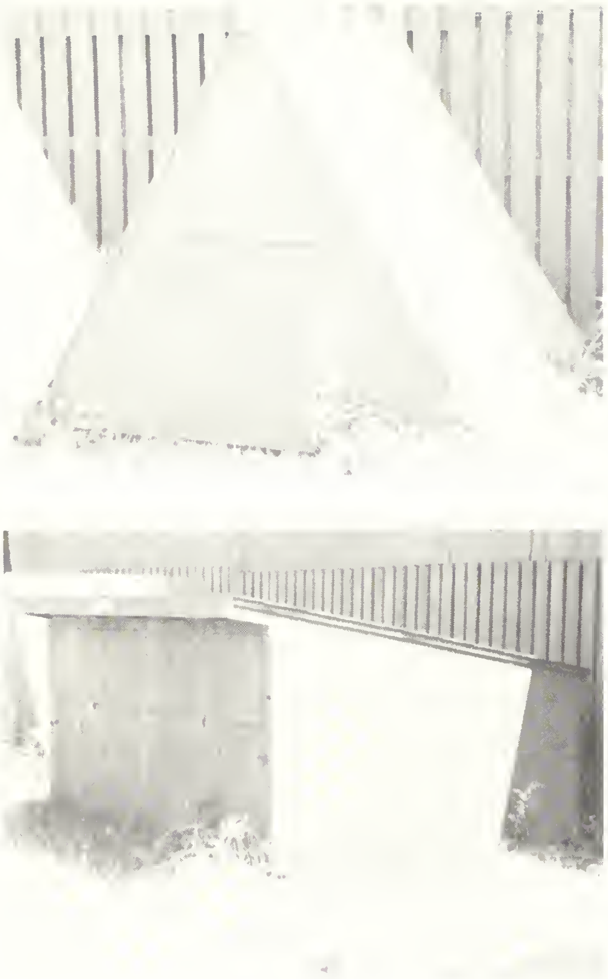


Figure 5.—"A" and shed-type portable hog houses. (Photo courtesy of University of Illinois, Department of Agricultural Engineering)

SUMMARY AND DISCUSSION

The decline in the use of lumber on farms cannot be attributed entirely to a reduced rate of farm building construction. Although the number of farm buildings constructed annually has declined rapidly since 1949, the buildings have been larger, and declines in the annual total square footage of farm buildings have been much slower. The value of investment in farm buildings expressed as a percentage of gross farm product has been fairly stable. It is clear that a good deal of the decline in lumber used on farms has been caused by the increasing use of oth materials, both wood and nonwood.

Grain and machine storage buildings bo contained large amounts of metal and account for about 30 percent of all new farm buildin in the Central and Appalachian Regions duri the years 1963-1965. Buildings with both fra and exterior walls made of lumber were still t most common type, but metal was the predo inant exterior wall material when all frame typ were considered — 41 percent of all the ne buildings had metal exterior walls.

A large and increasing number of farm buil ings are built by contractors and manufacture rather than by the farm operator. This tre may be associated with declines in wood u since the nonfarmer builders are capable of usi a wider range of materials than are farm op ators. About 40 percent of the new farm buil ings were constructed by persons other than t farm operator during the 1963-1965 period. is apparent that contractors and manufactur exert considerable influence on building desi and material use.

The importance of nonfarmer builders a applies to the construction of portable fa structures. Approximately one-half of all n portables added during the 3-year study peri were purchased complete. Structures made tirely of metal or entirely of lumber occurred equal numbers and accounted for over 81 perce of all the portables. Nearly all (94 percent) the metal structures were purchased comple while about 87 percent of the lumber structu were built on the farm.

Most wood materials were purchased in assembled and uncut form from lumberyards a sawmills. These traditional forms and market channels for wood materials may not be adequ to serve the needs of building contractors today's farmer builder who needs convenie ready-to-use components. In order to encour more effiicient use of wood in farm buildir promotional efforts should be directed tow farm building contractors and manufactur and toward marketing wood materials in m convenient forms at more convenient locatic

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WILLARD H. CARMEAN

H CENTRAL FOREST EXPERIMENT STATION
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Site Index Curves For Black, White, Scarlet, And Chestnut Oaks In The Central States

Willard H. Carmean

The site index method is the most widely ccepted means for estimating site quality in the Jnited States. However, proper application of his method of site evaluation requires suitable rees for the required height and age measurenents. Also needed are accurate site index curves uitable to the tree species and to the area where ite is being estimated (Carmean 1970).

Satisfactory site index measurements can e taken only from older dominant and coominant trees that have been free-growing and ninjured throughout their lives. Such trees are iost commonly found in older, even-aged, fully tocked stands that have not been disturbed by ast cutting, heavy grazing, or repeated burning. n the Central States extensive areas of evenged upland oak stands now occupy areas oriinally clearcut for charcoal, mine props, and ailroad ties. Dominant and codominant trees n such stands are very well suited for site index neasurements.

But errors in site index estimation still may ccur if site index curves do not accurately porray the variable patterns of tree height growth hat may exist within a particular forest region Carmean 1970). For the Central States the only ite index curves for upland oaks are harmonized urves presumed to be applicable to all species of upland oak (Schnur 1937). However, upland oaks in the Central States have an extremely wide range and grow on lands having great differences in soil, topography, climate, and site quality. Presently we do not know if these older harmonized curves accurately describe the patterns of tree height growth found in this large and variable region. Nor do we know if these general curves are suitable for all species of upland oak found in our mixed oak forests.

Our studies are based on stem analysis measurements for four species of upland oaks growing on a wide range of site in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri. Results show that each of these four species of oak have different patterns of height growth; also we have found polymorphic height growth patterns for different levels of site quality. Refined site index curves are presented for black, white, scarlet, and chestnut oaks growing in the Central States.

THE DATA

Stem analyses were made on a total of 559 dominant and codominant oaks growing on 204 1/5-acre plots (table 1). A wide range of site index was observed for each of four species of

Table 1.—Number of plots and trees used in constructing site index curves from stem analyses of four species of upland oaks in the Central States[1]

Species	State					Totals
	Ohio	Kentucky	Indiana	Illinois	Missouri	
	- - - - - Total number of plots 2/ - - - - -					
Black oak	9(27)	7(30)	16(36)	3(10)	85(197)	120(300)
White oak	8(26)	5(25)	17(37)	4(12)	7(12)	41(112)
Scarlet oak	5(20)	8(34)	--	1(2)	11(32)	25(88)
Chestnut oak	13(43)	4(15)	1(1)	--	--	18(59)
Totals	35(116)	24(104)	34(74)	8(24)	103(24)	204(559)

1/ Trees in Kentucky, Indiana, Illinois, and many of the Missouri trees were sectioned as a part of a hardwood decay study conducted by the Northeastern Forest Experiment Station. Data for the remainder of the Missouri trees were furnished by Robert A. McQuilkin, North Central Forest Experiment Station. A portion of the statistical computations was accomplished using cooperative funds from the Kentucky Conservation Department.

2/ Numbers in parentheses are the number of trees sectioned.

oaks, and stand ages ranged from 33 to 129 years of age. All plots were in even-aged, well stocked stands apparently undisturbed by past cutting, grazing, or severe burning. From one to six dominant and codominant trees of each species were felled and sectioned on each plot. Each tree was sectioned at 1.0 foot, 4.5 feet, and at 4-foot intervals thereafter up to the growing tip of the tree. Total tree height was recorded and annual rings were field counted at each of the section points.

ANALYSIS AND RESULTS

Procedures followed in the compilation and analysis of data generally are those recommended by Curtis (1964). Details of the procedures we followed are described elsewhere.[1] Briefly, height-age curves for individual trees were combined into average species curves for each plot. Then adjustments were made for bias resulting from section points falling below terminal buds, and for bias due to an association between stand age and site quality. Next, estimated tree height at 1 year of age, and at successive 5-year intervals was read from the adjusted plot height-age curves for each plot. Data for each species were th stratified into 10-foot site index classes bas upon tree height at 50 years observed from t average plot height-age curves.

A large number of equations were tested determine which was best suited to the actu data. Several equations adequately express the variable height growth patterns characterist of different species of oak growing on a wi range of sites. However, a nonlinear growt curve fitted the data best at all age classes. Th equation we used is:

$$H = b_1(1-e^{-b_2 age})^{b_3}$$

where H = tree height at any age

b_1 = coefficient expressing asymptoti tree height, (i.e., estimated ultimate tree height)

b_2 = coefficient determining rate of tree height growth

b_3 = coefficient determining initial pattern of height growth

e = base of natural logarithm ≅ 2.71

[1] *Willard H. Carmean. Site index curves for upland oaks in the Central States. (Unpublished manuscript)*

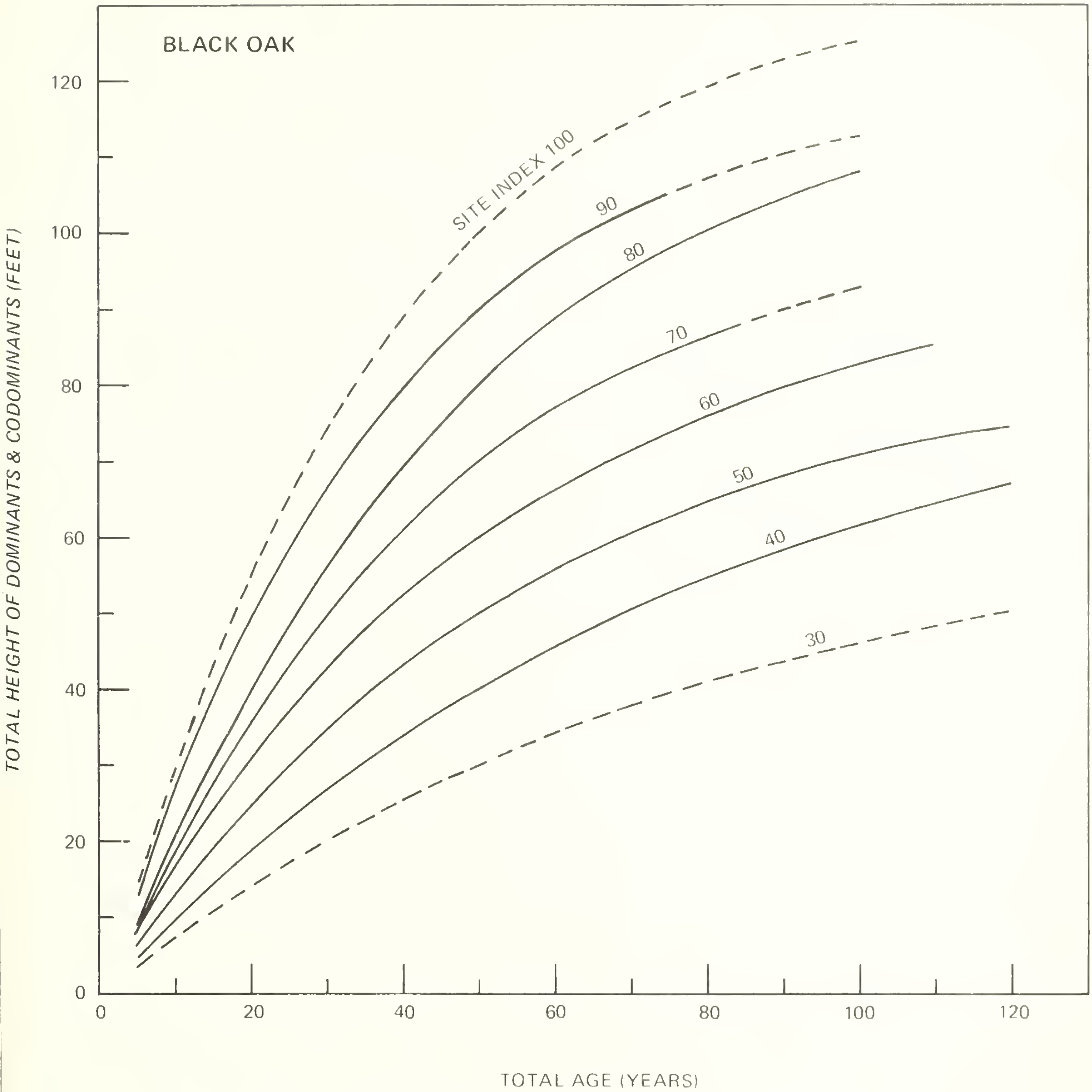

Figure 1.—Site index curves for black oak in the Central States. These curves are based on stem analyses of 300 dominant and codominant black oaks growing on 120 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri.

Extra copies of site-index charts are available upon request.

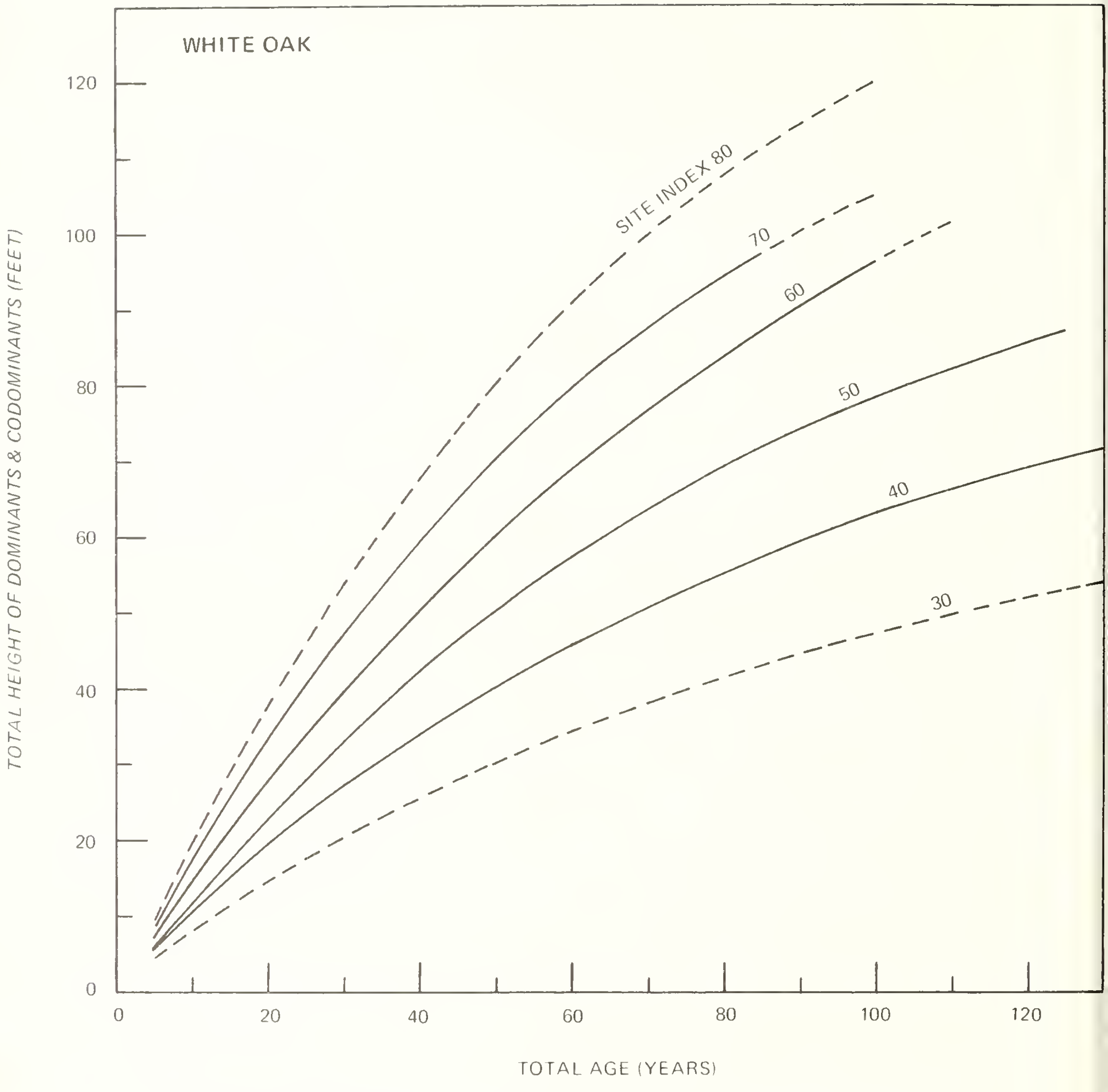

Figure 2.—Site index curves for white oak in the Central States. These curves are based on stem analyses of 112 dominant and codominant white oaks growing on 41 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Indiana, southern Illinois, and southern Missouri.

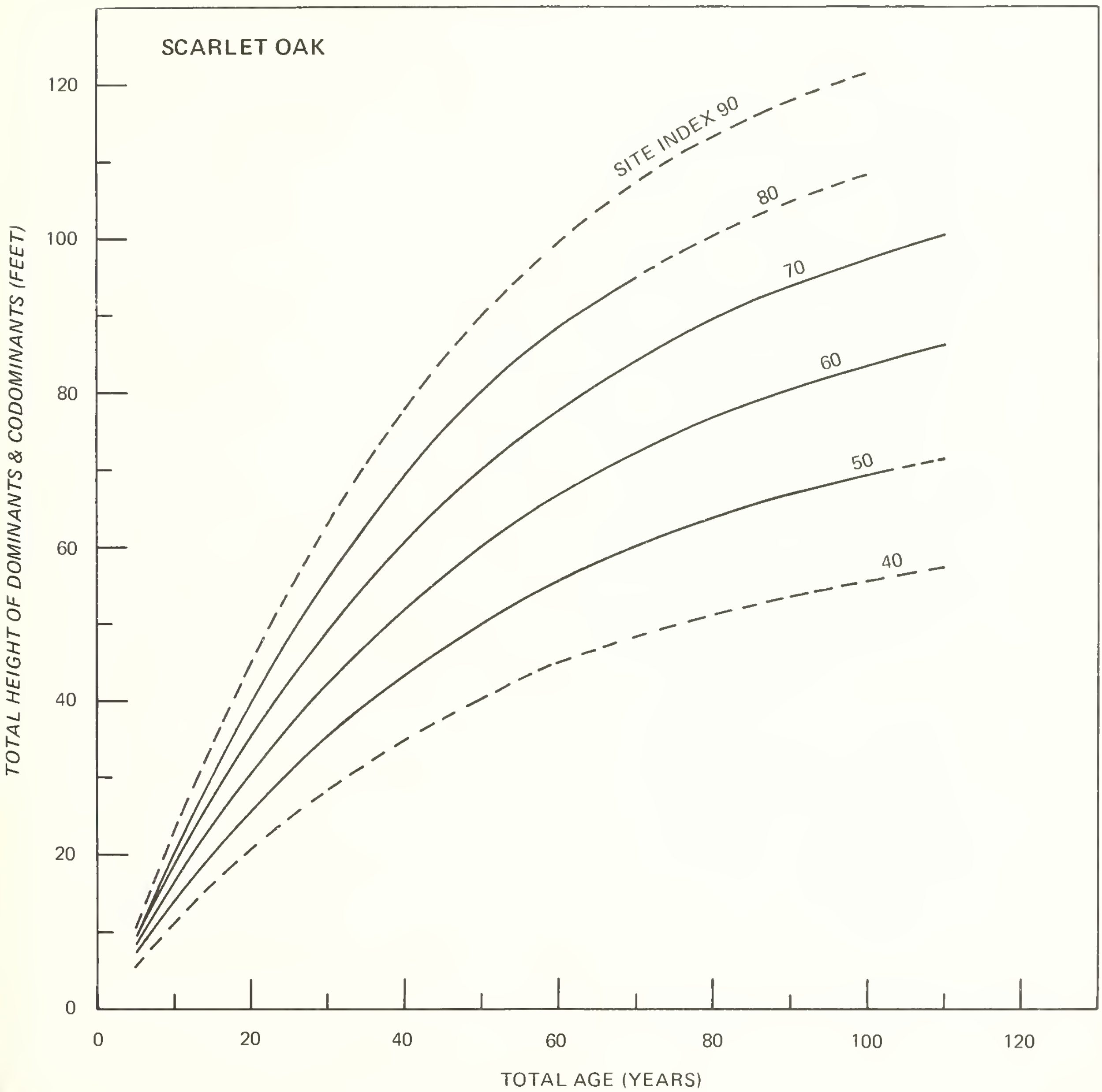

Figure 3.—Site index curves for scarlet oak in the Central States. These curves are based on stem analyses of 88 dominant and codominant scarlet oaks growing on 25 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, southern Illinois, and southern Missouri.

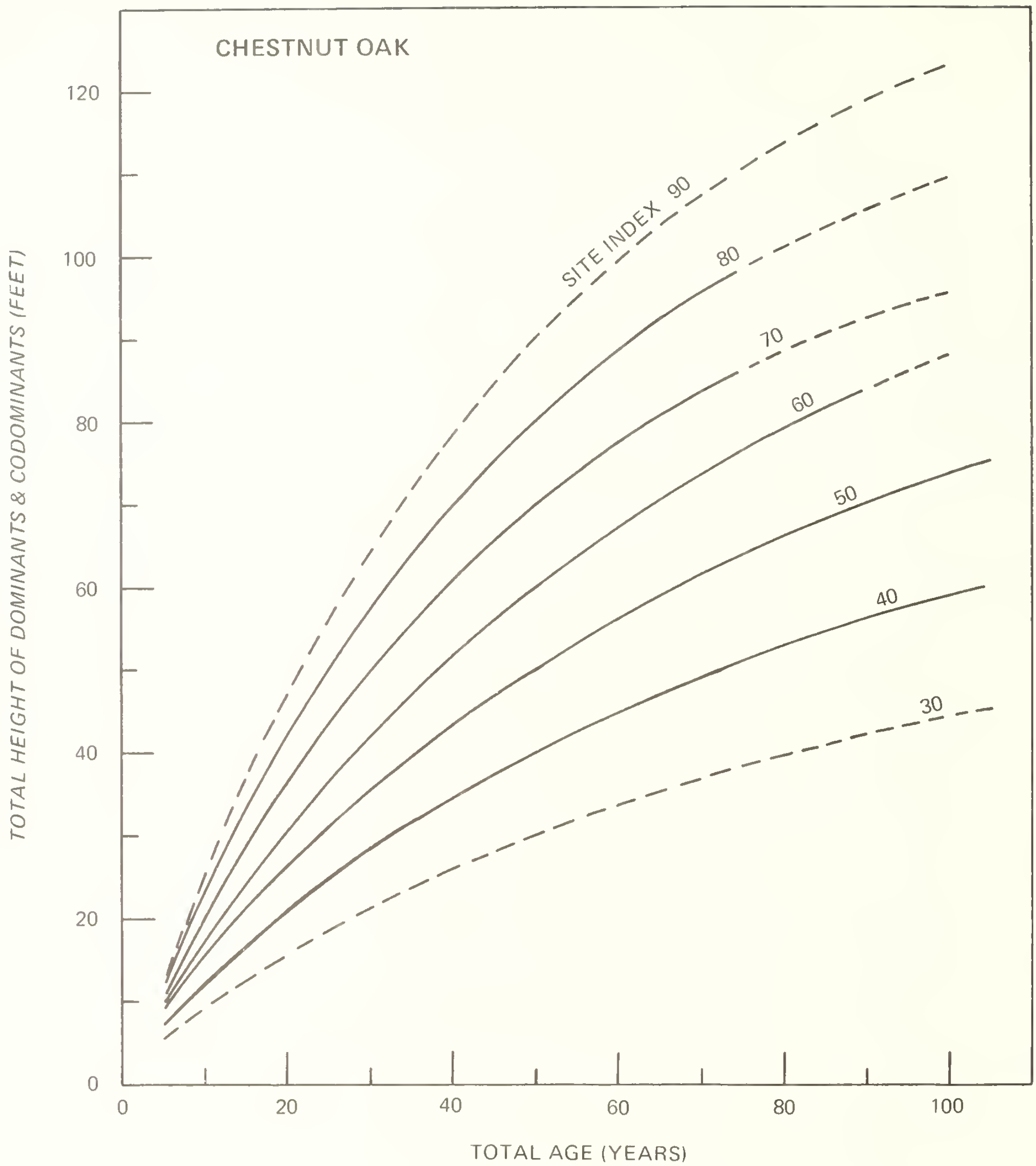

Figure 4.—Site index curves for chestnut oak in the Central States. These curves are based on stem analyses of 59 dominant and codominant chestnut oaks growing on 18 plots located in the unglaciated portions of southeastern Ohio, eastern Kentucky, and southern Indiana.

This growth equation was used to compute verage height growth equations for black and hite oak by 10-foot site index classes. Broader ite index classes were used to compute equations or scarlet and chestnut oak because fewer data ere available for these species. Each of the esulting equations was computed from data estricted to narrow site index classes, hence hese equations are independent of each other nd are not influenced by height growth patterns haracteristic of other site index classes. The hany height growth equations computed for lack, white, scarlet, and chestnut oaks are given sewhere.[1]

Examination of the various regression coeffi- ents and the resulting height-growth curves howed that significant differences in pattern of eight growth existed among the various oak pecies. Also for each species of oak signi- ant polymorphic height growth patterns were bserved for different levels of site quality. How- ver, early height growth was found to be almost near for all species rather than sigmoid as is haracteristic for many tree seedlings. No con- stent differences in height growth patterns were ssociated with the different States where data ere collected.

The height growth equations computed from his study were used to construct separate site ndex curves for black, white, scarlet, and chest- ut oaks (figs. 1 through 4). The broken lines how where site curves were extended using the eight growth equations, or where curves for very ood or very poor sites were computed based on quations for adjacent site classes. Consistent ee growth patterns were observed within plots nd within site classes but no consistent growth atterns were associated with different States. hus we consider these site index curves to be t least applicable throughout the unglaciated ortions of the Central States.

DISCUSSION

One important finding is that the pattern of eight growth differs among the various species f upland oaks. Our stem analyses reveal that hite oak has a decidedly different height growth attern from that of black and scarlet oak; chest- ut oak has a growth pattern intermediate be- ween white oak and that of black and scarlet oak. We have found that white oak has relatively slow height growth in early years in contrast to the more rapid early height growth of black and scarlet oak. However, after 50 or 60 years black and scarlet oak slow in growth while white oak maintains a relatively rapid rate of height growth past 100 years of age. Until 60 or 70 years white oak may be shorter than black or scarlet oak, but in later years white oak surpasses the other oaks and by 100 years will be the tallest oak in the stand. For example, if black and white oak are both 70 feet tall at 50 years (site index 70) then white oak will be about 13 feet taller than black oak at 100 years (figs. 1 and 2).

Another finding is that polymorphic height growth patterns occur on different sites. Trees on very good sites have a very rapid surge of early height growth in contrast to trees on poorer sites which have much slower early height growth. After 20 or 30 years the rapid growth on good sites is expended. Trees then slow in growth and by 60 or 70 years annual height growth on all sites is rather similar.

The third finding is that height growth does not slow as much as predicted by the conventional harmonized site index curves for upland oaks (Schnur 1937). Our curves and the conventional curves are fairly similar until about 60 years of age – especially on medium sites. However, at about 60 years the conventional curves show a more pronounced slowing in height growth than our species curves. Differences between our curves and the standard curves are particularly pronounced for white oak which maintains a relatively rapid rate of height growth past 100 years. These differences mean that site index will be overestimated if the conventional site index curves are used in older oak stands for estimating site index (Carmean 1971).

Our site curves also are different from the harmonized site index curves for upland oaks in the southeast (Olson 1959), and for red oak in the Lake States (Gevorkiantz 1957). Olson's curves show even more pronounced slowing in height growth in older ages than do the conventional site index curves. In contrast, the Gevorkiantz curves do not display as much slowing in height growth as do the Schnur and Olson site index curves. The Gevorkiantz curves for red oak are decidedly different from our white oak curves (fig. 2), but they do have a height growth pattern very close to the pattern of our black oak site index curves (fig. 1).

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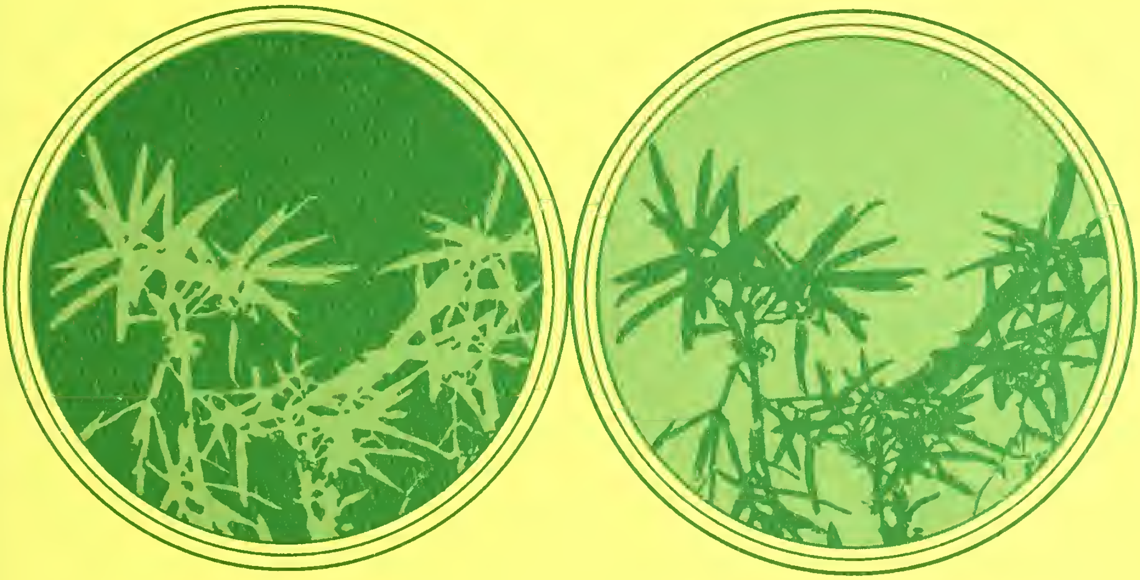
Wilderness ECOLOGY



virgin plant communities of the Boundary Waters Canoe Area

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NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE • U. S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication March 29, 1971.

WILDERNESS ECOLOGY: VIRGIN PLANT COMMUNITIES OF THE BOUNDARY WATERS CANOE AREA

Lewis F. Ohmann and Robert R. Ream

Wilderness lands under USDA Forest Service jurisdic-n are to be managed to promote, perpetuate, and iere necessary, restore their wilderness character (Sec-n 251.71 Code of Federal Regulations). But before entific techniques are chosen to accomplish this goal a wilderness it is important to establish a sound ological foundation. A basic part of this foundation ist be a quantitative knowledge of the structure and mposition of the plant communities. This paper pre-its basic ecological information for the upland natural nt communities of a northeastern Minnesota wilder-s area, the Boundary Waters Canoe Area (BWCA).

The BWCA (fig. 1) is unique in the National Wilder-s Preservation System for the following reasons: (1) It the only large (1,062,000 acres of land and water) deral wilderness area in the northeastern United tes. (2) It is the only lake-land wilderness. Water kes up 190,000 acres or 18 percent of the area, pro-ing 1,200 miles of canoe routes. (3) It is divided into major zones: a Portal Zone where the vegetation is naged for timber harvest with cognizance of primi-recreation values, and an Interior Zone where timber vest is not permitted. The management of vegetation commercial timber harvest in the Portal Zone neces-ites emphasis of silvicultural goals and techniques. is study focuses on the Interior Zone where wilderness ls and ecological techniques are applicable.

About 40 percent of the BWCA is occupied by ural vegetation. [1/] The balance of the area has been ged, either in the "cut-out and get-out" period of the early 1900's or under controlled National Forest or State timber harvest programs of recent years (fig. 1) (Heinselman 1969). A study currently underway is fo-cused on the vegetation now present on areas logged during the early period. If the plant communities within this logged area are found to be different from those in the virgin area, studies aimed at developing techniques for restoration of the plant communities of this logged area may be undertaken.

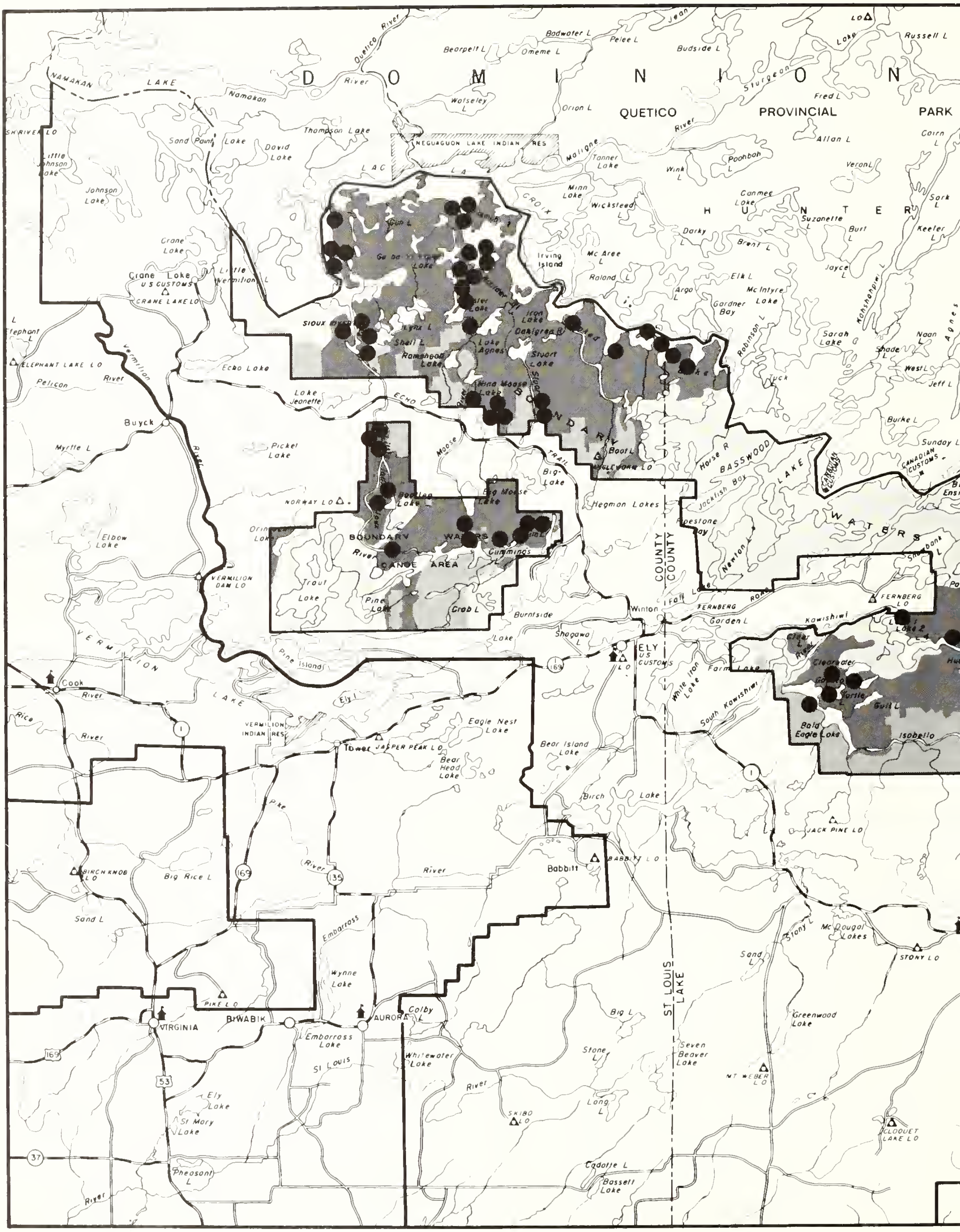
Heinselman (1969) has shown that fires had a very important influence on the biotic communities of the BWCA until fire control measures became effective (about 40 years ago). Such fires must have exerted their greatest influence on the drier upland communities.

In light of the above considerations it was decided that the first study of the plant communities of the BWCA should be restricted to the upland virgin (natural) vegetation of the Interior Zone.

OBJECTIVE

The vegetation of the BWCA is made up of many dif-ferent plant species growing together in various mixtures at different locations. If we are to advance our know-ledge of the effects of man, fire, wind, insects, disease, and time on the development and changes in this mosaic of plants, it is essential to break this mosaic down into natural units called plant communities. Plant communi-ties may differ from one another in the species they con-tain, in the relative amounts of the species, or both. The objective of this study was to conduct an inventory and systematic analysis, and develop a classification of the upland virgin plant communities in this wilderness area. Thus, this paper deals primarily with the quantitative description and classification of the plant communities. Because it is intended to serve as both a description of the plant communities and as a source of quantitative ecological baseline data, it also contains an extensive appendix of data.

J For the purpose of this study, virgin (natural) vege-ion is defined as native species resulting primarily m environmental factors present in the ecosystem or to settlement (and potentially still effective) or m gradual successional change. Environmental factors lude windstorms; insect and disease outbreaks, and e.


DOMINION
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Quetico River
Namakan Lake
Namakan
Badwater L
Pelee L
Budside L
Beorpelt L
Omeme L
Russell L
Sturgeon
Fred L
Watseley L
Orion L
Thompson Lake
Sand Point Lake
David Lake
NEGUAGUON LAKE INDIAN RES
Maligne
Tanner Lake
Allan L
Poohbah L
Veron L
Wink L
Minn Lake
Wicksteed
Canmee Lake
Suzanette L
Burt L
Sark L
Keeler L
Darky L
Brent L
Mc Aree L
Irving Island
Roland L
Elk L
Joyce L
Argo L
Mc Intyre Lake
Gardner Bay
Robinson L
Kahshahpiwi L
Sarah Lake
Naan L
Shade L
West L
Jeff L
Tuck L
Burke L
Sunday L
CANADIAN CUSTOMS
Little Johnson Lake
Johnson Lake
Crane Lake
Crane Lake U S CUSTOMS
CRANE LAKE LO
Little Vermilion L
SHRIVER LO
Elephant L
ELEPHANT LAKE LO
Pelican
Vermilion River
Echo Lake
Lake Jeanette
ECHO TRAIL
Buyck
Myrtle L
Pickel Lake
Moose
Big Lake
Hegman Lakes
Boot L
NORWAY LO
Elbow Lake
Trout Lake
Pine Lake
Crab L
Burntside
Cummings L
Big Moose Lake
BOUNDARY WATERS CANOE AREA
BASSWOOD LAKE
Horse R
Jackfish Bay
Pipestone Bay
Newton L
WATERS
COUNTY
COUNTY
Fall Lake
FERNBERG ROAD
FERNBERG LO
Garden L
Kawishiwi
Winton
Shagawa L
ELY
US CUSTOMS
LO
Farm Lake
White Iron Lake
South Kawishiwi
Clearwater
Turtle L
Gull L
Bald Eagle Lake
Isabella
VERMILION DAM LO
VERMILION LAKE
Pine Island
Cook
Rice
River
Ely L
VERMILION INDIAN RES
Eagle Nest Lake
Bear Island Lake
Tower
JASPER PEAK LO
Bear Head Lake
Birch Lake
Pike
JACK PINE LO
BIRCH KNOB LO
Big Rice L
River
Babbitt
BABBITT LO
Sand L
Embarrass
Wynne Lake
PIKE LO
VIRGINIA
BIWABIK
AURORA
Colby L
Embarrass Lake
St Louis
Whitewater Lake
Big L
Stone L
Seven Beaver Lake
MT WEBER LO
Stony L
Mc Dougal Lakes
Sand L
STONY LO
Greenwood Lake
Ely Lake
St Mary Lake
River
SKIBO LO
Long L
CLOQUET LAKE LO
Pheasant L
Cadotte L
Bassett Lake
River
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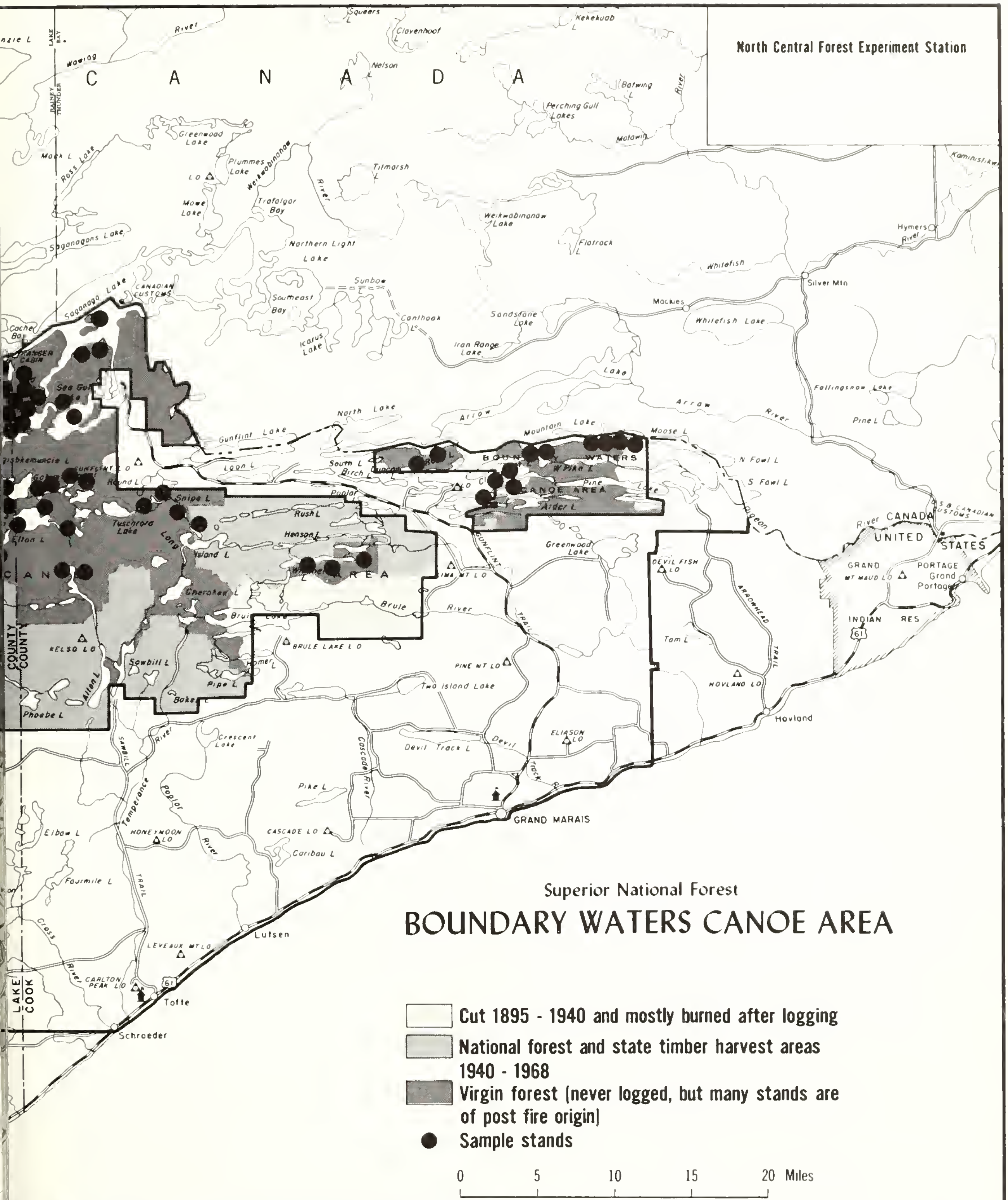


…re 1. — Location of sample stands within the Boundary Waters Canoe Area. A few …nds are outside the virgin forest area on the map, but these are also undisturbed.

THE STUDY AREA

The BWCA is a part of the Superior Upland Physiographic Region. Preglacial erosion has left a rugged topography with elevation above sea level ranging from 1,119 feet at Crane Lake to 2,232 feet in the Misquah Hills. Local relief may range up to 500 feet.

This area is a part of the Laurentian Peneplain and is probably as geologically complex as any part of the world. It is underlain exclusively by Pre-Cambrian rocks. The numerous lakes lie in solid rock basins, some in granite (Saganaga Lake and Lac LaCroix), and some in ancient greenstones and slates (Knife Lake). The configuration of the bedrock determines the landform; thus long, narrow, steep ridges are typical on the slates, while low, irregular, round-topped hills prevail on the granites.

Soils of the BWCA are derived from sandy and gravelly loam glacial deposition. They are generally shallow throughout the area with rock outcrops common along ridgetops and along lake and stream shores. Glacial boulders are common within the soils.

The climate of the BWCA is typical of its midcontinent location. Winters are long and cold with a moderately heavy snowfall, and summers are warm and moist. The average annual precipitation is about 27 inches, including an average snowfall of about 59 inches. Temperatures vary between extremes of -50° F. and 100° F. The average monthly mean temperatures range from a low of about 12° F. in January to a high of 62° F. in July. The growing season is about 100 days.

METHODS

The sample design, vegetation sampling, and data summarization methods used have been described in detail (Ohmann and Ream 1971). These include random selection of stands in the sample, the use of 20 plotless sampling points for trees and saplings, 20 milacre plots for tree seedlings and tall shrubs, and 20 smaller plots for sampling other vegetative components of each stand. Data from 106 stands were summarized by computer.

General analytical procedures have been described in Ream and Ohmann (1971). Procedures pertinent to this paper include: (1) use of principal component analysis and optimal agglomeration techniques to classify the plant communities, (2) summarization of data from stands within each community type, (3) testing the statistical significance of certain species characteristics among the community types, and (4) development of an Environment Index and a Fire Disturbance Index.

Community Classification

Our philosophy in classification follows that Whittaker (1962) in that quantitative approaches themselves cannot solve the problems of classificat Rather, the function of community similarity meas ments is to aid in making the human judgments ultimately produce the decisions on criteria and limits. We agree with Whittaker and many others stands rarely fall into natural groups clearly separ from each other because of their complex composit and varying degrees of similarity.

After testing several measures of species contribu to community structure and composition, such as area and percent cover, we decided that frequency occurrence was the best measure to use in construc the plant community classification. This conf Orloci's (1968) conclusion that some species meas ments may contain "too much information" to be us in community classification. It also confirms a sin finding by Grigal (1968).

Frequency of occurrence values (Oosting 1956) each species in each stand were used to calcula similarity coefficient, which was subjected to polyth agglomerative clustering analysis (Orloci 1967). analysis utilizes as the agglomeration criterion minimum increase of the within-group sum of squ resulting from the fusions of the groups. The fusio two entities is accepted if the resultant increase in within-group sum of squares is less than it would b fusing either of the two with any other entity in sample. The process is repeated in successive cycles a hierarchy of the samples is completed (Orloci 19 The computer program (OPTAGG) used was mod from Orloci by Dr. E. Cushing, University of Minnes This analysis provides stand relationships depi two-dimensionally as a dendrogram, based on average within-group dispersion as a percentage of sample dispersion. However, the level of clustering representing a useful classification can be more rea selected if the same stand relationships are viewe more than two dimensions. The same data were, t fore, subjected to principal components analysis (O 1966) using a computer program (PRINCOMP) mod from Orloci. Vector representations of species v provide a point representation of each sample star orthogonal space (Groenewoud 1965). The points plotted and their three-dimensional relationships to other were compared with the two-dimensional relationships of the cluster dendrogram. The dendro cluster level showing closest similarity to stand clust orthogonal space was selected as the best community pe classification.

Summarization of Community Data

Individual species data for all stands within a cluster ommunity type) were summarized by use of a comter program (COMSUM). Input for this program is the nched output from the four programs written for nd-data summarization (Ohmann and Ream 1971). bles 6 through 17 in the Appendix contain the MSUM output.

Statistical Tests of Community Data

Species that occurred in at least 50 of the 106 stands the sample were used to determine if the communities fered from each other statistically in individual species racteristics. Since frequency of occurrence values re used to establish the classification, we used two er values for this test, basal area or percent cover, and portance value (Cottam and Curtis 1956).

Environment Index

Environmental aspects of the sampled stands were grated into three gradients — moisture, nutrient, and t. The importance of these gradients has been dissed in detail by Bakuzis (1959). The methods and e in assigning measured variables to and weighting portance within each gradient generally follow those Grigal (1968) and Grigal and Arneman (1970).

Components of the moisture gradient were: (1) Soil er retaining capacity of the B soil horizon as measured 1/3-bar minus 15-bar soil moisture as a percent of ndry weight; (2) soil depth over bedrock; (3) silt and y particle size fraction of the B soil horizon; (4) total sible annual insolation (Frank and Lee 1966); (5) nd aspect (azimuth); and (6) bonus value was assigned stands on lower slope positions and in valleys to ount for water seepage.

Components of the heat gradient were: (1) Total sible annual insolation; (2) slope position; (3) disce to nearest body of water over 5 acres in size; (4) and clay particle size fraction of the B soil horizon; (5) stand aspect (azimuth).

Components of the nutrient gradient were: (1) Caln, potassium, phosphorus, and pH values of the B horizon; and (2) bonus value was assigned to stands ower slope positions and valleys to account for possiflushing of nutrients.

The values for each stand were averaged within each mmunity to provide a gradient value for each of the communities. The three gradient values were then averaged to provide the Environment Index. The Index has a possible range from 1 to 5. Lower values indicate drier, warmer, and lower nutrient conditions. Higher values indicate moister, cooler, and higher nutrient conditions.

Fire Disturbance Index

Fire has been shown to be an important environmental factor influencing the vegetation of the area (Heinselman 1969). We recognize that time is fundamentally different from other factors that specify a system (Ashby 1960). An index of the time elapsed since the last major fire disturbance in each of the sampled stands was established from tree ages, and each stand was rated on a scale from 1 to 5 (1 for the most recent to 5 for the most ancient fires). The values for each stand were averaged for each community to form the Fire Disturbance Index. Low values indicate recent disturbance, and high values indicate less recent disturbance and thus more time for succession to be expressed.

DEFINITIONS

Basal area. — Square feet of tree cross section (at d.b.h.) per acre (BA).

Browse Index. — An estimate of the influence of browsing by wildlife on woody twigs of tall shrubs. Measured in four categories for each species as follows: 0 = not browsed, 1 = 0 to 1/3 browsed, 2 = 1/3 to 2/3 browsed, 3 = more than 2/3 browsed. Index is the average for species in a community type.

Commonness Index. — A measure of the commonness of a species in all the stands of a community type. It is directly related to the chance of finding a particular species at a given point within a stand of a community type (Curtis 1959). This Index may range from 0 to 10,000 for a species and is obtained by multiplying the average frequency-of-occurrence in sample points or plots within a community type by the percent of stands within a community type in which the species was present. This has also been called the Frequency x Presence Index (Curtis 1959).

Community Type. — A group of stands that are more similar to each other than to other stands as determined by the use of objective analytical procedures. The term has been reduced to "community" in the text but it should be recognized that the description is for the abstract community type (group of stands) rather than a concrete example of the community type (stand). Each stand within the type is similar to the description for the type (within variation described in the text). Names that have been assigned to these community types reflect an important feature of the type, usually the most important tree species.

Density. – Number of stems per acre.

Dominant. – The most important species in a community type in terms of number of individuals per acre, basal area per acre, percent cover, or frequency of occurrence.

Herb. – Flowering vascular plants, ferns, club mosses, and horsetails of a herbaceous nature.

Importance value. – A summation of relative values of density, basal area (or cover), and frequency for species within a community type. This provides a means of comparing each species contribution to the composition of the type.

Index of Distinctness. – A measure of the degree to which a community type is visibly distinct from related community types as indicated by the number of prevalent species which attain their highest measured values in that community type, expressed as a percentage of the total number of prevalent species in that community type (Curtis 1959).

Index of Diversity. – A measure of the floristic richness of a community type, calculated by dividing the difference between the total number of species in all of the stands of a community type and the average number of species per stand by the Napierian logarithm of the number of stands within the community type (Curtis 1959).

Index of Homogeneity. – A measure of similarity among stands within a community type, expressed as a ratio of the sum of presence values of the prevalent species to the sum of presence values of all species in the community type (Curtis 1959). The Index ranges from 0.00 for no similarity to 1.00 for totally alike floras.

Low shrub. – Shrub species of less importance to wildlife browse production. They were sampled in the 1- by 2-foot plots along with the herbs, mosses, etc.

Modal species. – A species that has its maximum presence value in a given community type (Curtis 1959).

Mosses and lichens. – Layer of vegetation nearest the ground composed of feather mosses, other mosses, reindeer moss (lichens), and other lichens.

Number of species. – Tree, sapling, and seedling size classes are treated as separate species thus inflating the number of species recorded in a community type. Certain other species are lumped by groups, such as grasses, and sedges, thus deflating the species number totals.

Presence. – A term indicating the degree to which a species occurs in the stands that make up a community type, expressed as a percentage of the total numbe[r of] stands within the community type (Curtis 1959).

Prevalent species. – The topmost species counted to a number equal to the average number of spe[cies] found in all stands within a community type whe[n] species are arranged in decreasing order of their pres[ence] percentages (Curtis 1959).

SAF cover type. – A classification scheme prese[nted] by the Society of American Foresters (1954) that [de]scribes commercially important forest types.

Sapling. – Tree species between 0.96 and 3.95 in[ches] in diameter at breast height (d.b.h.).

Seedling. – Tree species less than 0.96 inch in d.b[.h.] which may be of seed or sucker origin.

Stand. – An area of virgin vegetation more or [less] uniform in physiognomy, composition, and hab[itat] conditions.

Tall shrub. – The vegetation layer important in [the] production of woody winter feed (browse) for wild[life]. To facilitate sampling, shrub species were placed [in] two arbitrary categories before fieldwork began, tall [and] low shrubs. Tall shrubs were sampled in milacre plots.

Tree. – Woody species over 3.96 inches in d.b.h.

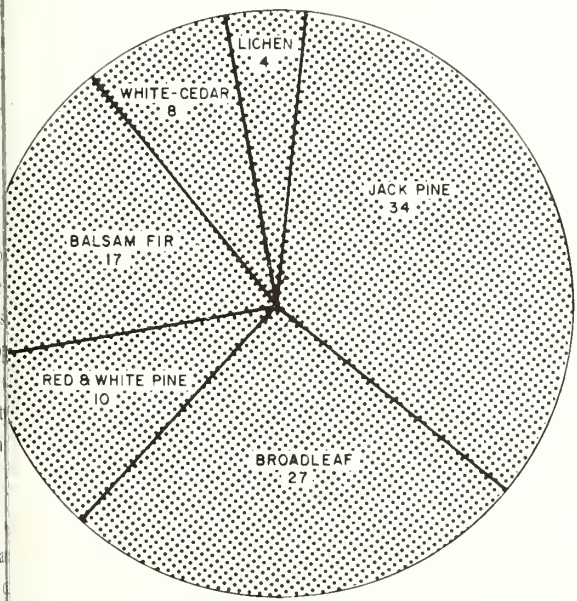
THE PLANT COMMUNITIES

The 106 stands in the sample were classified into plant community types (table 1). Only one of the[se] types, the lichen community type, is nonforest. It i[s re]stricted to rock outcrops on ridgetops and upper slo[pes]. It is characterized by the importance of lichens [and] mosses and by the lack of many woody plants. This t[ype] comprises slightly less than 4 percent of the stands in [the] sample (fig 2).

Another four community types are alike in [one] respect – the importance of jack pine (scientific na[mes] appear in Appendix table 5) in the canopy. Over [one-]third of the stands in the sample are in this group (fig[...]). In two of these communities, jack pine (oak) and [jack] pine (fir), jack pine is the dominant of the can[opy]. Major differences between these communities are [the] physical setting, the tree reproduction present, and [the] species of low shrubs present. In the other two com[mu]nities, jack pine-black spruce and black spruce-jack p[ine], jack pine shares canopy dominance with black spr[uce]. The major difference between these communities is [the] totally different aspect of the understory. In contras[t to] the jack pine-black spruce community, the black spr[uce-]jack pine community has virtually no shrub and [herb] layer, but has a well developed moss layer that co[vers] the ground and the numerous boulders which wo[uld] otherwise be bare.

Table 1. — Index values for moisture, heat, and nutrient gradients, their average (the Environment Index), and the Fire Disturbance Index range from 1 to 5. The lower numbers represent drier, warmer, and poorer sites, and more recent fire disturbance.

Item	Community											
	Lichen	Jack pine (fir)	Jack pine (oak)	Black spruce-jack pine	White pine	Jack pine-black spruce	Maple-aspen-birch	Aspen-birch	Red pine	Budworm-damage	Fir-birch	White-cedar
Moisture gradient	2.6	3.6	3.3	3.1	3.1	2.8	2.9	2.9	2.8	3.4	3.2	3.1
Heat gradient	2.4	3.2	3.1	3.1	3.1	2.9	3.4	3.1	3.5	3.3	3.8	3.8
Nutrient gradient	--	2.8	2.7	2.9	2.7	1.9	2.8	3.1	2.2	3.1	3.1	3.2
Environment Index	2.5	3.2	3.0	3.0	3.0	2.6	3.0	3.0	2.8	3.3	3.4	3.4
Fire Disturbance Index	2.0	2.1	2.4	2.4	2.8	2.9	3.1	3.2	3.5	3.5	4.4	4.6



ure 2. — Distribution (in percent) of sample stands among community-type groups.

The jack pine (oak) community is most similar to F cover type 1, the jack pine (fir) and jack pine-k spruce communities to SAF type 6, and the black ice-jack pine community to SAF types 6 or 12.

Evidence points to a future decrease of the jack pine ponent with a corresponding increase in the more rant black spruce and balsam fir, with some white ice, paper birch, white-cedar, and mountain-ash as or associates. A shift to more mountain-ash as an erstory (subcanopy) tree, an increase in mountain maple and fly honeysuckle in the tall shrub layer, an increase in creeping snowberry, bishop's-cap, goldthread, bedstraw, and club-mosses in the herb layer, and perhaps a generally greater predominance of mosses over herbs will likely occur.

Two of the community types are dominated by broadleaf trees. These are the maple-aspen-birch and the aspen-birch community types. The two differ principally in the importance of red maple as a tree, sapling, and seedling. Together they comprise more than 25 percent of the stands in the sample (fig. 2). The outstanding features of these two communities are the importance of broadleaf trees, and the luxuriant growth of the tall shrub and herb layers. This group is of much importance to wildlife species that currently inhabit the area. Browse indices for many of the shrub species are high. In addition to providing deer (*Odocoileus virginianus* Boddart.) and moose (*Alces alces* L.) browse, these two communities may be important to ruffed grouse (*Bonasa umbellus* L.) and beaver (*Castor canadensis* Kuhl.).

Two of the types described are those most often associated with the virgin forest in the mind of the visitor to the wilderness area. They are the red and the white pine community types. Actually these two communities make up a rather small part of the stands in the sample, about 10 percent (fig. 2).

One of the features of the two pines so important in these communities is their longevity. Also, mature red pines in particular and white pines to a lesser degree are fire resistant. In nature, fires often burn through these communities removing any understory present. This produces an excellent seedbed, which, if a seed crop is present, may result in a new generation of understory pines. When this occurs at about the time the pine overstory has started to open due to age or some other factor, the community type can maintain itself. At present most of the red and white pine stands that were sampled are not yet at the point where the tree canopy is opening; and because of fire protection they have an understory which is not pine but balsam fir or spruce. With continued protection from fire, spruce and fir will eventually replace the pine.

Two community types, the budworm-disturbed and the fir-birch, are characterized by the presence of balsam fir. It is important as a tree, sapling, and seedling. It should not be inferred that all stands in the budworm-disturbed type have been damaged by the spruce budworm (*Choristoneura fumiferana* Clem.). In fact, there is budworm damage to stands in both communities, but to a lesser extent in the fir-birch community. Seven of the 10 budworm community stands were damaged and five of the eight fir-birch community stands showed some damage. Another difference between the two communities that may contribute to a greater abundance of fir in the fir-birch community is the longer period since the last major fire disturbance in the fir-birch stands.

Seventeen percent of the stands in the sample (fig. 2) fell into these two community types. They appear to be ecologically capable of increasing with continued protection from fire.

The final plant community is dominated by northern white-cedar. The white-cedar community type comprises about 8 percent of the stands in the sample (fig. 2). Most of these stands were located at relatively high elevations on north-facing slopes of the east-west trending ridges of the Rove Slate Geological Formation in the eastern portion of the BWCA, Mountain-ash, mountain maple, and ground-hemlock are characteristic species of this community type.

Lichen

The lichen community is the only nonforested community type recognized from data collected in this study. It is restricted to rock outcrops on ridgetops and upper slopes (fig. 3). It has the lowest ranking of all the communities on the Environment Index, indicating the xeric nature of the habitat on which it occurs (table 1).

The community contains the fewest species (32) and the lowest average number of species in any one stand

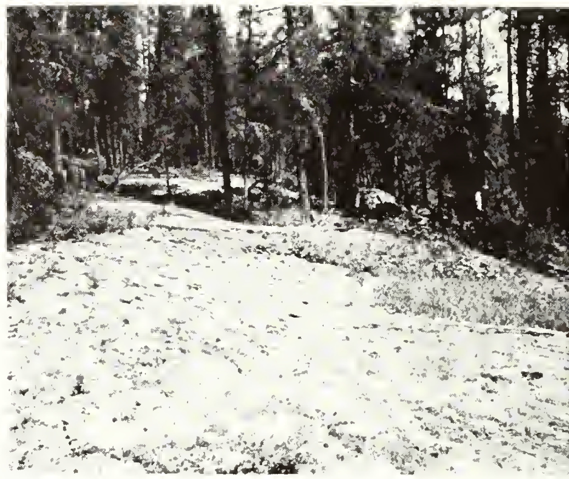


Figure 3. — A lichen community on the rock outcrop the foreground with a jack pine (oak) communit the background.

(11.5). The flora is depauperate (Index of Diversity 11.4) but consistent among stands (Index Homogeneity 0.99). It is the most distinct commu type, as might be expected due to its nonforest nat (Index of Distinctness 50.0) (table 2). The depauper flora may be misleading because two important fl components of this community were treated as gro rather than individuals. Lichens other than the rein mosses, and mosses other than the feather mos Dieranum, and the hairycap moss were treated as grou together they account for 40 percent of the gro cover within the community. About 30 percent of surface in this community is bare rock. The rein mosses (actually lichens) and the hairycap moss are important in this essentially two-layered commun The more scattered second layer contains a few sh species such as bush honeysuckle, which averages 8, stems per acre. Juneberry, mountain maple, and wil are also present. Tree seedlings are also found in layer, with jack pine, red maple, red oak, quaking as mountain-ash, and paper birch represented. Three he pink corydalis, bristly sarsaparilla, and white cinque are the species most unique to this community.

Sophisticated objective methods are not require separate this community type from the others, but type serves as a good check on the methods used. If stands in this type did not separate out as a uni group, one could not have much confidence in methods used for defining community types. In analysis, the stands constituting this community grou closely and were well separated from the other gro

Table 2. — Comparison of the virgin plant communities

Community	Number of stands	Percent total stands	Number of species	Families in species	Number of modal species	Index of Diversity	Index of Homogeneity	Index of Distinctness
Lichen	6	5.7	32	19	9	11.4	0.99	50.0
Jack pine (oak)	11	10.4	81	25	12	17.7	.46	17.9
Jack pine (fir)	7	6.6	95	30	15	24.7	.55	8.9
Jack pine-black spruce	7	6.6	83	26	5	20.5	.50	7.3
Black spruce-jack pine	10	9.4	75	23	6	20.7	.82	16.0
Aspen-birch	13	12.3	112	30	27	25.7	.59	25.6
Maple-aspen-birch	15	14.2	104	34	18	21.8	.49	15.9
White pine	6	5.7	80	23	8	21.2	.53	10.0
Red pine	4	3.8	67	25	16	20.4	.56	24.3
Budworm	10	9.4	102	31	11	23.8	.53	11.1
Fir-birch	8	7.5	86	30	13	20.2	.49	19.5
White-cedar	9	8.5	85	28	25	20.8	.56	35.1

The lichen community may be viewed as an early ge of succession after some major disturbance, such fire, or as primary succession on rock outcrop bared ough glaciation (Oosting 1956). No doubt most of se communities have been disturbed more than once ce glacial time by wildfire, which removed the umulated organic material. Any mineral soil that may e accumulated through glacial deposition, weathering the rock, or movement by air or water would then be ject to erosion. Wildfires may have been frequent ugh to prevent this community from progressing ard a woody community type.

With continued lack of disturbance, principally ough protection from wildfire, this community type l have more shrubs and small trees. Over a long time ould accumulate more soil and become a woody-plant nmunity rather than a lichen-dominated community.

Jack Pine (Oak)

One of the most characteristic features of this comnity is its physiographic setting — bald rock ridges rock outcrops (fig. 3). Bare rock is almost always sent, and the type is often interspersed with smaller s of lichen community.

This community occupies a middle position in the ironment Index. It drops well into the lower half of Fire Disturbance Index, when period since fire is sidered (table 1). This reflects the fact that the ds are not extremely old, but have mostly originated r major fires in 1864, 1894, and 1910. All of these s occurred under especially droughty conditions and ned extensive areas (Heinselman 1969).

Although stands of this type are usually situated on etops or upper slopes, they do occur down to midpe. Slopes on which the stands are found average about 10 percent, with as little as 3 percent on ridgetops to as much as 24 percent at midslope.

Although jack pine grows best on well-drained loamy sands, it can adapt to very dry sandy or gravelly soils where other species can scarcely survive, and it will also grow over rock outcrops and bald rock ridges (USDA Forest Service 1965). Soils in this community type are characteristically very shallow, generally less than 20 inches above bedrock and as little as 6 inches above bedrock in some stands. Most of the sampled stands were on granite bedrock. This may, in part, reflect the response of this resistant substrate to glaciation. The higher elevations were probably scraped to bedrock by glaciation, and much of what was later deposited during glacial recession eroded, resulting in shallow soils overlying the slow-weathering granite of these ridges.

This community shows the lowest floral richness of the forested communities (Index Diversity 17.7), and a high variability in species occurrence among stands, as indicated by the low Index of Homogeneity (0.46) (table 2). Eighty-one species of plants (representing 25 families) are found in this community. None of these families are unique to the community. The families Cupressaceae, Fagaceae, and Orchidaceae, though represented in this community, did not occur in the samples from the jack pine (fir) community stands.

Prevalent modal species in this community are jack pine (trees and saplings); red oak (saplings and seedlings); Bebb willow (tall shrub); and late sweet blueberry and wintergreen (low shrubs) (table 3).

Jack pine is *the* dominant tree of the community with an average density of 315 trees per acre and 82 square feet of basal area per acre (BA). This would classify the site as very poor to poor for 60-year-old jack

Table 3. — The prevalent modal species within each community. The number below each listing is the additional species within the community that are modal but not prevalent. T, SA, and SE represent tree, sapling, and seedling size classes of tree species, respectively

Lichen	Jack pine (oak)	Jack pine (fir)	Jack pine-black spruce
Pink corydalis	Jack pine (T)	White spruce (SA)	Black spruce (T)
Hairy-cap moss	Jack pine (SA)	Goldthread	Black spruce (SE)
Cladonia mitis	Red oak (SA)	Twin-flower	Bunchberry
Cladonia rangiferina	Red oak (SE)	Running clubmoss	
All other lichens	Bebb willow		
Spotted peltigera	Late sweet blueberry		
	Wintergreen		
3	5	11	2

Black spruce-jack pine	Aspen-birch	Maple-aspen-birch	White pine
Black spruce (SA)	Quaking aspen (T)	Red maple (T)	White pine (T)
Dicranum	Quaking aspen (SA)	Red maple (SA)	Bush honeysuckle
Plume moss	Quaking aspen (SE)	Red maple (SE)	Wild sarsaparilla
Schreber's moss	Paper birch (SA)	Common twisted-stalk	Wood anemone
	Beaked hazel	False lily-of-the-valley	
	Green alder	Star-flower	
	Round-leaved dogwood	Ground pine	
	Clinton's lily		
	Large-leaf northern aster		
	Upland strawberry		
	Bracken fern		
2	16	11	4

Red pine	Budworm-damaged	Fir-birch	White-cedar
Red oak (T)	White spruce (T)	Balsam fir (T)	White-cedar (T)
Red pine (T)	Dewberry	Balsam fir (SA)	White-cedar (SA)
Red pine (SA)	Red raspberry	Paper birch (T)	White-cedar (SE)
White pine (SA)	Fringed bindweed	Paper birch (SE)	Balsam fir (SE)
White pine (SE)	One-sided pyrola	Mountain maple	Mountain-ash (SE)
Juneberry		Sweet bedstraw	White spruce (SE)
Sweet fern		Stiff clubmoss	Fly honeysuckle
Velvet-leaf blueberry		All Other mosses	Ground-hemlock
Cow-wheat			Thimbleberry
			Bishop's cap
			Violet
			Oak fern
			Hylocomium
7	6	5	12

pine (USDA Forest Service 1965). The next most important tree species is black spruce, with only 26 trees and less than 5 BA.

Jack pine is also important in the sapling class with a density of 69 stems and 4 BA. Black spruce saplings are almost as important, with 55 stems and 2 BA. Paper birch is less important in density and basal area than jack pine and black spruce, but it has a higher Index of Commonness because it is more widespread. Many of the jack pine in the sapling class are actually the same age as larger jack pine trees due to suppression and thus are not transgressive individuals important in succession.

The most important seedlings are red maple, red oak, and black spruce, with average densities of 9,000, 300, and 250 stems respectively. Red maple is a prolific s producer, thus small red maple seedlings are numer most will not live through the first few growing seas however.

Bush honeysuckle is the most important tall sh with an average density of almost 5,000 stems. Juneb shows only 1,500 stems but has a Browse Index of compared with 0.4 for bush honeysuckle; thus it is m important to wildlife. Beaked hazel is another impor tall shrub, with a density of over 2,000 stems an Browse Index intermediate between juneberry and b honeysuckle (table 4).

Late sweet blueberry is an important member of low shrub class. It, along with wintergreen, velvet

Table 1. — Density per acre (D), basal area per acre (BA), importance value (IV), and Browse Index (BI) for seven important tall shrubs in the 12 communities

Community	Willow D	Willow BA	Willow IV	Willow BI	Juneberry D	Juneberry BA	Juneberry IV	Juneberry BI	Bush honeysuckle D	Bush honeysuckle BA	Bush honeysuckle IV	Bush honeysuckle BI	Green alder D	Green alder BA	Green alder IV	Green alder BI
Lichen	409	0.1	12	1.50	100	0.1	4	1.85	8,375	1.8	29	0.90	0	0.0	0	0.00
Jack pine (oak)	328	.4	9	1.15	1,509	.4	15	1.17	4,796	1.0	39	.45	923	.6	10	.77
Jack pine (fir)	35	.1	1	2.00	479	.2	4	.92	6,014	1.3	36	.67	1,279	1.0	10	.60
Jack pine-black spruce	21	.1	1	1.30	707	.2	19	1.26	2,571	.5	39	.77	279	.2	8	.65
Black spruce-jack pine	5	.1	1	2.00	40	.1	4	1.75	840	.2	40	.73	60	.1	8	.00
Aspen-birch	386	.5	2	2.18	1,117	.8	4	1.34	21,309	4.5	27	.87	5,785	3.9	11	.83
Maple-aspen-birch	40	.3	1	.70	683	.4	6	.87	1,207	.3	8	.54	580	.5	4	.45
White pine	25	.1	1	2.00	892	.4	12	1.45	12,525	2.6	49	.97	442	.3	3	.60
Red pine	100	.1	2	3.00	1,700	.4	23	2.48	225	.1	5	.67	750	.4	14	2.00
Budworm-damaged	20	.1	1	1.83	215	.1	5	.77	2,025	.4	19	.61	435	.4	3	1.00
Fir-birch	0	.0	0	.00	88	.1	2	1.58	338	.1	4	.51	25	.1	1	1.50
White-cedar	6	.1	1	1.00	44	.1	1	1.17	317	.1	5	.72	56	.1	1	.00

Community	Beaked hazel D	Beaked hazel BA	Beaked hazel IV	Beaked hazel BI	Fly honeysuckle D	Fly honeysuckle BA	Fly honeysuckle IV	Fly honeysuckle BI	Mountain maple D	Mountain maple BA	Mountain maple IV	Mountain maple BI
Lichen	0	0.0	0	0.00	0	0.0	0	0.00	8	0.1	1	0.00
Jack pine (oak)	2,296	.8	15	.76	50	.1	1	.33	159	.1	2	1.00
Jack pine (fir)	5,500	2.8	27	1.04	564	.1	5	.78	2,100	1.3	14	.82
Jack pine-black spruce	1,479	.8	22	.63	93	.1	2	.25	164	.1	2	1.50
Black spruce-jack pine	25	.1	3	1.00	90	.1	7	1.75	0	.0	0	.00
Aspen-birch	13,383	7.4	32	1.08	609	.1	2	1.50	4,856	3.3	14	1.85
Maple-aspen-birch	7,613	3.9	42	.68	293	.1	2	1.50	3,767	2.3	30	.95
White pine	3,068	1.3	20	.87	375	.1	3	.60	1,583	1.8	16	.55
Red pine	1,438	.5	27	1.13	0	.0	0	.00	0	.0	0	.00
Budworm-damaged	3,355	1.6	28	.69	790	.2	14	.92	1,425	.9	25	1.46
Fir-birch	1,396	.8	15	.73	744	.2	8	.72	6,690	4.2	68	1.45
White-cedar	950	.6	12	.75	661	.1	13	.81	5,661	4.3	53	1.66

berry, and sweet-fern (a tall shrub), are all indicators elatively open, dry conditions.

he most important herbs and mosses are false lily-of-valley, large-leaf northern aster, Dicranum moss and eber's feather moss, and reindeer moss (lichens).

ack pine occurs primarily in a pioneer stage of sucon after mineral soil has been bared. In nature most ds originate following fire. The stands in this comity range from 60 to 105 years old, reflecting the s since the last major fire. In the absence of disturb-, jack pine tends to give way to more tolerant ies. In parts of Minnesota, on loamy sands or sandy ns, succession moves toward red pine and eastern e pine and then to northern hardwoods. Sometimes ed and white pine stages are absent and the trend is rd shrubs like alder and hazel, and then to aspen paper birch followed by either northern hardwoods ruce-fir (USDA Forest Service 1965). In the north-part of the Great Lakes-St. Lawrence Region (as de-l by Rowe (1959)) jack pine is replaced by black spruce, white spruce, and balsam fir or by red and white pine, which are followed in turn by a spruce-balsam mixture (Cayford *et al.* 1967). In northeastern Minnesota and Canada, jack pine is thought to be succeeded by black spruce, white spruce, balsam fir, and paper birch (LeBarron 1948). Sapling and seedling data from this community within the BWCA generally support LeBarron's interpretation of jack pine succession for northeastern Minnesota. However, significant amounts of red maple and red oak reproduction and smaller amounts of red and white pine reproduction are present. Thus, while we believe this community is following the general pattern of succession to spruce and fir proposed for northeastern Minnesota and Canada, it also shows a tendency toward hardwood or red and white pine stages which have been proposed for other portions of this region.

The data suggest that this type will decrease with continued protection from disturbance. The process may be much slower in this community than in others where

Figure 4. — Dense balsam fir reproduction in a jack pine (fir) community.

jack pine is an important constituent because of the poor site quality.

Jack Pine (Fir)

This community is similar to the jack pine (oak) community in two respects: (1) Both are totally dominated by jack pine (trees), and (2) both show a relatively short period since last major fire.

The jack pine (fir) community (fig. 4) ranks high on the Environment Index. It has the highest value on the moisture gradient but is much lower on the nutrient gradient. The short period since disturbance is indicated by a low ranking on the Fire Disturbance Index (table 1).

It differs from the jack pine (oak) community in four major respects: (1) Soils are much deeper, mostly more than 20 inches, and often more than 40 inches above bedrock; (2) bedrock outcrop is not generally found in the stands, although the ground surface may contain numerous large boulders; (3) it is more consistently found on mid- to lower slopes, as well as occasionally on upper slopes and ridgetops; and (4) it is more often located on north to northeast facing slopes.

Not only are the soils deep, but they tend to be high in silt and clay content. This is also true for the soils of the jack pine (oak) community. The silt-plus-clay fraction in the B soil horizon is higher for these two communities than any of the others. This has also been no for another study area of the BWCA. 2/ We believe presence of jack pine communities on soils with hig silt-clay content reflects the influence of a history of disturbance rather than restriction of jack pine to cer sites through interspecific competition.

The total number of species found in the commu is 95, with an average of 46 per stand. Thirty families represented, none of which are unique to the comm ity. Three families, the Equisetaceae, Osmundaceae, Polygonaceae, are found here but not in any of the o jack pine communities. Only the aspen-birch commu shows a higher Index of Diversity than this commun The flora is highly variable from stand to stand wi the type, as indicated by the Index of Homogeneit 0.55 (table 2).

Prevalent modal species are white spruce sapli twinflower, goldthread, and running club-moss. In a tion to these there are 11 other modal species that not prevalent (table 3).

2/ Ohmann, L. F. A study of two recent wildfire in the Boundary Waters Canoe Area. 1969. (Unpubli study plan on file at North Central Forest Exp. USDA Forest Serv., St. Paul, Minn.)

As in the jack pine (oak) community, jack pine is *the* lominant of the canopy with an average density of 303 stems and a BA of 90. Balsam fir with 40 trees and 7 BA ınd black spruce with 57 stems and 10 BA are of lesser mportance. Other trees are quaking aspen, paper birch, vhite spruce, and even fewer bigtooth aspen, balsam poplar, and red maple.

The dominant saplings are balsam fir and black pruce, which combined account for 250 stems and 10 3A. Balsam fir is more evenly spread through the stands of the community but black spruce is present in greater numbers and has a slightly greater basal area. Paper birch s also important in the sapling class. As in the jack pine oak) community, the few jack pine saplings present are he same age as the overstory trees and are not really ransgressive. Other saplings present include quaking spen, white spruce (which has its greatest value as a apling in this community (fig. 12 in Appendix)), bigooth aspen, and red maple.

The most important tree seedling is balsam fir, with ,400 stems and 2 percent ground cover. Red maple, uaking aspen, and paper birch seedlings are fewer with 00, 300, and 220 stems, respectively. Black spruce eedlings are uncommon, with an average of 135 stems, nd are not found in every stand within the community.

The tall shrub layer is much better developed here han in the jack pine (oak) community and is dominated y bush honeysuckle and beaked hazel, with an average f 6,000 and 5,500 stems each. Mountain maple is also nportant, with over 2,000 stems per acre. Other tall hrubs, in order of decreasing importance, are green lder, fly honeysuckle, juneberry, and willow. Of these, villow, beaked hazel, juneberry, and mountain maple how the heaviest browsing by wildlife (table 4).

The low shrub class is not well developed; the most nportant species is late sweet blueberry, which has an verage ground cover of about 1 percent (compared with lmost 7 percent in the jack pine (oak) community able 7 in Appendix)). Dewberry is the second most imortant, with velvet-leaf blueberry, wintergreen, prickly ose, pipsissewa, and creeping snowberry (which reaches s maximum importance here (fig. 15 in Appendix)) all f lesser importance.

The herb layer is well developed. The five most ommon flowering herbs have a combined ground cover f 25 percent. The most important of these is large-leaf orthern aster; others are false lily-of-the-valley, bunchcrry, twinflower, and Clinton's lily.

As is generally the case when the herb layer is well developed, mosses and lichens are scarce.

The five most common mosses and lichens have a combined ground cover of 19 percent. The most important are Schreber's feather moss and Dicranum moss.

The community is rather young in terms of succession, and will apparently give way to more tolerant balsam fir, and white and black spruces.

Jack Pine-Black Spruce

This is the third of the four communities in which jack pine is a major canopy constituent. In many ways the community is much like the two previously described; however, in those jack pine is clearly dominant, while here it is only codominant with black spruce.

On the Environment Index it is the lowest ranking of the jack pine group (table 1). It is lower for the following reasons: (1) low water retention capacity of the B soil horizon; (2) location of stands on southerly and southwesterly facing slopes; (3) location of stands farther from water bodies; and (4) low levels of calcium, potassium, phosphorous (and low pH) in the B soil horizon. This community ranks highest of the jack pine group in the Fire Disturbance Index (table 1). Most of the stands originated in 1864, a few in 1894, and one as late as 1918. The stands are slightly older than those in other jack pine community types.

Stands were found on upper and lower slopes, but not in valleys or on ridgetops. Slope of the terrain within stands averaged 8 percent, with a range from 3 to 13 percent. Soil depths are consistently between 24 and 36 inches over bedrock; bedrock outcropping is uncommon, but large boulders at the soil surface and in the upper soil horizons are conspicuously present.

Eighty-three species representing 26 families were encountered, with an average of 42 species per stand. None of the families are unique to the type.

Only five plants are modal and three of these are prevalent (table 3). The latter are black spruce trees and seedlings, and bunchberry. The two nonprevalent modal plants are the flat-stemmed ground-pine (a club-moss) and bigtooth aspen seedlings. The Index of Diversity is 20.5 and the Index of Homogeneity 0.50 for this community (table 2).

The most numerous tree is black spruce with 160 stems, compared with 127 stems for jack pine. However, jack pine has 54 BA, while black spruce has only 32.

This means that the jack pine are larger but that there are fewer of them. Other trees of much less importance are quaking aspen, paper birch, white pine, red pine, balsam fir, white spruce, and red maple.

The sapling class is dominated by black spruce with 186 stems and 6 BA. Paper birch is a distant second with 25 stems and less than 1 BA. Also present in this class are balsam fir, red maple, quaking aspen, and a few other species.

Red maple is the most numerous seedling (4,000 stems),but it is probably not as important in terms of successional processes as black spruce. Although the black spruce seedlings number only 550 per acre, they provide a ground cover almost equal to the 4,000 red maple seedlings. Also present are quaking aspen, paper birch, balsam fir, and white pine seedlings.

Tall shrubs are less abundant here than in either the jack pine (oak) or jack pine (fir) communities. Bush honeysuckle is the most common with 2,500 stems, but has a low Browse Index (table 4). Beaked hazel is second with 1,500 stems, but also a low Browse Index. Juneberry is only the third most important shrub in stems per acre, but it has a relatively high average Browse Index (table 4). Other shrubs are green alder, fly honeysuckle, and mountain maple.

The low shrub class is dominated by the late sweet blueberry. Of lesser importance are wintergreen, velvetleaf blueberry, raspberry, prickly rose, and other species.

The herb and moss-lichen components are about equally well represented. Bunchberry is the most important herb and Schreber's feather moss is the most important moss. False lily-of-the-valley, large-leaf northern aster, Clinton's lily, and bracken fern are other important herbs. Dieranum moss is also important.

The two best indicators of this community are the black spruce dominance of the sapling class and bunchberry dominance of the herbs.

While jack pine is important in this community, black spruce is more consistently present in all stands. One stand in this type does not have jack pine in it at all. In another stand red pine is more important than jack pine, while in others white pine is more important. The type could as well have been called the mixed pine-black spruce community.

The fact that jack pine tends to dominate the tree class may be due to the initial composition of the stand after the last fire and more rapid growth of the jack pine. This resulted in black spruce being suppressed, ai consequently many of the black spruce stems now fa into the sapling class instead of the tree class.

In some stands the jack pine trees present were dyin Thirty more jack pines would have been included in tl sample of 560 trees had they been alive.

As noted above, many of the black spruce saplings this community are actually the same age as the blac spruce trees. Paper birch, balsam fir, and red maple a probably the species in this community that are ir portant in succession. The presence of black spru seedlings, however, indicates the ability of black spru to maintain itself. Another feature of young blac spruce that may be of some importance in succession their capability of layering (vegetative reproduction).

Jack pine will become less important in this cor munity in the near future. Red pine and white pine w continue to be present in the community for a long time, due to their greater longevity. Black spruce w probably become more important in the tree class ar somewhat less important in the sapling class, as mo balsam fir, paper birch, and other tolerant speci become more important. Concurrent changes in tl understory plants will also occur; more mountain map and fly honeysuckle will become established; and mo cover will increase over herb cover.

Black Spruce-Jack Pine

This community is not very similar to the others the jack pine group (fig. 5). It is characterized by ve poor development of shrub and herb components ai an extremely well developed moss layer, which produc a carpet-like appearance on the ground. Surface bould are common but are mostly covered by the luxuria growth of mosses, and thus appear more like moun rather than boulders.

The community is in the middle of the Enviro ment Index and its position is influenced by peri since disturbance, as indicated by its lower ranking in tl Fire Disturbance Index (table 1).

Stands are most often located on southerly ai westerly facing slopes, and on mid- to lower slop (although some occur on upper slopes and ridgetop Slopes averaged 9 percent and ranged from 5 to : percent.

Soil depths are mostly in the range of 18 to : inches above bedrock. They are deeper than the soils

Figure 5. — The sparse understory and moss-covered forest floor of a black spruce-jack pine community.

the jack pine (oak) community but generally shallower than those of the jack pine (fir) community. Bedrock outcrops in the stands are limited, but boulders on the surface and in the upper part of the soil profile are a major feature.

Many stands in this community originated from fires in 1864, 1894, and 1903. Some stands that did not fall within the sample followed a 1910 fire.

The lack of a well developed shrub and herb layer probably accounts for the relatively low number of species encountered in this community — a total of 75 in the type and an average of 26 per stand. Twenty-three families are represented in the flora, none of which are unique to this community. The Index of Homogeneity is the highest of all of the forested communities (0.82), indicating that the stands in this type are similar to each other floristically (table 2).

The four prevalent modal species are black spruce (saplings), Schreber's and plume feather mosses, and Dicranum moss (table 3). This is another indication of the luxuriant moss growth. Two other species are modal in this community but are not prevalent — Labrador tea (a shrub), and creeping lattice-leaf (an orchid).

Two species dominate the tree class: black spruce, which is very common (409 stems) but of relatively small diameter (67 BA), and jack pine, which is less common (315 stems) but of larger diameter (78 BA). Of much less importance are scattered balsam fir, paper birch, quaking aspen, white spruce, and an occasional northern white-cedar.

The sapling class is dominated by black spruce, with 444 stems and 18 BA. Many of these are suppressed. Less common saplings are paper birch, balsam fir, a few suppressed jack pine, and scattered stems of white spruce and white-cedar.

Balsam fir seedlings are most abundant (1,395 stems), but they constitute only 0.8 percent of the ground cover. Black spruce averages fewer seedlings (610), but covers 1.1 percent of the area. White-cedar is of some importance with 360 stems and 1.3 percent cover. This is the only community in the jack pine group in which white-cedar is present in any important amount. Other seedlings present are quaking aspen, paper birch, mountain-ash, and red maple.

The tall shrub class is not well developed; in fact only 6 of 10 stands in this type have tall shrubs present. The only tall shrub of any importance is bush honeysuckle, with only 840 stems and 0.2 BA (table 4, and fig. 14 in Appendix). Some stands of this community have a few stems of juneberry, and some have a few beaked hazel or fly honeysuckle. A few scattered individuals of other species are also present.

The low shrub class is also poorly represented. Some of the stands have a few prickly rose, late sweet blueberry, velvet-leaf blueberry, wintergreen and a few other species.

Herbs are not conspicuous, as indicated by a combined ground cover of only 3.9 percent for the five most important species. These are false lily-of-the-valley, twinflower, large-leaf northern aster, bunchberry, and wild sarsaparilla. In contrast to the herbs, the five most important mosses have a total of 59.2 percent ground cover. In addition to the prevalent modal species of the community listed, reindeer moss and other lichens are also important.

The community is similar to SAF cover type 6 — jack pine-black spruce — which is considered to be a transition type in which jack pine is succeeded by the longer-lived and more tolerant black spruce. The quantity of black spruce is thought to increase in relation to the age of the stand (Society of American Foresters 1954). While time may be a major factor in determining the importance of black spruce, it is apparent that initial composition following disturbance is also significant. The stands described here are not yet old enough to show much more than initial composition and very early understory development. In our community the understory black spruce may be mostly suppressed individuals that originated following the initial disturbance and thus are the same age as the overstory trees. Species seeding into this community type must be able to penetrate the thick carpet of feather mosses. The presence of black spruce in the sapling and seedling classes of this community certainly supports the idea that black spruce will increase in time at the expense of the jack pine. The presence of large numbers of balsam fir seedlings, however, suggests that it may be transitional to a type where black spruce predominates but with balsam fir as a co-ordinate species (SAF cover type 7).

Aspen-Birch

The most conspicuous features of this community are the importance of quaking aspen trees, the presence of large numbers of quaking aspen and paper birch saplings, the well developed tall shrub layer of bush honeysuckle and beaked hazel, and the well developed herb component (fig. 6).

The community falls about midway on the Environment Index, being lower on the moisture gradient and somewhat higher on the nutrient gradient than most of the other communities (table 1). When last major fire disturbance is considered (Fire Disturbance Index), the aspen-birch community ranks eighth (table 1).

Slope positions are about equally divided among ridgetop, upper, mid-, and lower slopes. Slope averages 11 percent, with a range from 5 to 22 percent.

Soils are generally deep, with 36 to 40 inches common, although a few of the upper slope positions have as little as 12 inches.

Six of the stands examined originated from a fire in 1875, four from a fire in 1864, and a few from more recent fires.

This community contains the largest number of species (112), representing 30 families. One family is

Figure 6. — The aspen-birch community has a conspicu-ous tall shrub layer.

unique to this community — the Aristolocheaceae — represented by wild ginger. One family (the Orchidacea represented by the round-leaf rein-orchid) is presen in this community and not in the other broad-leaf com-munity.

The flora of this type has the largest Diversity Inde and a relatively high Homogeneity Index (0.59) (table 2). The largest number of modal species for all communitie are represented here with 27, 11 of which are also con-sidered prevalent (table 3). Three of the prevalent modal are trees, saplings, and seedlings of quaking aspen. Pape birch saplings are also prevalent. Three tall shrubs ar represented in this category: beaked hazel, green alder and round-leaf dogwood. Four herbs are also in thi category: large-leaf northern aster, Clinton's lily, bracke fern, and upland strawberry (table 3).

Quaking aspen is the most important of the 11 specie in the tree class; it accounts for 102 stems and 42 BA ou of the total of 190 stems and 80 BA for all trees. Of th others, only paper birch and balsam fir are of any im-portance.

The sapling class is codominated by quaking aspen with 102 stems and 4.3 BA, and paper birch with 11 stems and 3.5 BA. Balsam fir is present (43 stems and 1.4 BA), along with eight other species.

The tall shrub layer is very dense, with 49,000 stems and 22 BA. The two most important species are bush honeysuckle and beaked hazel, neither of which is heavily browsed in this community. Mountain maple and juneberry are less abundant, but they are browsed heavily (average Browse Index 1.8 and 1.3, respectively). Willow is even less important, but it is also heavily browsed with an average Index value of 2.2 (table 4). Ten other species are represented in the tall shrub class.

Low shrubs are not well represented in this community. Dewberry is the most common, while velvet-leaf blueberry is the most important with an average ground cover of 1 percent. Late sweet blueberry, raspberry, and a few others are also present.

The herbs are much more significant than mosses and lichens. The plant with the highest Commonness Index in the community is large-leaf northern aster with an average ground cover of 22 percent (its highest value for any community – fig. 16 in Appendix). Also important are wild sarsaparilla with 7 percent and Clinton's lily with 4 percent ground cover. False lily-of-the-valley and bunchberry are also common but show a lower average ground cover.

The nearest SAF cover type equivalent is type 16 (aspen) or type 11 (aspen-paper birch). These are generally recognized as pioneer vegetation types that eventually give way to a number of different communities. The specific succession depends on the region (USDA Forest Service 1965). In the BWCA this type will probably give way to some combination of balsam fir-spruce-paper birch. One often sees stands with an aspen-birch canopy and a well developed understory of balsam fir with scattered black and white spruce.

Twelve percent of the virgin vegetation stands in the sample were classified as aspen-birch community. The type will decrease with continued protection from disturbance. With this change in vegetation a corresponding change in wildlife species can be expected.

Maple-Aspen-Birch

The most outstanding feature of the community is the importance of red maple in all three size classes. It falls close to the aspen-birch community on the Environment Index. The community is slightly higher on the heat gradient and slightly lower on the nutrient gradient. It ranks seventh highest on the Fire Disturbance Index (table 1).

This type appears equally adapted to valley and upper slopes. No other community was found as frequently in valleys. Slope steepness is highly variable, averaging 12 percent but ranging from 2 to 35 percent.

Soil depths are generally 20 to 40 inches. A few of the stands located in the western BWCA at low elevations (about 1,320 feet) are on lacustrine deposits. These sediments are postulated to be from glacial Lake Agassiz, which may have extended into this area of northern Minnesota. Some of these stands have poor drainage.

The majority of stands in this type originated in the major fire years of 1864 and 1894. Two are located in areas believed to have last burned prior to 1800, one in 1759 and the other in 1784.

Thirty-four families represented by 104 species were encountered in these stands, with an average of 46 species per stand. The Tiliaceae family, represented by a few basswood seedlings, was found only in one stand. Several families are found here that are not encountered in the aspen-birch community: the Balsaminaceae, represented by jewelweed; the Equisitaceae, represented by horsetail; the Fagaceae, represented by red oak; and the Polygonaceae, represented by fringed bindweed.

Both the Index of Diversity (21.8) and Index of Homogeneity (0.49) are lower than in the aspen-birch community. The Index of Distinctness is 15.9, compared with 25.6 for the aspen-birch community (table 2).

Eighteen species are modal and seven of these are prevalent modal species (table 3). The only tree represented in this category is red maple, which tends to make this community distinct from the aspen-birch community. Three herb species in this category are also common in all the other communities: false lily-of-the-valley (present in 98 percent of all 106 stands sampled), starflower (present in 71 percent of all stands), and common twisted stalk (present in 46 percent of all stands). Ground-pine, a club moss, is also a modal prevalent species.

The tree class is dominated by quaking aspen with 123 stems and 56 BA, but red maple and paper birch are also significant. Smaller balsam fir trees are also present, as are a few black spruce and in some stands a few large white pine trees.

The sapling class dominance is shared by paper birch, red maple, and balsam fir with 112, 90, and 111 stems and 4, 3, and 4 BA respectively. Quaking aspen, black spruce, white spruce, and a few others are also represented in this class.

Red maple is the most numerous seedling present with an average of over 19,000 stems and 5 percent ground cover. Balsam fir is also important with 1,500 stems and 2 percent ground cover. Quaking aspen, paper birch, white pine, red oak, and mountain-ash are less important.

The tall shrubs are less numerous here than in the aspen-birch community, but are still conspicuous. Beaked hazel is the most common with about 7,600 stems, and mountain maple is second with 3,800 stems. Bush honeysuckle, juneberry, round-leaf dogwood, fly honeysuckle, and green alder are also present. Fly honeysuckle has the highest average Browse Index (1.5) for the community (table 4).

As in the aspen-birch community, the low shrubs are not very prominent. Only three are of much importance, late sweet blueberry, raspberry, and dewberry (fig. 15 in Appendix).

Herbs are more important than mosses and lichens. Some of the most important herbs have been mentioned as prevalent modal plants. Others that are important although not modal are large-leaf northern aster, Clinton's lily, wild sarsaparilla, bunchberry, violet, bracken fern, and goldthread. Many other species are also present. The majority of mosses are not feather mosses, although Schreber's feather moss and Dicranum moss are present.

The most similar SAF cover type might be type 11, if one considers the red maple as only an associate in the stand. The role of red maple in this community is difficult to ascertain, since the description is based on averages for the 15 stands that make up the community. In some of the stands the vigor of red maple may be due to the presence of fine-textured lacustrine soils, in others it may be due to valley slope position and perhaps slightly poorer subsoil drainage, and in still others due to nutrient flushing. In a few stands it may also be due to the age of the stand. Red maple may act as an intermediary species, living longer than aspen and being somewhat more tolerant (USDA Forest Service 1965); thus it replaces the aspen to a degree and is in turn replaced by fir and spruce. Whatever the reason, it certainly is a prominent feature of the stands of this community now, but will probably decrease in importance with time as fir and spruce become more important. About 15 percent of the upland virgin vegetation stands in th sample were classified as maple-aspen-birch communit

White Pine

Only six of the randomly selected stands compo the white pine community (fig. 7). The communi ranks in the middle of both the Environment Ind and the Fire Disturbance Index. While it is compa tively high on the moisture gradient, it ranks lower the heat and nutrient gradients (table 1).

Figure 7. – A supercanopy of white pine and understo of balsam fir in a white pine community.

The stands are on midslope to ridgetop positio slope averages 17 percent, but ranges from 4 to 45 pe cent. Stands are found on northeast- to south-faci slopes. Soil depth is generally more than 24 inches a often more than 40 inches above bedrock.

The stands comprising this community are slight older than those in most of the communities describ thus far. In some cases there are remnants of old stands present; for example, in one stand the ma canopy originated following a fire in 1875 but there a individuals present from a previous stand that originat following a fire in about 1680. Most of the stan sampled originated following fires in 1864 or 1875.

A total of 80 species are present, with an average 41 per stand. Twenty-three families are represented the flora, none of which are unique to the communit The community does contain a few families that we not found in the red pine community. They are t Fabaceae, Rubiaceae, and Violaceae, as represented b lathyrus and vetch, bedstraw, and violet, respectivel Eight species are modal in the community, the followi four of which are prevalent (table 3): white pine, bu honeysuckle (tall shrub), and wild sarsaparilla and wo anemone (herbs). Those modal but not prevalent a prickly rose, pussytoes, meadow strawberry, and virgin's-bower. The Indices of Diversity and Homogeneity are not very different from those of the red pine community. The two communities do have different values on the Index of Distinctness (white pine community 10.0, red pine community 24.3) (table 2).

The tree class is strongly dominated by white pine, which has 188 trees and 125 BA. The second most important tree is balsam fir with 91 stems and 12 BA. Red pine is present in the tree class, but to a limited extent, with only 24 stems and 16 BA. Also present are paper birch, quaking aspen, white spruce, jack pine, red maple, and black spruce.

The sapling class is composed primarily of balsam fir with 166 stems and 6 BA. Paper birch, white pine, red maple, and quaking aspen each have from 10 to 20 stems per acre. Scattered individuals of other species are also present.

Balsam fir is also the dominant tree seedling, with over 15,000 stems per acre but only about 1 percent ground cover. White pine seedlings are present also, averaging over 2,000 stems and 0.3 percent ground cover. Quaking aspen, paper birch, red maple, white spruce, mountain-ash, black spruce, and also a few red pine seedlings are present.

The tall shrub class is made up mostly of bush honeysuckle, with over 12,000 stems per acre. This species is browsed more heavily here than in any of the other communities in which it occurs (table 4). This probably reflects its dominance of the tall shrubs; if an animal is present and must eat, it will utilize this less-preferred species. Beaked hazel averages over 3,000 stems per acre. Mountain maple and juneberry are also of some importance.

Velvet-leaf blueberry is the most common low shrub of the community, late sweet blueberry is second, and prickly rose, dewberry, raspberry, and wintergreen are less common. The low shrub layer is not well developed.

Herbs are more important than mosses and lichens in this community. Most important are large-leaf northern aster, false lily-of-the-valley, and bunchberry. Schreber's feather moss and Dicranum moss are present but of less importance than the other type of mosses.

This community is really a two-layered forest: a supercanopy of large, old white pine trees with scattered red pines and a lower layer of balsam fir trees and saplings. In the past this understory was probably periodically eliminated by ground fires passing through, perhaps killing some pines, and often establishing a seedbed for pine regeneration. It is possible that the fires were frequent enough so that an understory of fir never was as well established as it is today.

It is likely that the already small area occupied by this type will gradually decrease as the old pines die and are not replaced. This will occur slowly due to the longevity of white pine, unless the process is speeded up by the influence of white pine blister rust (*Cronartium ribicola*).

Species present in the tall shrub and herb layers, such as mountain maple, fly honeysuckle, goldthread, and bedstraw, are also characteristic of the fir-birch community type. This might be a reflection of the dense balsam fir understory in this community.

Red Pine

An attractive feature of this community is the presence of open stands of old, majestic red and white pines (fig. 8). This is perhaps the most aesthetically pleasing of all the communities for most visitors and campers.

Figure 8. – The understory in the red pine community has a dry, open aspect.

The community ranks comparatively low on the Environment Index, primarily due to its lower values on the moisture and nutrient gradients; it ranks ninth in the Fire Disturbance Index (table 1). This reflects, as in the white pine community, both the longevity of the species and also a general lack of disturbance of the stands for a long time.

Only four stands of this community were encountered in the random sample, so the resulting data are variable (and may be less reliable). These stands could be grouped with those of the white pine community to describe a red and white pine community type. The resulting tree data might be less variable, but the two communities are sufficiently different in all regards to classify them separately.

The four stands all occupied different slope positions, ranging from ridgetop to lower slope. Slope was either quite steep or very moderate; two stands averaged 5 and 9 percent, and two averaged 31 and 35 percent. Soil was moderately deep — from 20 to 36 inches. Soil texture, soil water retention capacity, and soil depth were all lower than in the white pine community, and were lower than in most of the other communities also. Average pH was the lowest of all communities, and nutrient levels were also low. Distance to nearest water body of 5 acres or more was low; only the fir-birch community was more consistently near water. This may reflect the small sample number or it may reflect the importance of the protection water bodies can provide from certain fires. Such protection could alter the frequency of fire disturbance in these communities. Red pine produces a seed crop on the average of every 3 to 7 years (USDA Forest Service 1965). Thus, these areas may have received better protection than the general upland area during some of the past holocausts when even the fire resistance of mature red pine would not have prevented total destruction of the canopy. This is speculation of course, but it is supported by the casual observation that red pine stands occur more often around the shorelines of large lakes than farther inland.

The red pine community has the fewest species (67) of the forested communities, averaging 38 per stand. Twenty-five families are represented, which is about the same as in the other communities. No families are unique to this type, but several are not encountered in the white pine community. These are the Cupressaceae, Fagaceae, Myricaceae, and Orchidaceae, all of which are represented by species indicative of open, dry conditions.

Sixteen species are modal, nine of which are also prevalent (table 3). Among these are red pine (trees and saplings), white pine (saplings and seedlings), juneberry and sweet-fern (tall shrubs), velvet-leaf blueberry (low shrub), and cow-wheat (herb).

Tree-class dominance is shared by red pine with 157 trees and 147 BA and white pine with 90 trees and 58 BA. Paper birch, jack pine, red maple, and red oak are also present. Balsam fir, black spruce, white spruce, and white-cedar are less common.

Saplings are not abundant in this community, averaging only 66 stems per acre of all species. Although no one species really dominates, white pine is the most numerous with 22, followed by black spruce with 10, and red pine, paper birch, red maple, balsam fir, white-cedar, jack pine, red oak, and white spruce with six or less.

Red maple is the most numerous seedling with abou 4,500 stems per acre, but only 0.8 percent ground cover White pine averages 3,300 stems but has 1.9 percen ground cover. Black spruce, paper birch, quaking aspen red oak, red pine, mountain-ash, white spruce, and a fe others are also present but less important at this time.

The tall shrub layer is poorly developed, with june berry most common (1,700 stems per acre) and also im portant as a browse source. Juneberry's Browse Inde is higher here (2.5 of a possible 3.0) than in any of th communities in which it occurs (table 4). Beaked haze averages more than 1,400 stems. Scattered individuals o other tall shrubs such as bush honeysuckle, green alde sweet fern, low juniper, and willow are present.

Late sweet blueberry dominates the low shrub clas with an average of 7 percent ground cover; velvet-lea blueberry and wintergreen are also important with 5 an 3 percent, respectively. This is the only community i which bearberry is of much importance (fig. 15 in Ap pendix).

The mosses and lichens are more prominent tha herbs. The ground layer appears rather open and scat tered. The five most important herbs combined contr bute 11 percent ground cover, while the five most im portant mosses and lichens together account for 26 pe cent ground cover. The most important plants in thi layer are Dicranum moss and Schreber's feather moss lichens other than the reindeer mosses, and herbs such a false lily-of-the-valley, large-leaf northern aster, and cow wheat.

This community will apparently be present for som time with a gradual increase in black spruce, red maple red oak, and to a lesser extent balsam fir and whit spruce. These species may form a subcanopy below supercanopy of the red and white pines. This communit shows many of the same conditions as the jack pine (oak community; that is, shrubs and lichens characteristi of dry conditions are prominent, and red maple and re oak are associates in the tree, sapling, and seedlin classes. Yet the species important in the generally ac cepted succession for this area, black spruce, pape birch, white spruce, and balsam fir, are also present. Th presence of white pine in the sapling and seedling classe indicates that white pine may continue to be present i the community to some extent (assuming that bliste rust does not prevent it). There is little evidence t support the successional sequence developed by th USDA Forest Service (1965) — i.e., red pine replacin jack pine. The nearest equivalent is SAF forest cove type 15 (red pine).

Budworm-Disturbed

The budworm-disturbed community is characterize by dominance of balsam fir in the sapling and seedlin classes, and by the severe spruce budworm damage to most stands (fig. 9).

igure 9. — Spruce budworm damage opens the canopy in the budworm-damaged community, resulting in a heavy growth of shrubs.

The community is located on the upper end of the Environment Index because of its comparatively high anking in the moisture and nutrient gradients, and ranks enth on the Fire Disturbance Index (table 1).

Most stands are found in north-facing mid- to upper lope position. Slope within the stands averages 10 perent, with a range from 5 to 18 percent.

Soils are commonly between 20 to 40 inches above edrock. Almost every field description indicated numerus large boulders in the upper soil horizons, or more ock than soil in the soil profile.

Most of the stands were last disturbed by wildfire in 864, although a few were older and a few younger.

A total of 102 species of plants are encountered, ith an average of 46 per stand. Thirty-one families are epresented, none of which are unique to the type. leven plants are modal, the following five of which are revalent (table 3): white spruce (tree); raspberry and ewberry (low shrubs); and shinleaf and fringed bindeed (herbs). The Index of Distinctness is 11.1, as comared with 19.5 for the fir-birch community. The type is ore homogeneous than the fir-birch community and lso shows a greater degree of floral diversity (table 2). ll of these differences reflect the presence of plant pecies that commonly occupy disturbed sites.

The tree class is not dominated by balsam fir but by lack spruce, paper birch, and quaking aspen, with 65, 9, and 57 stems and 18, 12, and 31 BA, respectively. alsam fir has only 35 stems and 6 BA. If the standing ead trees were considered, balsam fir would have an average density of 110 stems and 19 BA. Thus the larger balsam fir have been influenced strongly by the budworm. Six other species are also present in the tree class.

The sapling class is dominated by balsam fir, indicating the budworm has had less influence on the smaller balsam fir. Balsam fir saplings have an average density of 128 stems and 3 BA. Paper birch, with an average of 40 stems and 2 BA, and black spruce, with an average of 21 stems and 1 BA, are also important.

The seedling class is also dominated by balsam fir — 3,600 stems and 4.5 percent ground cover. Paper birch and red maple are numerically important with almost 1,500 and 1,200 stems, but they account for only 0.6 and 1.1 percent of the ground cover. Eight other species are present; two of these are mountain-ash with 160 stems and white-cedar with 15 stems per acre. In the fir-birch community these two are much more important.

The tall shrub class is well developed, with over 8,000 stems per acre. The most important tall shrub is beaked hazel with 3,000 stems and 1.6 BA, followed by bush honeysuckle with 2,000 stems and 0.4 BA. Mountain maple is also important with 1,500 stems and 0.9 BA. Other tall shrubs present are fly honeysuckle, juneberry, and green alder. Of those listed, mountain maple is most utilized by wildlife with an average Browse Index of 1.5 (table 4).

The low shrub class is well represented, with about twice as much ground cover as in the fir-birch community. This probably reflects the open conditions due to disturbance. The only communities having a larger average ground cover of low shrubs are the dry, open jack pine (oak) and red pine communities. Raspberry is the most important low shrub with almost 8 percent ground cover. Dewberry is also important with 1.1 percent ground cover. Of lesser importance are late sweet blueberry, velvet-leaf blueberry, prickly rose, and a few others.

The prominence of the herb and moss layer also reflects the disturbed conditions. The five most important species of mosses, lichens, and herbs combined account for more than 46 percent ground cover. A higher value is found only in the black spruce-jack pine community, due principally to the dense mat of mosses. In this community both mosses and herbs are important. The most important herbs are false lily-of-the-valley, bunchberry, large-leaf northern aster, twinflower, and Clinton's lily. The most important mosses are Schreber's feather moss and Dieranum.

About 9 percent of the stands in the upland virgin vegetation sample were classified as budworm-disturbed community. After the current budworm disturbance, a community similar to the fir-birch type will probably be regenerated. Our data support the observation of Ghent *et al.* (1957) that there is an increase of formerly less-abundant shrub species following spruce budworm outbreaks. Bakuzis and Hansen (1965) also point out that competing shrub vegetation may delay balsam fir reproduction. Newfoundland conditions studied by W. M. Robertson (Candy 1951) showed balsam fir natural regeneration in softwood forest cover types to be 2,000 stems per acre. Following disturbance by cutting he found 2,800 stems, and after disturbance by fire only 35 stems per acre. While there is a well developed shrub layer in the budworm-damaged stands, there is probably an adequate stocking (average of 76 percent on milacre plots) and density (3,600 stems per acre) of balsam fir to regenerate the community.

Fir-Birch

The most unique features of this community are (1) its proximity to water, (2) the importance of balsam fir in all three tree size classes, (3) the importance of mountain maple as a tall shrub, and (4) the poor development of the ground cover flora.

The community ranks high on the Environment Index. It has a relatively high rating on the moisture gradient primarily due to soil depth, and ranks high on the heat gradient due to slope position and nearness to water. It ranks high on the nutrient gradient due to high calcium content of the B soil horizon. This community ranks eleventh on the Fire Disturbance Index (table 1). While stands are old (long period since fire disturbance), they are not quite as old as those of the white-cedar community.

Stands tend to be on lower slopes, and occasionally on mid- to upper slopes at lower elevations. Slope within the stands averages 12 percent, ranging from 5 to 30 percent.

Soils are deep (for this area), ranging from 20 to more than 40 inches above bedrock. Distance from stand to nearest water body 5 acres or larger averages about 70 meters and ranges from 20 to 135 meters. This community is on the average closer to water than any of the others, the next closest being the red and white pine communities.

Thirty families represented by 86 species were encountered, with an average of 42 species per stand. The families Boraginaceae and Taxaceae were encountered only in this and the white-cedar community. Thirteen species are modal and eight of these are prevalent (table 3). Balsam fir (trees and saplings), and paper birch (trees and seedlings) are among these. One tall shrub (mountain maple) is prevalent, as are bedstraw, stiff club-moss, and mosses other than hairycap moss an feather mosses.

Balsam fir, with 154 stems and 26 BA, and pape birch, with 106 stems and 27 BA, are codominant in th tree class. Black spruce and white-cedar are less im portant with 31 and 23 stems and 9 and 11 BA. Whit spruce, quaking aspen, white pine, mountain-ash, an jack pine are also present.

Balsam fir dominates the sapling class with 260 stem and 8 BA. Paper birch is important with 77 stems and BA. Black spruce, white-cedar, quaking aspen, whit spruce, and mountain-ash are of less importance.

Balsam fir also dominates the seedling class wit almost 10,000 stems per acre and about 6 percent groun cover. Paper birch is also important in this class wit 2,000 stems and 0.5 percent ground cover. Mountain-as and white-cedar are rather important with 550 and 1,50 stems and 0.5 and 0.4 percent ground cover.

The well-developed tall shrub class has over 9,00 stems per acre, and unlike this class in most of the othe communities, it is dominated by mountain maple bot in numbers (6,600 stems) and in basal area (4.2). Beake hazel is of secondary importance with 1,400 stems an 0.8 BA. Fly honeysuckle, bush honeysuckle, juneberry round-leaf dogwood, green alder, ground-hemlock, an chokecherry are also present. Of special interest is ground hemlock, which was encountered only in this and th white-cedar community. Here it is of minor importance A number of the tall shrubs noted above were utilize by wildlife (table 4). Browse Index values averaged 1. for mountain maple, 1.5 for ground-hemlock, 1.5 fo green alder, and 1.5 for juneberry.

The low shrub class is poorly developed in this type It is dominated by raspberry, which accounts for a average of 4.0 percent ground cover. The total groun cover for all the low shrubs is only 5.7 percent, thu raspberry (an indicator of disturbance) may reflect th smaller amount of spruce budworm damage present i stands of this community.

The five most common mosses, lichens, and herb average only 32 percent ground cover. Only the white cedar community type has a lower value. This probabl reflects the low light penetration and perhaps increase precipitation interception by the dense canopy. Mosse and lichens are more prominent than herbs: the mosses other than hairycap or feather mosses, average 11.5 pe cent, Schreber's feather moss averages 9.3 percent, an Dicranum moss averages 1.5 percent ground cover. Large leaf northern aster, bunchberry, false lily-of-the-valley twinflower, violet, wild sarsaparilla, Clinton's lily, bed straw, and goldthread are the most prominent herbs.

About 8 percent of the upland virgin vegetation stands sampled were classed as fir-birch community. The type could increase considerably as other communities progress along the evident successional trends and as severely budworm-damaged stands recover. On the other hand, the type could temporarily decrease with a renewal of the current budworm outbreak. Any decrease will eventually be compensated for by succession in other types and eventual recovery of damaged stands. The high tolerance of the major species encountered in this community indicates the capability of the type to maintain itself (fig. 10)

White-Cedar

An unusual characteristic of this community is the dominance of northern white-cedar on an upland site. White-cedar is more common on lowland or poorly drained sites in this area.

The community ranks highest on the Environment Index. It is high on the heat gradient due primarily to low total annual insolation and also to high values for aspect, slope position, and distance to water. It is also high on the nutrient gradient due to its high calcium content in the B soil horizon. The white-cedar community ranks twelfth on the Fire Disturbance Index (table 1).

Average elevation is the highest of all communities at 1,802 feet (range is 1,530 to 1,930 feet). The stands are found mostly on north- to northeast-facing slopes at lower slope positions. Slope gradient averages 19 percent and ranges from 5 to 39 percent.

Soils are generally deep, between 20 and 40 inches above bedrock. Boulders are numerous in some of the stands, but no bedrock outcrop is apparent.

All of the stands were extensively burned prior to 1871, and one dated back to 1680.

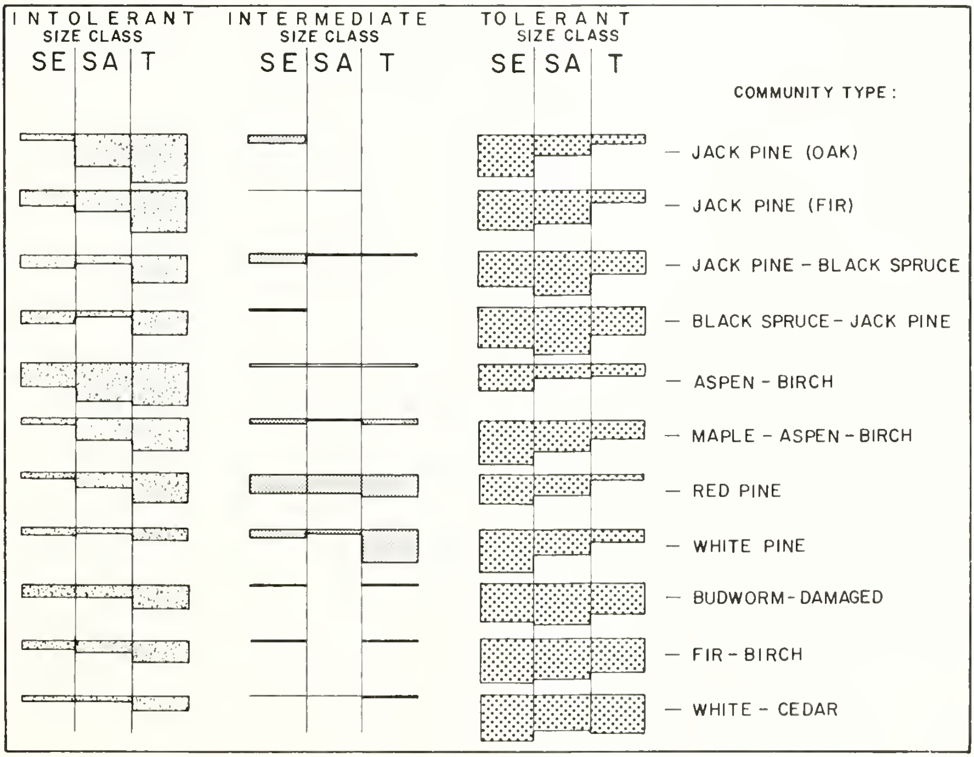


Figure 10. — Average importance value of tree species within each community (forested) in three tolerance classes and three size classes. T = tree size class; SA = sapling size class; and SE = seedling size class. Tolerance classes are a combination of those of Graham (1954) and Baker (1949), as follows:

Tolerant: balsam fir, basswood, black spruce, mountain-ash, red maple, white-cedar, white spruce.

Intermediate: black ash, red oak, white pine.

Intolerant: bigtooth aspen, jack pine, paper birch, quaking aspen, red pine, tamarack.

Twenty-eight families represented by 85 species (an average of 38 species per stand) were encountered. Two families are unique to this type: the Ophioglossaceae and Oxalidaceae. Two families are found only here *and* in the fir-birch community: the Boraginaceae and Taxaceae.

Twenty-five (second highest of all communities) modal species are found, 13 of which are prevalent (table 3). Six of these are tree species: white-cedar (trees, saplings, and seedlings); balsam fir, mountain-ash, and white spruce (seedlings); fly honeysuckle and ground-hemlock (tall shrubs); thimbleberry (low shrub); oak fern (fern); bishop's-cap and violet (herbs); and Hylocomium, a feather moss.

The community ranks second highest on the Index of Distinctness, following the lichen community (table 2).

The tree class is dominated by white-cedar with 214 stems and 83 BA. Paper birch and balsam fir are of secondary importance, with 75 and 77 stems and 28 and 17 BA, respectively. White spruce, quaking aspen, white pine, black spruce, mountain ash, and red pine are also present.

White-cedar and balsam fir codominate the sapling class with 169 and 177 stems and 6 and 5 BA. Paper birch, white spruce, mountain-ash, black spruce, white pine, jack pine, and quaking aspen are also found.

Balsam fir dominates the seedling class numerically with more than 14,000 stems per acre, but comprises only 1.7 percent ground cover. White-cedar is less abundant with slightly over 2,000 stems per acre and a ground-cover value of 1.2 percent. Mountain-ash is also important with 800 stems per acre and 0.7 percent ground cover. Paper birch, white spruce, white pine, quaking aspen, red maple, and black spruce are of minor importance.

The tall shrub layer is fairly well developed, with over 12,000 stems per acre; the largest contributors to this total are mountain maple and ground-hemlock, with 5,661 and 4,317 stems each – the highest values for these species in any community (fig. 14 in Appendix). Species common in most of the other communities, such as bush honeysuckle, juneberry, willow, beaked hazel, and green alder, are less abundant here. Mountain maple and ground-hemlock are evidently highly utilized by wildlife, as indicated by the average Browse Index values of 1.7 and 2.1 (table 4).

The low shrub layer is poorly developed; only the black spruce-jack pine community has a sparser low shrub cover. Thimbleberry and dewberry are the only important species.

The herb layer is also sparse; the five most important mosses, lichens, and herbs only total 20-percent ground cover, the lowest of all the forested communities. False lily-of-the-valley, bunchberry, starflower, large-leaf northern aster, Clinton's lily, and violet are the most important herbs.

The white-cedar community type seems to be best developed on the eastern half of the BWCA, on fairly steep north-facing slopes of the Rove Slate Geological Formation. These sites are on the north slopes of east-west trending ridges, which parallel elongated lakes. They may have historically had a lower fire frequency than most of the BWCA, and thus contain more mature forest.

The data suggest that the community will remain much the same for a long period of time. White-cedar is a rather long-lived species. Balsam fir may become more important if it is not disturbed by the spruce budworm. Several factors can influence this community. Fire, of course, would set the type back, but the influence of the spruce budworm on balsam fir and the influence of white-tailed deer on the white-cedar reproduction may also be important. White-cedar is a preferred winter browse species; in many areas white-cedar stands are used by deer as winter yards.

DISCUSSION

Community Dynamics

Plant communities are dynamic; they are constantly changing and cannot be frozen in time, either as they are now, or as they were at some time in the past. In the past the BWCA was mapped as part of the Northern Pine Belt by Sargent (1884), the Lake Forest Region by Weaver and Clements (1938), and as part of the Hemlock-White Pine-Northern Hardwood Forest by Nichols (1935) and Braun (1950). Nichols referred to the region as a "mesophytic forest comprising a mixture of evergreen coniferous and deciduous broadleaf trees." Braun characterized the region as a "pronounced alternation of deciduous, coniferous and mixed forest communities." The area has been considered as a transitional zone between the boreal and eastern deciduous forest formations, or as a formation in itself composed of one or more associations (Flaccus and Ohmann 1964).

Maycock and Curtis (1960) studied the boreal conifer-hardwood forests of the Great Lakes Region. They selected for study only stands that contained white spruce as an indicator of boreal conditions. Based on data from Minnesota, Wisconsin, Michigan, and Ontario, they concluded the Great Lakes Forest Region to be composed of both boreal and deciduous forest species, with boreal species predominating toward the north.

Published reports of plant community studies conducted wholly within the BWCA are nonexistent. But a number of studies have been concerned specifically with vegetation of northeastern Minnesota and have been based on data or observations in or near the BWCA. Among the earliest were those by Bergman and Stallard (1916) and Bergman (1924). They concluded the area to be a pine climax with primary (both xerarch and hydrarch) and secondary succession leading to the pine climax. This conclusion is repeated by Brann (1950). Waring (1959) postulated a mesophytic climax of white and red pine above an understory of balsam fir and spruce. Waring's conclusion in part supports Cooper's (1913) concept of balsam fir-white-spruce-white birch climax vegetation for the general area.

Buell and Niering (1957) included three fir-spruce stands located within the BWCA in their study of fir-spruce-birch forests of northern Minnesota. They found that all three stands from the BWCA had been recently occupied by pine forests.

Based on our study of the virgin upland vegetation of the BWCA, we believe that with continued protection from disturbance the following dynamic changes in the plant communities will take place:

The lichen community will become more woody; that is, the shrub layer will become more important, and a poorly developed scrubby tree canopy will start to form. As soil development proceeds, the sites could probably support a jack pine-black spruce type and eventually a black spruce-feather moss community.

The jack pine-dominated communities where black spruce is important and also the red pine community will probably become dominated by black spruce. They will perhaps eventually become a black spruce-feather moss type with a poorly developed shrub or herb component. The successional trend to more tolerant species in the communities can be seen in the composition of the sapling and seedling classes (fig. 10).

The jack pine community where fir is important and the other communities (not already fir-dominated) seem to be headed toward dominance by balsam fir, paper birch, white-cedar, white spruce, and to a lesser extent black spruce. A scattered supercanopy of white and/or red pine may also be present. The tall shrub layer may be dominated by mountain maple and fly honeysuckle, the low shrubs by dewberry, and the ground flora by scattered mosses and representative herbs such as false lily-of-the-valley, bunchberry, large-leaf northern aster, starflower, wild sarsaparilla, goldthread, twinflower, and bedstraw.

A method of making these predictions more quantitative is badly needed. We have a study underway to accomplish this for the tree species. Based on current composition of tree, sapling, and seedling components, we hope to be able to predict percent composition of tree species in a stand 50 years into the future.

The community changes discussed above can be interrupted by many kinds of disturbances — wildfire, windstorms, insect epidemics, disease, the influence of animals such as the white-tailed deer and beaver, or indirectly through the influence of predators such as the fisher (*Martes pennati* Erxleben), marten (*Martes americana* Turton), or timber wolf (*Canis lupus* L.). Animal populations shift with the changes in plant communities. Herbivores depend directly on the kinds of plants in the communities and predators are affected by changes in herbivore populations.

Maintenance of virgin (natural) plant communities in all stages of succession is best accomplished by allowing all of the natural disturbance factors to operate by chance. However, some factors cannot always be allowed to operate because they may threaten property adjacent to a wilderness area, or endanger visitors in the area. The alternative might be to introduce controlled disturbance.

If the policy is to maintain the area as natural as possible, the only disturbance factor that is ecologically and economically feasible seems to be the controlled use of fire (Heinselman 1970). A research program aimed at determining the ecological effects of prescribed fires in standing forest is needed to provide the basis for such an operational community-maintenance program.

Community Comparisons

Comparison of the cluster analysis dendrogram with the principal components analysis led to the selection of 12 community types. The efficiency of the cluster analysis at the selected level is 59 percent, implying that almost 60 percent of variability in the sample is accounted for by the heterogeneity of the 12 community types (Orloci 1967). The first three components of the principal components analysis account for 46 percent of the variation. The vegetation is apparently quite variable, even though it is all upland natural vegetation in a relatively small region.

Although the names assigned to the community types reflect important features of the communities (usually the dominant tree or trees), they are arbitrary and are provided primarily for ease of discussion and identification.

The prevalent modal species for each community are listed in table 3. A modal species is one that has its maximum presence value in a given community. If the species is, by presence ranking, above the average for all species in the community, it is also considered a prevalent species. According to Curtis (1959), this is equivalent to the "floristic-characteristic species combination" of Raabe (1952). The number below each list of prevalent modal species (table 3) is the number of other modal species in the community. These species occurred less frequently in the community and thus are not considered prevalent.

Community comparisons are shown in table 2. The number of stands and percent of all stands sampled for each community reflects in a general way a real distribution of each of the types within the region, because the stands were randomly selected. Although the community types presented here are not directly equivalent to the "cover types" designated by the Society of American Foresters, the areas occupied by our community types and the corresponding "cover types" reported for the Boundary Waters Canoe Area in 1948 (Management Plan for the Roadless Area, Superior National Forest) are fairly similar.

The number of species varies from 32 in the lichen community to 112 in the aspen-birch community. These figures are not absolute because certain plants were treated as groups rather than at the specific level. Plants in this category include mosses other than feather mosses, Dicranum, and hairycap moss, lichens other than the reindeer mosses and peltigera, grasses, and sedges.

Floristic analysis by stand and community shows a minimum of 132 species encountered in the sample. These represent 47 different families. No single family shows a clear predominance, but there is a definite difference in importance of some families. Six families contributed 42 percent of all the species. These are the Ericaceae, Rosaceae, Pinaceae, Polypodiaceae, Compositae, and the Caprifoliaceae. Twelve families contributed 61 percent of the total species composition. In addition to those already listed they are the Liliaceae, Lycopodiaceae, Betulaceae, Salicaceae, Cladoniaceae, and the Ranunculaceae families. In terms of frequency of occurrence in the sample plots and points, the families contributing most were the Dicranaceae, Gramineae, Betulaceae, Aceraceae, Liliaceae, Hypnaceae, Pinaceae, and the Primulaceae (table 18 in Appendix). The number of families represented in each of the communities ranges from 19 for the lichen to 34 in the maple-aspen-birch community. A chi-square test failed to show any significant difference in number of families represented in each of the communities.

The Index of Diversity, a measure of floral richness, shows the flora of the lichen community to be least diverse and the flora of the aspen-birch community most diverse (table 2).

It is important to know how closely stands within a community type resemble each other — that is, how homogeneous the community type is. The Index of Homogeneity shows this. In the BWCA the values range from 0.46 for the jack pine (oak) community to 0.9[illegible] for the lichen community (table 2). In Wisconsin, Curtis (1959) reported a range from 0.44 for the wet-mesic southern forest community to 0.65 for the dry-mesic southern forest community, with the boreal forest community rating 0.58. This again indicates that even though the stands within a community type are more similar to each other than to stands of other communities, there is still much variability.

The Index of Distinctness provides some indication of the uniqueness of each community. The number of modal prevalent species is expressed as a percentage of the total number of prevalent species for a community (Curtis 1959). This is based on the assumption that if many of the most common species have optimum presence values in a particular community, that community should be more distinct than one in which the most common species do not show an optimum presence. The Distinctness Index ranges from 7.3 for the jack pine-black spruce community to 50.0 for the lichen community (table 2). This compares with a range of 10.2 to 56.1 for all forest community types in Wisconsin (Curtis 1959). This Index must be cautiously interpreted; for example, Curtis (1959) shows an Index of 56.1 for dry-mesic southern forest and 56.3 for bracken-grassland communities, and again, 28.6 for lake-beach and 29.[illegible] for wet-mesic prairie communities. However, even though the Index values are similar in these two sets of examples, the community types are quite distinguishable from each other. Comparisons must be restricted to community types which appear similar physiognomically, have similar floras, and therefore might be expected to have similar Index values. Curtis (1959) recognized this when he referred to distinctness of *related communities.* As an example, the jack pine (fir) and the jack pine (oak) communities of our study appear similar but have Index values of 8.9 and 17.9, respectively. Another example might be the apparently similar maple-aspen-birch and aspen-birch communities with Distinctness Index values of 15.9 and 25.6, respectively (table 2). We conclude that, in terms of this Index, the plant communities as classified are rather distinct entities.

Another way of comparing the communities is to test for statistical differences in species characteristics. The only common species not showing a statistically significant difference among communities is paper birch seedlings. Two species, wild sarsaparilla and fly honeysuckle, are significantly different only at the 5-percent level of probability. While this is more evidence that the communities as classified are indeed unique, it does not show which (or if all) communities are different. This same idea is shown graphically in figures 11 through 17 in the Appendix in which importance of either density values (tree and tall shrub species) or percent ground cover values (low shrubs and herbs) for the most important species are depicted.

The Environment and Fire Disturbance Indices are simplified attempts to show some exceedingly complex relationships (table 1). Many other factors could have been included and some used as readily omitted. The Environment Index value differences among communities are low and are probably not even statistically significant. Yet, the position of most of the communities on this Index and especially on the Fire Disturbance Index (even if fortuitous) makes sense ecologically. The changes in ranking that occur when the period since fire disturbance is considered are especially interesting. We believe this indicates that the history of periodic disturbance may be more important than many environmental factors over a relatively small region such as the virgin vegetation area of the BWCA. We also feel, but cannot show, that the species composition prior to the last major fire disturbance is also important. The environmental factors that do seem important may be related to the history of disturbance also. For instance, distance to nearest water body of 5 acres or larger may reflect protection from certain types of fires. Nutrient levels are thought to increase as vegetation progresses toward a climax. This is certainly related to periodicity of disturbance. Slope aspects and positions that are more favorable microclimatically for vegetation may be less favorable in terms of fire disturbance. These examples all point to the interrelationship of environmental factors, of which fire is but one, and it is doubtful that any one or two characteristics can change without modifying others (Billings 1952). We conclude that differences in the structure and composition of the plant communities of the virgin vegetation of the BWCA are primarily due to differences in the time elapsed since the last major wildfire disturbance and the composition of the vegetation present at the time of that disturbance. Thus we see major changes occurring in the plant communities due to the fire protection policy of the Forest Service.

The significance of man's influence on ecosystems through disruption of the periodic natural disturbances has been most recently expressed by Loucks (1970). He hypothesized that evolution in ecosystems has brought about an adaptation to a repeated pattern of changing environments in which species replacement is repeated over and over in time. The periodicity of this is thought to be several centuries in the northern lake forest, where he estimates white pine to have been recycled at intervals of 300 to 400 years. It is possible that if the virgin vegetation becomes primarily fir-spruce-birch forest, the spruce budworm could replace wildfire as a recurring natural cyclic disturbance. This would not, however, set community succession as far back as fire. According to Loucks (1970), modern man's halting of the random rejuvenation of the ecosystem through periodic disturbance is the greatest upset of the ecosystem of all time.

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APPENDIX

Species Nomenclature and Occurrence

Scientific and family names for tree species follow tle (1953); those for shrubs and herbs follow Gleason 963) with a few exceptions, in which either Lakela 965) or Fernald (1950) are used. Scientific names for lichens follow Hale and Culbertson (1965), and those for mosses follow Grout (1928-1940).

The first two data columns of table 5 represent the number and percent of stands in which the species occurred. The last two data columns represent the average percent frequency of occurrence in sample points or plots, and the maximum percent of frequency of occurrence in any stand.

Table 5. – Scientific names and occurrence for species in the virgin plant communities of the BWCA

Nomenclature			Presence		Frequency	
Common name	Scientific name	Family name	Number of stands	Percent of stands	Average	Maximum
EES						
lsam fir	Abies balsamea (L.) Mill.	Pinaceae	70	66.0	26.1	100
lsam poplar	Populus balsamifera L.	Salicaceae	1	.9	.1	5
gtooth aspen	Populus grandidentata Michx.	Salicaceae	11	10.4	.8	10
ack ash	Fraxinus nigra Marsh.	Oleaceae	1	.9	.1	5
ack spruce	Picea mariana (Mill.) B.S.P.	Pinaceae	71	67.0	28.7	100
ck pine	Pinus banksiana Lamb.	Pinaceae	60	56.6	31.6	100
untain-ash	Sorbus americana Marsh.	Rosaceae	4	3.8	.5	30
per birch	Betula papyrifera Marsh.	Betulaceae	85	80.2	29.2	100
aking aspen	Populus tremuloides Michx.	Salicaceae	72	67.9	29.3	100
d maple	Acer rubrum L.	Aceraceae	33	31.1	9.5	90
d oak	Quercus rubra L.	Fagaceae	6	5.7	.8	35
d pine	Pinus resinosa Ait.	Pinaceae	19	17.9	6.2	100
ite-cedar	Thuja occidentalis L.	Pinaceae	22	20.8	10.8	100
ite pine	Pinus strobus L.	Pinaceae	34	32.1	12.2	100
ite spruce	Picea glauca (Moench) Voss.	Pinaceae	56	52.8	7.4	50
PLINGS						
lsam fir			74	69.8	39.5	100
lsam poplar			1	.9	.1	5
gtooth aspen			10	9.4	.8	20
ack ash			3	2.8	.2	10
ack spruce			68	64.2	31.2	100
ck pine			28	26.4	7.7	100
untain-ash			18	17.0	1.1	20
per birch			89	84.0	38.6	100
aking aspen			56	52.8	16.1	100
d maple			38	35.8	14.1	100
d oak			10	9.4	1.8	35
d pine			6	5.7	1.4	40
ite-cedar			16	15.1	7.0	100
ite pine			21	19.8	4.5	80
ite spruce			42	39.6	4.5	45
EDLINGS						
lsam fir			82	77.4	37.5	100
sswood	Tilia americana L.	Tiliaceae	1	.9	.1	5
gtooth aspen			2	1.9	.1	10
ack ash			4	3.8	.5	20
ack spruce			41	38.7	6.1	50
ck pine			2	1.9	.2	15
untain-ash			49	46.2	9.6	80
per birch			75	70.8	13.4	70
aking aspen			74	69.8	16.6	70
d maple			53	50.0	25.8	100
d oak			14	13.2	4.2	85
d pine			6	5.7	.3	5
marack	Larix laricina (DuRoi) K. Koch.	Pinaceae	1	.9	.1	5
ite-cedar			17	16.0	4.1	65
ite pine			41	38.7	9.3	95
ite spruce			37	34.9	3.6	35
LL SHRUBS						
aked hazel	Corylus cornuta Marsh.	Betulaceae	82	77.4	31.9	100
bb willow	Salix bebbiana Sarg.	Salicaceae	26	24.5	2.3	30
sh honeysuckle	Diervilla Lonicera Mill.	Caprifoliaceae	86	81.1	36.6	100
okecherry	Prunus virginiana L.	Rosaceae	8	7.5	.4	10
wny arrow-wood	Viburnum rafinesquianum Schult.	Caprifoliaceae	7	6.6	.8	20
derberry	Sambucus spp.	Caprifoliaceae	1	.9	.1	5
y honeysuckle	Lonicera canadensis Marsh.	Caprifoliaceae	63	59.4	8.3	45
een alder	Alnus crispa (Ait.) Pursh.	Betulaceae	39	36.8	7.9	80
ound-hemlock	Taxus canadensis Marsh.	Taxaceae	6	5.7	2.4	100
iry climbing honeysuckle	Lonicera hirsuta Eat.	Caprifoliaceae	10	9.4	1.5	42
neberry	Amelanchier spp. Medic.	Rosaceae	79	74.5	14.5	60
w juniper	Juniperus communis L.	Cupressaceae	4	3.8	.5	30
untain fly honeysuckle	Lonicera villosa (Michx.) R.dS.	Caprifoliaceae	1	.9	.1	15
untain maple	Acer spicatum Lam.	Aceraceae	62	58.5	27.3	95
ncherry	Prunus pensylvanica L.F.	Rosaceae	14	13.2	.9	20
d osier	Cornus stolonifera Michx.	Cornaceae	3	2.8	.3	20
und-leaved dogwood	Cornus rugosa Lam.	Cornaceae	28	26.4	5.4	60
eckled alder	Alnus rugosa (DuRoi) Spreng.	Betulaceae	2	1.9	.1	5
iraea	Spiraea spp. L.	Rosaceae	1	.9	.1	5
eet fern	Comptonia peregrina B.&B., Small, Rydb.	Myricaceae	6	5.7	1.3	70
llow	Salix spp. L.	Salicaceae	8	7.5	1.4	45

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Table 5 continued

Common name	Scientific name	Family name	Presence: Number of stands	Presence: Percent of stands	Frequency: Average	Frequency: Maximu
LOW SHRUBS						
Bearberry	Arctostaphylos Uva-ursi (L.) Spreng.	Ericaceae	5	4.7	0.5	15
Creeping snowberry	Gaultheria hispidula (L.) Muhl.	Ericaceae	11	10.4	.6	10
Current	Ribes spp. L.	Saxifragaceae	5	4.7	.4	10
Dewberry	Rubus pubescens Raf.	Rosaceae	46	43.4	8.0	55
Labrador tea	Ledum groenlandicum Oeder.	Ericaceae	1	.9	.0	5
Late sweet blueberry	Vaccinium angustifolium Ait.	Ericaceae	65	61.3	17.0	100
Pipsissewa	Chimaphila umbellata (L.) Bart.	Ericaceae	19	17.9	1.2	15
Prickly rose	Rosa acicularis Lindl.	Rosaceae	27	25.5	1.9	20
Red raspberry	Rubus strigosus Michx.	Rosaceae	29	27.4	5.0	90
Thimbleberry	Rubus parviflorus Nutt.	Rosaceae	4	3.8	.8	35
Velvet-leaf blueberry	Vaccinium myrtilloides Michx.	Ericaceae	45	42.5	5.6	65
Wintergreen	Gaultheria procumbens L.	Ericaceae	28	26.4	9.0	90
HERBS						
American vetch	Vicia americana Muhl.	Fabaceae	5	4.7	.3	10
American pyrola	Pyrola rotundifolia L.	Ericaceae	6	5.7	.4	10
Barren strawberry	Waldsteinia fragarioides (Michx.) Tratt.	Rosaceae	4	3.8	.2	5
Bishop's cap	Mitella nuda L.	Saxifragaceae	17	16.0	3.2	55
Bristly sarsaparilla	Aralia hispida Vent.	Araliaceae	1	.9	.1	10
Bunchberry	Cornus canadensis L.	Cornaceae	89	84.0	28.1	95
Clinton's lily	Clintonia borealis (Ait.) Raf.	Liliaceae	71	67.0	18.9	100
Common twisted-stalk	Streptopus roseus Michx.	Liliaceae	46	43.4	6.3	55
Cow-wheat	Melampyrum lineare Desr.	Scrophulariaceae	25	23.6	2.8	65
Creambells	Uvularia sessilifolia L.	Liliaceae	2	1.9	.1	10
Creeping lattice-leaf	Goodyera repens (L.) R. BR.	Orchidaceae	14	13.2	.8	10
Early sweet pea	Lathyrus ochroleucus Hook.	Fabaceae	13	12.3	.7	10
False lily-of-the-valley	Maianthemum canadense Desf.	Liliaceae	98	92.5	48.4	95
Fireweed	Epilobium angustifolium L.	Onagraceae	4	3.8	.2	5
Fringed bindweed	Polygonum cilinode Michx.	Polygonaceae	4	3.8	1.2	60
Fringed milkwort	Polygala paucifolia Willd.	Polygalaceae	1	.9	.1	5
Goldenrod	Solidago spp. L.	Compositae	1	.9	.1	5
Goldthread	Coptis groenlandica (Oeder) Fern.	Ranunculaceae	28	26.4	3.9	55
Grasses		Gramineae	80	75.5	22.4	95
Grape-leaved colts-foot	Petasites vitifolius Rydb.	Compositae	8	7.5	.7	15
Greater lattice-leaf	Goodyera tesselata Lodd.	Orchidaceae	3	2.8	.2	15
Hepatica	Hepatica americana (DC) Ker.	Ranunculaceae	1	.9	.1	15
Indian-pipe	Monotropa uniflora L.	Ericaceae	1	.9	.1	5
Large-leaf northern aster	Aster macrophyllus L.	Compositae	93	87.7	44.1	100
Meadow strawberry	Fragaria virginiana Duchesne.	Rosaceae	3	2.8	.2	8
Northern bedstraw	Galium boreale L.	Rubiaceae	1	.9	.1	5
Northern enchanter's nightshade	Circaea alpina L.	Onagraceae	3	2.8	.3	15
Northern hound's tongue	Cynoglossum boreale Fern.	Boraginaceae	1	.9	.1	5
Northern lungwort	Mertensia paniculata (Ait.) G. Don.	Boraginaceae	1	.9	.1	15
One-flowered pyrola	Moneses uniflora (L.) Gray	Ericaceae	4	3.8	.2	10
One-sided pyrola	Pyrola secunda L.	Ericaceae	21	19.8	2.5	30
Pearly everlasting	Anaphalis margaritacea (L.) Benth. & Hook	Compositae	1	.9	.1	5
Pink corydalis	Corydalis sempervirens (L.) Pers.	Fumariaceae	3	2.8	.1	5
Pink shinleaf	Pyrola asarifolia Michx.	Ericaceae	1	.9	.1	10
Pussy's toes	Antennaria spp. Gaertn.	Compositae	2	1.9	.3	30
Rough hawkweed	Hieracium scabrum Michx.	Compositae	1	.9	.1	10
Round-leaved rein-orchid	Habenaria orbiculata (Pursh) Torr.	Orchidaceae	4	3.8	.2	5
Red baneberry	Actaea rubra (Ait.) Willd.	Ranunculaceae	1	.9	.1	5
Sedges		Cyperaceae	33	31.1	3.8	75
Shinleaf	Pyrola virens Schweigg.	Ericaceae	8	7.5	.5	10
Spreading dogbane	Apocynum androsaemifolium L.	Apocynaceae	8	7.5	.5	10
Star-flower	Trientalis borealis Raf.	Primulaceae	71	67.0	12.1	65
Sweet bedstraw	Galium triflorum Michx.	Rubiaceae	32	30.2	3.2	55
Touch-me-not	Impatiens capensis Meerb.	Balsaminaceae	5	4.7	.5	25
Trailing arbutus	Epigaea repens L.	Ericaceae	3	2.8	.1	5
Twin-flower	Linnaea borealis L.	Caprifoliaceae	64	60.4	13.6	60
Upland strawberry	Fragaria vesca L.	Rosaceae	30	28.3	4.7	65
Violet	Viola spp. L.	Violaceae	50	47.2	6.6	60
Virgin's bower	Clematis virginiana L.	Ranunculaceae	2	1.9	.1	5
Wake-robin	Trillium grandiflorum (Michx.) Salisb.	Liliaceae	1	.9	.1	5
White cinquefoil	Potentilla tridentata Soland.	Rosaceae	1	.9	.1	5
White-flowered shinleaf	Pyrola elliptica Nutt.	Ericaceae	7	6.6	.4	10
White wood-sorrel	Oxalis montana Raf. (Small)	Oxalidaceae	1	.9	.1	10
Wild ginger	Asarum canadense L.	Aristolochiaceae	1	.9	.1	15
Wild lettuce	Lactuca canadensis L.	Compositae	1	.9	.1	5
Wild sarsaparilla	Aralia nudicaulis L.	Araliaceae	83	78.3	18.6	75
Wood anemone	Anemone quinquefolia L.	Ranunculaceae	21	19.8	1.9	30

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Table 5 continued

Nomenclature			Presence		Frequency	
Common name	Scientific name	Family name	Number of stands	Percent of stands	Average	Maximum
FERNS AND FERN ALLIES						
Beach fern	Dryopteris Phegopteris B. & B.	Polypodiaceae	1	0.9	0.1	5
Bladder fern	Cystopteris fragilis (L.) Bernh.	Polypodiaceae	1	.9	.1	5
Bracken fern	Pteridium aquilinum (L.) Kuhn.	Polypodiaceae	38	35.8	5.9	60
Grape fern	Botrychium virginianum (L.) Sw.	Ophioglossaceae	1	.9	.1	15
nterrupted fern	Osmunda claytoniana L.	Osmundaceae	5	4.7	.3	10
Lady fern	Athyrium filix-femina (L.) Roth.	Polypodiaceae	4	3.8	.3	20
Oak fern	Gymnocarpium Dryopteris (L.) Newm.	Polypodiaceae	8	7.5	.8	35
Polypody fern	Polypodium virginianum Rydb.	Polypodiaceae	7	6.6	.4	15
Rusty woodsia fern	Woodsia ilvensis (L.) R. Br.	Polypodiaceae	1	.9	.1	5
Shield fern	Dryopteris spinulosa B. & B., Rydb., Small	Polypodiaceae	10	9.4	.8	25
Flat-stem groundpine	Lycopodium complanatum L.	Lycopodiaceae	11	10.4	.7	10
Ground pine	Lycopodium obscurum L.	Lycopodiaceae	47	44.3	7.5	55
unning clubmoss	Lycopodium clavatum L.	Lycopodiaceae	42	39.6	4.8	45
hiny clubmoss	Lycopodium lucidulum Michx.	Lycopodiaceae	3	2.8	.2	10
tiff clubmoss	Lycopodium annotinum L.	Lycopodiaceae	29	27.4	4.1	40
Horsetail	Equisetum spp. L.	Equisetaceae	3	2.8	.2	10
MOSSES						
icranum	Dicranum spp. Hedw.	Dicranaceae	67	63.2	27.2	100
airy-cap moss	Polytrichum spp. Hedw.	Polytrichaceae	55	51.9	7.0	75
ylocomium	Hylocomium splendens (Hedw.) Bry. Eur.	Hypnaceae	17	16.0	2.4	40
Peat moss	Sphagnum spp. L.	Sphagnaceae	4	3.8	.3	15
Plume moss	Hypnum crista-castrensis L.	Hypnaceae	31	29.2	2.7	50
chreber's moss	Calliergonella schreberi (Willd., Br. & Sch.) Grout	Hypnaceae	91	85.8	37.8	100
ll other mosses			103	97.2	56.2	100
ICHENS						
eindeer moss	Cladonia alpestris (L.) Rabenh.	Cladoniaceae	1	.9	.2	25
	Cladonia mitis Sandst.	Cladoniaceae	18	17.0	5.0	100
	Cladonia rangiferina Wigg.	Cladoniaceae	42	39.6	8.8	100
	Cladonia sylvatica (L.) Hoffm.	Cladoniaceae	4	3.8	.2	10
potted peltigera	Peltigera aphthosa (L.) Willd.	Peltigeraceae	3	2.8	2.1	80
ll other lichens			67	63.2	15.2	100
ROUND COVER CHARACTERISTICS						
are ground			23	21.7	1.9	25
are rock			64	60.4	13.2	100
ead wood (over 1 inch diameter)			103	97.2	33.2	85
itter			106	100.0	94.5	100
ive wood (over 1 inch diameter)			53	50.0	4.3	20

Community Baseline Data

Tables 6 through 17 present stand data summarized by community. The columns across each table represent species name or ground cover characteristic, number of stands in which the species occurred, percent of stands in which the species occurred, average frequency of occurrence in the sample points or plots, average density in stems per acre, average basal area in square feet p acre for tree and tall shrub species or average percen ground cover for other species, average values in percen for relative frequency, relative density, relative dom nance, and importance value, and finally, the Commo ness Index. Trees are indicated by (T) following th species name, saplings by (SA), and seedlings by (SE).

Table 6. – Stand data summary for the lichen community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Other lichens	6	100.0	93.3	--	28.1	18.3	--	28.2	23.0	9,333.3
Cladonia rangiferina	6	100.0	78.3	--	14.5	14.8	--	14.5	14.7	7,833.3
Other mosses	6	100.0	75.0	--	7.2	14.3	--	7.3	10.7	7,500.0
Cladonia mitis	6	100.0	59.2	--	8.9	11.0	--	9.0	10.0	5,916.7
Polytrichum spp.	6	100.0	33.3	--	4.5	6.0	--	4.5	5.3	3,333.3
Gramineae	6	100.0	19.2	--	1.6	59.3	--	67.3	63.3	1,920.0
Peltigera aphthosa	3	50.0	36.7	--	2.3	6.5	--	2.2	4.5	1,833.3
Vaccinium angustifolium	5	83.3	10.8	--	2.0	76.2	--	75.0	75.7	902.8
Diervilla Lonicera	3	50.0	9.2	8,375.0	1.8	21.7	32.7	32.7	29.0	458.3
Cyperaceae	3	50.0	3.3	--	.2	8.1	--	5.2	6.6	165.0
Corydalis sempervirens	3	50.0	2.5	--	.1	6.2	--	2.0	4.0	125.0
Amelanchier spp.	2	33.3	3.3	100.0	.1	6.8	2.3	2.3	3.8	111.1
Calliergonella schreberi	2	33.3	2.5	--	.1	.5	--	.2	.3	83.3
Salix spp.	1	16.7	4.2	366.7	.1	9.3	11.5	11.5	10.7	69.4
Dicranum spp.	1	16.7	3.3	--	.1	.5	--	.2	.3	55.6
Acer rubrum	1	16.7	2.5	25.0	.1	10.0	10.0	14.8	11.7	41.7
Pinus banksiana (SE)	1	16.7	2.5	33.3	.1	7.2	4.2	6.7	6.0	41.7
Rubus strigosus	1	16.7	2.5	--	.3	7.2	--	8.3	7.7	41.7
Quercus rubra (SE)	1	16.7	1.7	16.7	.1	6.7	6.7	1.8	5.0	27.8
Maianthemum canadense	1	16.7	1.7	--	.1	2.2	--	.7	1.5	27.8
Salix bebbiana	1	16.7	1.7	41.7	.1	2.5	.2	.2	.8	27.8
Populus tremuloides (SE)	1	16.7	1.7	41.7	.1	4.8	5.2	3.3	4.5	27.8
Aralia hispida	1	16.7	1.7	--	.3	5.5	--	8.0	6.8	27.8
Prunus pensylvanica	1	16.7	.8	8.3	.1	8.3	3.3	3.3	5.0	13.9
Sorbus americana (SE)	1	16.7	.8	8.3	.1	2.3	1.0	1.2	1.5	13.9
Melampyrum lineare	1	16.7	.8	--	.1	2.0	--	.5	1.3	13.9
Acer spicatum	1	16.7	.8	8.3	.1	1.3	.1	.1	.5	13.9
Streptopus roseus	1	16.7	.8	--	.1	1.2	--	1.5	1.3	13.9
Anemone quinquefolia	1	16.7	.8	--	.1	8.3	--	8.3	8.3	13.9
Betula papyrifera (SE)	1	16.7	.8	50.0	.1	2.3	6.2	5.5	4.7	13.9
Aster macrophyllus	1	16.7	.8	--	.1	2.0	--	1.7	1.8	13.9
Potentilla tridentata	1	16.7	.8	--	.1	2.2	--	1.7	1.8	13.9
Trientalis borealis	1	16.7	.8	--	.1	2.0	--	.8	1.5	13.9
Aralia nudicaulis	1	16.7	.0	--	.1	.0	--	1.3	.7	.0
Ground cover characteristic:										
Bare rock	6	100.0	94.2	--	29.7	18.5	--	29.7	23.8	9,416.7
Dead wood	3	50.0	7.5	--	.7	1.3	--	.8	1.2	375.0
Bare ground	3	50.0	5.0	--	.2	1.0	--	.2	.7	250.0
Litter	6	100.0	35.8	--	4.0	6.7	--	4.0	5.2	3,583.3

Table 7. — Stand summary data for the jack pine (oak) community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness index
ecies:										
Pinus banksiana (T)	11	100.0	97.7	314.9	82.3	67.4	80.8	83.5	77.3	9,772.7
Maianthemum canadense	11	100.0	65.5	--	3.7	33.7	--	23.7	28.9	6,545.5
Betula papyrifera (SA)	11	100.0	57.9	51.9	1.3	25.2	24.5	19.5	23.3	5,790.9
Dicranum spp.	11	100.0	56.4	--	7.9	16.1	--	8.0	12.0	5,636.4
Diervilla Lonicera	11	100.0	52.7	4,795.5	1.0	40.0	45.6	30.7	38.8	5,272.7
Vaccinium angustifolium	10	90.0	54.1	--	6.6	49.1	--	55.5	52.4	4,917.4
Calliergonella schreberi	11	100.0	49.1	--	13.8	14.2	--	14.0	14.0	4,909.1
Acer rubrum (SE)	10	90.9	49.5	9,118.2	1.9	51.2	60.7	46.0	52.6	4,504.1
Gaultheria procumbens	11	100.0	45.0	--	3.8	45.2	--	38.5	41.9	4,500.0
Pinus banksiana (SA)	11	100.0	44.5	69.3	3.9	23.3	26.7	34.7	28.3	4,454.5
Picea mariana (SA)	9	81.8	50.0	54.6	1.9	22.2	25.6	27.4	25.2	4,090.9
Aster macrophyllus	11	100.0	40.0	--	7.3	18.2	--	33.1	25.6	4,000.0
Other mosses	11	100.0	38.6	--	4.5	10.7	--	4.5	7.6	3,863.6
Amelanchier spp.	11	100.0	27.7	1,509.1	.4	19.5	12.4	12.8	14.9	2,772.7
Acer rubrum (SA)	9	81.8	26.1	21.3	.5	11.5	10.5	8.5	10.2	2,134.7
Picea mariana (T)	9	81.8	20.5	26.5	4.5	12.2	6.9	3.8	7.6	1,673.6
Gramineae	9	81.8	20.5	--	.9	9.6	--	5.4	7.4	1,673.6
Cladonia rangiferina	9	81.8	17.3	--	2.5	4.5	--	2.5	3.6	1,413.2
Other lichens	8	72.7	19.1	--	3.7	4.9	--	3.7	4.4	1,388.4
Corylus cornuta	8	72.7	18.2	2,295.5	.8	11.8	16.8	17.1	15.1	1,322.3
Polytrichum spp.	8	72.7	17.3	--	1.3	4.4	--	1.3	2.8	1,256.2
Aralia nudicaulis	10	90.9	13.2	--	1.2	8.5	--	9.2	8.7	1,198.3
Cornus canadensis	8	72.7	13.6	--	.9	5.8	--	4.5	5.1	991.7
Trientalis borealis	8	72.7	10.5	--	.3	4.5	--	1.5	2.9	760.3
Pteridium aquilinum	8	72.7	9.5	--	3.3	3.6	--	11.4	7.5	694.2
Populus tremuloides (SA)	7	63.6	10.5	5.3	.1	4.1	2.5	2.5	3.1	665.3
Alnus crispa	6	54.5	11.4	922.7	.6	7.2	9.7	13.3	10.0	619.8
Betula papyrifera (T)	7	63.6	8.6	10.2	1.4	4.4	2.6	1.3	2.9	549.6
Salix bebbiana	8	72.7	7.3	172.7	.2	6.9	3.9	11.4	7.4	528.9
Abies balsamea (SA)	8	72.7	6.8	2.8	.1	3.3	1.7	1.4	2.2	495.9
Quercus rubra (SE)	5	45.5	10.9	322.7	.3	9.7	6.5	11.3	9.0	495.9
Betula papyrifera (SE)	7	63.6	7.7	154.5	.2	7.1	4.6	6.5	6.0	491.7
Melampyrum lineare	5	45.5	10.5	--	.3	4.4	--	1.2	2.8	475.2
Cladonia mitis	6	54.5	8.6	--	1.6	2.1	--	1.5	1.9	471.1
Acer rubrum (T)	7	63.6	7.3	8.5	1.3	4.3	1.9	1.3	2.5	462.8
Quercus rubra (SA)	5	45.5	8.7	3.8	.1	4.3	2.6	1.8	2.8	396.7
Linnaea borealis	4	36.4	10.5	--	.9	4.8	--	4.7	4.7	380.2
Picea mariana (SE)	6	54.5	6.8	245.5	.9	10.5	14.4	18.8	14.5	371.9
Populus tremuloides (T)	7	63.6	5.5	5.9	1.1	3.5	1.5	1.0	2.0	347.1
Abies balsamea (SE)	4	36.4	7.3	154.5	.2	7.8	6.5	4.7	6.4	264.5
Populus tremuloides (SE)	6	54.5	4.5	95.5	.1	6.3	4.2	3.9	4.8	247.9
Clintonia borealis	5	45.5	5.0	--	.3	2.2	--	2.4	2.3	227.3
Comptonia peregrina	3	27.3	8.2	995.5	.2	5.1	5.3	4.4	4.8	223.1
Pinus strobus (SE)	4	36.4	5.5	72.7	.2	5.0	2.0	3.8	3.6	198.3
Pinus strobus (SA)	4	36.4	5.0	2.8	.1	2.0	1.4	1.3	1.7	181.8
Populus grandidentata (SA)	4	36.4	3.6	1.8	.1	1.3	1.1	1.5	1.2	132.2
Pinus resinosa (T)	2	18.2	6.4	6.1	5.5	3.3	2.0	4.9	3.4	115.7
Lycopodium obscurum	4	36.4	2.7	--	.1	1.2	--	1.0	1.1	99.2
Pinus resinosa (SA)	2	18.2	5.0	1.4	.1	1.7	1.3	.9	1.3	90.9
Vaccinium myrtilloides	3	27.3	3.2	--	.5	2.9	--	3.5	3.2	86.8
Populus grandidentata (T)	4	36.4	2.3	3.4	1.1	1.4	.7	.7	1.1	82.6
Salix spp.	2	18.2	4.1	154.5	.2	1.6	.7	2.3	1.5	74.4
Picea glauca (SA)	4	36.4	2.0	1.3	.1	1.0	.5	.1	.5	72.7
Lycopodium clavatum	4	36.4	1.8	--	.1	.8	--	.7	.7	66.1
Quercus rubra (T)	3	27.3	2.3	2.5	.4	1.3	.6	.4	.8	62.0
Lonicera canadensis	3	27.3	2.3	50.0	.1	1.6	1.0	.5	1.1	62.0
Pinus strobus (T)	2	18.2	3.2	5.6	3.9	1.4	1.5	2.9	1.9	57.9
Acer spicatum	2	18.2	2.7	159.1	.1	2.9	2.0	1.9	2.3	49.6
Abies balsamea (T)	3	27.3	1.8	1.9	.3	1.0	.4	.2	.5	49.6
Hypnum crista-castrensis	2	18.2	2.3	--	.9	.8	--	1.0	.9	41.3
Goodyera repens	3	27.3	1.4	--	.1	.6	--	.1	.3	37.2
Prunus virginiana	3	27.3	1.4	18.2	.1	1.2	.2	.2	.5	37.2
Cladonia alpestris	1	9.1	2.3	--	1.0	.9	--	1.0	1.0	20.7
Apocynum androsaemifolium	2	18.2	.9	--	.1	.4	--	.3	.4	16.5
Anemone quinquefolia	2	18.2	.9	--	.1	.4	--	.1	.2	16.5
Gaultheria hispidula	2	18.2	.9	--	.1	.7	--	.3	.5	16.5
Prunus pensylvanica	2	18.2	.9	13.6	.1	1.2	.5	.2	.5	16.5
Lycopodium complanatum	1	9.1	.9	--	.1	.5	--	.3	.5	8.3
Rosa acicularis	2	18.2	.5	--	.1	.2	--	.3	.3	8.3
Picea glauca (SE)	1	9.1	.9	22.7	.2	.9	.5	4.6	2.0	8.3
Thuja occidentalis (SA)	1	9.1	.9	.6	.1	.3	.2	.5	.4	8.3
Juniperus communis	1	9.1	.5	40.9	.1	.6	1.5	4.9	2.4	4.1
Spiraea spp.	1	9.1	.5	122.7	.1	.3	.6	.5	.5	4.1
Sorbus americana (SE)	1	9.1	.5	4.5	.1	.9	.5	.4	.6	4.1
Pinus banksiana (SE)	1	9.1	.5	4.5	.1	.5	.2	.2	.3	4.1
Epigaea repens	1	9.1	.5	--	.1	.2	--	.2	.2	4.1
Hylocomium splendens	1	9.1	.5	--	.1	.1	--	.1	.1	4.1
Lycopodium annotinum	1	9.1	.5	--	.1	.3	--	.3	.3	4.1
Fragaria vesca	1	9.1	.5	--	.1	.2	--	.2	.2	4.1
Chimaphila umbellata	1	9.1	.5	--	.1	.4	--	.9	.6	4.1
Dryopteris spinulosa	1	9.1	.5	--	.1	.2	--	.2	.2	4.1
Ground cover characteristic:										
Litter	11	100.0	90.5	--	55.8	25.7	--	55.9	40.9	9,045.5
Dead wood	11	100.0	29.5	--	3.0	8.5	--	3.0	5.5	2,954.5
Bare rock	10	90.9	19.5	--	2.8	5.2	--	2.6	4.1	1,776.9
Live wood	6	54.5	4.1	--	.5	1.0	--	.5	.8	223.1
Bare ground	4	36.4	1.8	--	.1	.5	--	.1	.4	66.1

Table 8. — Stand data summary for the jack pine (fir) community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Pinus banksiana (T)	7	100.0	94.3	303.3	90.3	52.6	64.3	71.4	62.7	9,428.6
Abies balsamea (SA)	7	100.0	72.1	97.1	3.5	33.0	35.7	37.0	35.3	7,214.3
Diervilla Lonicera	7	100.0	68.6	6,014.3	1.3	40.0	39.7	29.1	36.3	6,857.1
Aster macrophyllus	7	100.0	67.9	--	13.8	18.6	--	43.7	31.1	6,785.7
Maianthemum canadense	7	100.0	63.6	--	2.1	17.9	--	7.6	12.7	6,357.1
Other mosses	7	100.0	57.1	--	5.7	19.0	--	6.0	12.3	5,714.3
Cornus canadensis	7	100.0	55.7	--	5.2	14.0	--	13.1	13.3	5,571.4
Picea mariana (SA)	7	100.0	51.4	148.0	4.5	22.0	23.9	24.1	23.3	5,142.9
Betula papyrifera (SA)	7	100.0	50.0	62.9	1.3	21.6	22.3	16.0	20.0	5,000.0
Calliergonella schreberi	7	100.0	43.6	--	9.5	14.7	--	9.6	12.1	4,357.1
Abies balsamea (SE)	7	100.0	39.3	1,378.6	2.1	44.0	49.7	49.7	47.9	3,928.6
Linnaea borealis	7	100.0	34.3	--	1.8	10.4	--	7.4	9.1	3,428.6
Abies balsamea (T)	7	100.0	31.4	39.9	7.0	14.4	10.3	4.9	9.7	3,142.9
Corylus cornuta	5	71.4	40.7	5,500.0	2.8	18.4	28.4	34.7	27.1	2,908.2
Picea mariana (T)	6	85.7	28.6	57.4	10.4	14.1	12.0	7.6	11.0	2,449.0
Gramineae	5	71.4	26.4	--	.7	6.4	--	1.7	4.0	1,887.8
Vaccinium angustifolium	6	85.7	20.7	--	1.1	35.7	--	37.3	36.6	1,775.5
Clintonia borealis	5	71.4	24.3	--	2.2	5.3	--	4.9	5.1	1,734.7
Acer spicatum	5	71.4	22.9	2,100.0	1.3	12.9	14.4	14.6	14.0	1,632.7
Populus tremuloides (SE)	6	85.7	16.4	300.0	.3	19.0	16.3	13.9	16.3	1,408.2
Dicranum spp.	5	71.4	19.3	--	2.4	6.3	--	2.4	4.3	1,377.6
Amelanchier spp.	5	71.4	18.6	478.6	.2	8.0	2.4	2.3	4.3	1,326.5
Populus tremuloides (T)	5	71.4	17.9	28.6	16.7	8.9	6.7	12.1	9.4	1,275.5
Populus tremuloides (SA)	7	100.0	11.4	11.3	.5	5.3	3.4	4.0	4.7	1,142.9
Pinus banksiana (SA)	4	57.1	19.3	28.6	1.7	8.9	9.1	13.3	10.4	1,102.0
Aralia nudicaulis	7	100.0	10.7	--	1.7	3.3	--	5.4	4.4	1,071.4
Betula papyrifera (T)	5	71.4	14.3	13.3	3.2	6.7	3.6	2.4	4.1	1,020.4
Trientalis borealis	5	71.4	14.3	--	.4	3.4	--	1.0	2.3	1,020.4
Lonicera canadensis	5	71.4	13.6	564.3	.1	7.9	4.9	3.7	5.4	969.4
Alnus crispa	4	57.1	16.4	1,278.6	1.0	8.1	7.6	13.9	10.0	938.8
Rubus pubescens	4	57.1	15.7	--	.8	20.9	--	20.3	20.7	898.0
Vaccinium myrtilloides	6	85.7	10.0	--	.5	15.4	--	13.4	14.7	857.1
Lycopodium clavatum	5	71.4	11.4	--	.6	2.4	--	1.3	1.9	816.3
Picea glauca (SA)	5	71.4	11.4	13.4	.3	4.7	3.0	3.3	3.7	816.3
Betula papyrifera (SE)	5	71.4	10.7	221.4	.5	10.6	10.1	12.9	11.3	765.3
Coptis groenlandica	3	42.9	17.1	--	.6	3.6	--	1.3	2.4	734.7
Acer rubrum (SE)	4	57.1	9.3	535.7	.2	9.6	13.9	7.0	10.3	530.6
Lycopodium obscurum	4	57.1	9.3	--	.9	2.1	--	2.1	2.1	530.6
Sorbus americana (SE)	4	57.1	7.9	85.7	.2	7.7	4.1	5.3	5.7	449.0
Other lichens	4	57.1	7.9	--	.4	2.4	--	.3	1.4	449.0
Picea glauca (T)	5	71.4	5.7	6.3	1.3	2.7	1.4	1.1	1.9	408.2
Cladonia rangiferina	4	57.1	7.1	--	.6	2.4	--	.6	1.6	408.2
Polytrichum spp.	4	57.1	5.7	--	.2	1.9	--	.1	1.0	326.5
Lycopodium annotinum	3	42.9	6.4	--	.7	1.4	--	1.4	1.4	275.5
Picea mariana (SE)	3	42.9	5.7	135.7	.7	4.9	4.1	9.9	6.3	244.9
Fragaria vesca	2	28.6	8.6	--	.3	3.1	--	1.1	2.1	244.9
Cornus rugosa	3	42.9	3.6	150.0	.1	2.0	.7	.6	1.0	153.1
Gaultheria procumbens	2	28.6	5.0	--	.1	5.0	--	1.4	3.3	142.9
Streptopus roseus	3	42.9	2.9	--	.1	.6	--	.3	.4	122.4
Rosa acicularis	3	42.9	2.9	--	.3	6.1	--	10.9	8.6	122.4
Cyperaceae	3	42.9	2.9	--	.1	.6	--	.1	.4	122.4

(Continued on next page)

Table 8 continued

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
pecies:										
Chimaphila umbellata	3	42.9	2.1	--	0.1	4.1	--	0.9	2.6	91.8
Populus grandidentata	2	28.6	2.9	3.0	.1	1.6	0.9	1.0	1.1	81.6
Pteridium aquilinum	4	57.1	1.4	--	1.4	.3	--	3.4	1.9	81.6
Gaultheria hispidula	2	28.6	2.9	--	.3	3.1	--	4.9	4.0	81.6
Acer rubrum (SA)	2	28.6	2.9	1.3	.1	1.6	.7	.1	.7	81.6
Pyrola elliptica	2	28.6	2.1	--	.1	.4	--	.1	.3	61.2
Hypnum crista-castrensis	2	28.6	2.1	--	.1	.7	--	.1	.4	61.2
Viola spp.	2	28.6	2.1	--	.1	.7	--	.3	.4	61.2
Melampyrum lineare	2	28.6	1.4	--	.1	.4	--	.1	.3	40.8
Rubus strigosus	2	28.6	1.4	--	.1	8.1	--	9.3	8.7	40.8
Dryopteris spinulosa	2	28.6	1.4	--	.2	.3	--	.4	.4	40.8
Lathyrus ochroleucus	2	28.6	1.4	--	.1	.4	--	.1	.3	40.8
Sorbus americana (SA)	2	28.6	1.4	.4	.1	.6	.3	.1	.4	40.8
Pinus strobus (SA)	2	28.6	1.4	.3	.1	.6	.3	.4	.4	40.8
Galium triflorum	2	28.6	1.4	--	.1	.4	--	.1	.3	40.8
Polygala paucifolia	1	14.3	2.1	--	.1	.9	--	.4	.7	30.6
Lonicera hirsuta	1	14.3	2.1	57.1	.1	.9	.3	.1	.4	30.6
Anemone quinquefolia	1	14.3	2.1	--	.1	.6	--	.1	.3	30.6
Populus grandidentata (T)	1	14.3	1.4	1.3	.6	.6	.3	.4	.4	20.4
Thuja occidentalis (SE)	1	14.3	1.4	14.3	.1	1.1	.3	.3	.6	20.4
Equisetum spp.	2	28.6	.7	--	.1	.1	--	.1	.1	20.4
Picea glauca (SE)	1	14.3	1.4	14.3	.1	1.3	.4	.6	.7	20.4
Epigaea repens	1	14.3	.7	--	.1	.3	--	.1	.2	10.2
Sphagnum spp.	1	14.3	.7	--	.1	.3	--	.1	.2	10.2
Ledum groenlandicum	1	14.3	.7	214.3	.1	.3	.9	.3	.4	10.2
Apocynum androsaemifolium	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Salix spp.	1	14.3	.7	14.3	.1	.7	.3	.3	.4	10.2
Arctostaphylos Uva-ursi	1	14.3	.7	--	.1	.9	--	1.1	1.0	10.2
Cornus stolonifera	1	14.3	.7	14.3	.1	.3	.1	.1	.2	10.2
Woodsia ilvensis	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Salix bebbiana	1	14.3	.7	21.4	.1	.4	.1	.1	.3	10.2
Athyrium filix-femina	1	14.3	.7	--	.1	.3	--	.1	.2	10.2
Osmunda claytoniana	1	14.3	.7	--	.9	.1	--	1.7	.9	10.2
Gymnocarpium Dryopteris	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Lycopodium complanatum	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Alnus rugosa	1	14.3	.7	14.3	.1	.3	.1	.1	.2	10.2
Populus balsamifera (T)	1	14.3	.7	.6	.2	.3	.1	.1	.1	10.2
Larix laricina (SE)	1	14.3	.7	7.1	.1	.6	.3	.1	.3	10.2
Polypodium virginianum	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Cladonia mitis	1	14.3	.7	--	.1	.3	--	.1	.3	10.2
Acer rubrum (T)	1	14.3	.7	.6	.1	.3	.1	.1	.2	10.2
Pinus strobus (SE)	1	14.3	.7	7.1	.1	1.0	.6	.6	.7	10.2
Mitella nuda	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Comptonia peregrina	1	14.3	.0	--	.1	.0	--	.7	.7	.0
round cover characteristic:										
Litter	7	100.0	97.9	--	73.2	34.4	--	74.0	54.0	9,785.7
Dead wood	7	100.0	39.3	--	4.6	13.7	--	4.6	9.4	3,928.6
Bare rock	4	57.1	5.0	--	1.0	2.0	--	1.0	1.4	285.7
Live wood	4	57.1	4.3	--	.3	1.4	--	.3	.9	244.9
Bare ground	1	14.3	.7	--	.7	.3	--	.7	.4	10.2

Table 9. - Stand data summary for the jack pine-black spruce community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Picea mariana (SA)	7	100.0	97.1	186.0	6.2	56.4	72.7	73.6	67.6	9,714.3
Picea mariana (T)	7	100.0	85.0	160.3	32.5	40.6	46.3	29.9	39.0	8,500.0
Calliergonella schreberi	7	100.0	80.7	--	26.7	23.9	--	26.9	25.3	8,071.4
Cornus canadensis	7	100.0	70.0	--	11.3	23.6	--	31.4	27.4	7,000.0
Maianthemum canadense	7	100.0	64.3	--	2.6	22.4	--	9.1	15.7	6,428.6
Pinus banksiana (T)	6	85.7	60.0	126.7	54.4	27.6	32.1	42.7	34.1	5,142.9
Dicranum spp.	6	85.7	55.0	--	6.3	15.4	--	6.4	10.9	4,714.3
Vaccinium angustifolium	7	100.0	45.0	--	4.0	51.1	--	57.4	54.3	4,500.0
Aster macrophyllus	7	100.0	39.3	--	7.7	12.4	--	24.7	18.6	3,928.6
Other mosses	7	100.0	37.1	--	3.4	11.0	--	3.3	7.3	3,714.3
Diervilla Lonicera	6	85.7	42.1	2,571.4	.5	40.4	41.4	35.7	39.1	3,612.2
Acer rubrum (SE)	6	85.7	35.0	3,807.1	1.6	25.3	36.1	32.4	31.3	3,000.0
Betula papyrifera (SA)	6	85.7	32.9	25.9	.8	16.3	10.3	9.6	12.0	2,816.3
Amelanchier spp.	7	100.0	24.3	707.1	.2	23.7	17.7	14.7	18.9	2,428.6
Populus tremuloides (T)	7	100.0	24.3	24.0	8.3	10.9	6.9	7.0	8.3	2,428.6
Clintonia borealis	7	100.0	19.3	--	1.6	6.1	--	4.7	5.3	1,928.6
Gaultheria procumbens	5	71.4	26.4	--	1.4	25.0	--	17.4	21.1	1,887.8
Corylus cornuta	6	85.7	19.3	1,478.6	.8	18.0	21.3	26.4	21.7	1,653.1
Abies balsamea (SA)	6	85.7	18.6	18.6	.6	9.4	5.7	5.3	6.9	1,591.8
Pteridium aquilinum	5	71.4	18.6	--	5.8	6.0	--	13.3	9.7	1,326.5
Picea mariana (SE)	5	71.4	17.9	542.9	1.2	16.9	17.0	30.9	21.7	1,275.5
Populus tremuloides (SE)	5	71.4	17.1	321.4	.2	17.6	14.1	9.7	14.0	1,224.5
Gramineae	5	71.4	15.0	--	.4	5.1	--	1.4	3.4	1,071.4
Betula papyrifera (SE)	6	85.7	12.1	307.1	.2	10.0	7.6	4.4	7.3	1,040.8
Polytrichum spp.	6	85.7	11.4	--	.5	3.1	--	.4	1.9	979.6
Linnaea borealis	5	71.4	13.6	--	1.0	4.1	--	2.3	3.3	969.4
Pinus strobus (SE)	4	57.1	16.4	314.3	.6	11.4	8.9	9.4	9.9	938.8
Betula papyrifera (T)	5	71.4	11.4	8.0	1.8	5.3	3.0	2.0	3.6	816.3
Lycopodium clavatum	5	71.4	10.0	--	.9	3.1	--	2.4	2.7	714.3
Aralia nudicaulis	5	71.4	10.0	--	1.2	3.9	--	4.1	4.0	714.3
Acer rubrum (SA)	4	57.1	10.0	3.9	.1	5.0	3.3	2.3	3.4	571.4
Other lichens	5	71.4	7.9	--	.3	2.1	--	.4	1.1	561.2
Pinus strobus (T)	3	42.9	12.9	10.0	8.7	5.7	3.7	9.0	6.1	551.0
Abies balsamea (SE)	4	57.1	7.9	242.9	.5	8.3	9.9	7.9	8.6	449.0
Trientalis borealis	4	57.1	7.1	--	.2	2.9	--	.9	1.7	408.2
Lycopodium annotinum	4	57.1	6.4	--	.6	2.4	--	2.6	2.4	367.3
Vaccinium myrtilloides	5	71.4	5.0	--	.3	7.4	--	9.3	8.3	357.1
Populus tremuloides (SA)	3	42.9	7.9	13.1	.6	3.7	2.7	3.3	3.3	336.7
Pinus resinosa (T)	2	28.6	11.4	13.4	8.1	4.3	4.0	6.3	4.9	326.5
Abies balsamea (T)	4	57.1	5.0	4.9	.7	2.4	1.3	.9	1.6	285.7
Lycopodium obscurum	4	57.1	4.3	--	.1	1.3	--	.3	.9	244.9
Sorbus americana (SE)	3	42.9	5.7	85.7	.1	4.1	2.1	2.1	2.7	244.9
Pinus strobus (SA)	3	42.9	5.7	1.7	.1	3.4	1.4	2.1	2.4	244.9
Cladonia rangiferina	4	57.1	3.6	--	.1	1.0	--	.1	.7	204.1
Cyperaceae	3	42.9	3.6	--	.1	1.0	--	.1	.7	153.1
Hypnum crista-castrensis	3	42.9	2.9	--	.3	.9	--	.3	.6	122.4
Picea glauca (SA)	2	28.6	4.3	1.1	.1	2.0	1.3	1.0	1.4	122.4
Querus rubra (SE)	2	28.6	4.3	92.9	.1	4.0	3.6	2.4	3.3	122.4
Lonicera canadensis	2	28.6	3.6	92.9	.1	3.3	1.7	.7	1.9	102.0
Alnus crispa	2	28.6	3.6	278.6	.2	4.6	8.0	10.9	7.7	102.0
Viola spp.	3	42.9	2.1	--	.1	.6	--	.1	.4	91.8
Lycopodium complanatum	3	42.9	2.1	--	.3	.7	--	1.0	.7	91.8
Picea glauca (T)	3	42.9	2.1	2.1	.8	.9	.6	.9	.9	91.8
Acer spicatum	2	28.6	2.9	164.3	.1	2.4	1.3	1.3	1.7	81.6
Acer rubrum (T)	2	28.6	2.9	1.9	.7	1.3	.9	.9	1.0	81.6
Rubus pubescens	2	28.6	2.1	--	.1	5.7	--	4.0	4.9	61.2
Pinus banksiana (SA)	2	28.6	2.1	6.6	.3	1.1	.9	1.3	1.1	61.2
Melampyrum lineare	3	42.9	1.4	--	.1	.6	--	.1	.3	61.2
Rubus strigosus	1	14.3	3.6	--	.4	3.6	--	4.1	3.9	51.0
Pinus resinosa (SA)	1	14.3	3.6	.9	.1	1.6	1.0	1.6	1.4	51.0
Pyrola elliptica	2	28.6	1.4	--	.1	.4	--	.1	.3	40.8
Gaultheria hispidula	2	28.6	1.4	--	.2	1.1	--	1.1	1.1	40.8
Goodyera repens	2	28.6	1.4	--	.1	.4	--	.1	.3	40.8
Rosa acicularis	2	28.6	1.4	--	.1	2.9	--	5.4	4.1	40.8
Chimaphila umbellata	2	28.6	1.4	--	.1	3.3	--	1.0	2.1	40.8
Anemone quinquefolia	1	14.3	2.1	--	.1	.6	--	.1	.4	30.6
Salix bebbiana	1	14.3	2.1	21.4	.1	2.0	.1	.1	.9	30.6
Comptonia peregrina	1	14.3	2.1	178.6	.1	1.7	4.0	4.0	3.3	30.6
Hylocomium splendens	1	14.3	1.4	--	.1	.3	--	.1	.1	20.4
Quercus rubra (SA)	1	14.3	1.4	.4	.1	1.0	.3	.1	.4	20.4
Populus grandidentata (T)	1	14.3	1.4	.9	.6	.6	.3	.6	.6	20.4
Populus grandidentata (SE)	1	14.3	.7	21.4	.1	.4	.4	.1	.3	10.2
Coptis groenlandica	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Pinus resinosa (SE)	1	14.3	.7	7.1	.1	.4	.1	.1	.1	10.2
Lonicera hirsuta	1	14.3	.7	114.3	.1	.7	2.9	2.9	2.1	10.2
Prunus pensylvanica	1	14.3	.7	14.3	.1	1.4	.7	.7	.9	10.2
Juniperus communis	1	14.3	.7	21.4	.1	1.9	.9	2.7	1.7	10.2
Polygonum cilinode	1	14.3	.7	--	.1	.4	--	.1	.3	10.2
Polypodium virginianum	1	14.3	.7	--	.1	.4	--	.7	.6	10.2
Picea glauca (SE)	1	14.3	.7	7.1	.1	1.0	.6	.4	.6	10.2
Streptopus roseus	1	14.3	.7	--	.1	.3	--	.1	.1	10.2
Fragaria virginiana	1	14.3	.7	--	.1	.1	--	.1	.1	10.2
Waldsteinia fragarioides	1	14.3	.7	--	.1	.3	--	.1	.1	10.2
Ground cover characteristic:										
Litter	7	100.0	98.6	--	55.1	29.9	--	55.4	42.6	9,857.1
Dead wood	7	100.0	32.1	--	5.8	9.4	--	5.9	7.9	3,214.3
Bare rock	5	71.4	6.4	--	.5	1.9	--	.6	1.3	459.2
Bare ground	2	28.6	2.1	--	.3	.6	--	.3	.4	61.2
Live wood	1	14.3	.7	--	.1	.1	--	.1	.1	10.2

Table 10. — Stand data summary for the black spruce-jack pine community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness index
ies:										
Picea mariana (SA)	10	100.0	98.5	444.3	18.0	70.7	84.8	84.5	80.2	9,850.0
Calliergonella schreberi	10	100.0	88.0	--	43.1	23.4	--	43.2	33.3	8,800.0
Picea mariana (T)	10	100.0	84.5	409.4	67.0	52.1	51.7	43.0	48.9	8,450.0
Dicranum spp.	9	90.0	73.0	--	11.5	19.0	--	11.4	15.3	6,570.0
Pinus banksiana (T)	9	90.0	67.5	315.2	78.1	37.2	41.0	50.9	43.0	6,075.0
Other mosses	9	90.0	36.5	--	2.9	9.5	--	2.8	6.4	3,285.0
Abies balsamea (SE)	8	80.0	21.5	1,395.0	.8	37.5	31.7	28.0	32.4	1,720.0
Maianthemum canadense	8	80.0	21.0	--	.7	23.0	--	12.5	17.8	1,680.0
Diervilla Lonicera	6	60.0	18.0	840.0	.2	42.3	39.4	36.7	39.5	1,080.0
Linnaea borealis	8	80.0	13.0	--	.6	19.8	--	21.7	20.8	1,040.0
Picea mariana (SE)	7	70.0	14.5	610.0	1.1	24.3	24.6	35.1	28.0	1,015.0
Hypnum crista-castrensis	8	80.0	11.5	--	1.0	3.0	--	1.0	2.1	920.0
Abies balsamea (SA)	6	60.0	13.5	22.3	.6	8.4	5.3	4.7	6.2	810.0
Betula papyrifera (SA)	6	60.0	13.5	28.3	1.0	9.2	4.6	4.3	6.0	810.0
Aster macrophyllus	7	70.0	11.5	--	1.8	11.9	--	26.6	19.3	805.0
Pinus banksiana (SA)	6	60.0	12.0	17.8	1.2	8.2	3.4	5.5	5.7	720.0
Cladonia rangiferina	8	80.0	9.0	--	.7	2.2	--	.7	1.5	720.0
Cornus canadensis	6	60.0	9.5	--	.5	10.7	--	11.9	11.3	570.0
Other lichens	5	50.0	10.0	--	.6	2.4	--	.6	1.5	500.0
Populus tremuloides (SE)	5	50.0	6.5	150.0	.1	17.5	21.5	13.2	17.4	325.0
Abies balsamea (T)	3	30.0	9.5	12.4	1.9	4.2	3.4	2.2	3.3	285.0
Aralia nudicaulis	4	40.0	6.5	--	.3	4.7	--	4.9	4.7	260.0
Hylocomium splendens	4	40.0	6.5	--	1.2	1.7	--	1.2	1.5	260.0
Betula papyrifera (T)	5	50.0	5.0	12.2	2.2	3.0	1.5	1.3	1.9	250.0
Rosa acicularis	5	50.0	4.0	--	.3	17.8	--	30.5	24.1	200.0
Gramineae	4	40.0	5.0	--	.1	3.8	--	1.4	2.6	200.0
Vaccinium angustifolium	4	40.0	4.5	--	.2	16.1	--	16.8	16.4	180.0
Populus tremuloides (T)	4	40.0	4.5	11.0	3.2	2.4	1.3	2.0	1.9	180.0
Polytrichum spp.	3	30.0	3.5	--	.1	.9	--	.1	.5	105.0
Betula papyrifera (SE)	4	40.0	2.5	60.0	.1	4.9	4.6	6.4	5.3	100.0
Amelanchier spp.	4	40.0	2.0	40.0	.1	5.2	3.2	3.1	3.8	80.0
Goodyera repens	3	30.0	2.5	--	.1	2.8	--	1.0	1.9	75.0
Clintonia borealis	3	30.0	2.0	--	.1	2.3	--	2.5	2.4	60.0
Lycopodium clavatum	3	30.0	2.0	--	.2	1.1	--	3.1	2.2	60.0
Picea glauca (SA)	2	20.0	3.0	4.4	.2	1.9	.7	.9	1.2	60.0
Viola spp.	3	30.0	1.5	--	.1	1.2	--	.3	.7	45.0
Vaccinium myrtilloides	2	20.0	1.5	--	.1	6.1	--	2.0	4.1	30.0
Gaultheria procumbens	2	20.0	1.5	--	.1	15.0	--	5.4	10.2	30.0
Anemone quinquefolia	2	20.0	1.5	--	.1	.8	--	.5	.7	30.0
Lonicera canadensis	2	20.0	1.5	90.0	.1	4.7	8.8	8.8	7.4	30.0
Corylus cornuta	2	20.0	1.5	25.0	.1	4.0	2.3	2.3	2.9	30.0
Thuja occidentalis (SE)	1	10.0	2.5	360.0	1.3	1.5	2.5	5.0	3.0	25.0
Thuja occidentalis (SA)	1	10.0	2.5	2.3	.1	1.4	.7	.4	.8	25.0
Acer rubrum (SE)	2	20.0	1.0	15.0	.1	10.3	10.1	10.1	10.2	20.0
Gaultheria hispidula	2	20.0	1.0	--	.1	12.5	--	12.0	12.3	20.0
Chimaphila umbellata	2	20.0	1.0	--	.1	6.3	--	1.8	4.1	20.0
Coptis groenlandica	2	20.0	1.0	--	.1	1.6	--	.9	1.2	20.0
Sorbus americana (SE)	2	20.0	1.0	10.0	.1	1.3	.7	.5	.8	20.0
Picea glauca (T)	2	20.0	1.0	1.3	.3	.5	.2	.2	.4	20.0
Goodyera tesselata	1	10.0	1.5	--	.1	.6	--	.1	.3	15.0
Juniperus communis	1	10.0	1.5	55.0	.1	2.7	3.3	4.6	3.6	15.0
Thuja occidentalis (T)	1	10.0	1.5	1.5	.4	.6	.5	.5	.5	15.0
Fragaria vesca	1	10.0	1.5	--	.1	.6	--	.4	.5	15.0
Rosa acicularis	1	10.0	1.0	45.0	.1	3.3	3.2	3.2	3.3	10.0
Melampyrum lineare	1	10.0	1.0	--	.1	.4	--	.1	.2	10.0
Vicia americana	1	10.0	1.0	--	.1	.4	--	.1	.2	10.0
Pyrola secunda	1	10.0	1.0	--	.1	.4	--	.2	.3	10.0
Streptopus roseus	1	10.0	1.0	--	.1	.4	--	.2	.3	10.0
Habenaria orbiculata	1	10.0	.5	--	.1	.7	--	.5	.6	5.0
Lathyrus ochroleucus	1	10.0	.5	--	.1	.3	--	.2	.2	5.0
Petasites vitifolius	1	10.0	.5	--	.1	.2	--	.1	.1	5.0
Lycopodium annotinum	1	10.0	.5	--	.1	.4	--	.1	.3	5.0
Picea glauca (SE)	1	10.0	.5	20.0	.1	2.0	4.0	1.2	2.4	5.0
Alnus crispa	1	10.0	.5	60.0	.1	5.0	8.0	9.5	7.5	5.0
Salix bebbiana	1	10.0	.5	5.0	.1	.9	.3	.2	.5	5.0
Pyrola virens	1	10.0	.5	--	.1	.4	--	.1	.3	5.0
Rubus pubescens	1	10.0	.5	--	.1	1.3	--	2.1	1.7	5.0
Lonicera hirsuta	1	10.0	.5	15.0	.1	1.7	1.6	1.6	1.6	5.0
Cyperaceae	1	10.0	.5	--	.1	.3	--	.2	.2	5.0
Ledum groenlandicum	1	10.0	.5	--	.2	2.5	--	7.1	4.8	5.0
Arctostaphylos Uva-ursi	1	10.0	.5	--	.1	1.3	--	.7	1.0	5.0
Pyrola rotundifolia	1	10.0	.5	--	.1	.6	--	.2	.4	5.0
Rubus strigosus	1	10.0	.5	--	.1	1.3	--	1.4	1.3	5.0
Pinus strobus (SE)	1	10.0	.5	5.0	.1	.7	.1	.3	.4	5.0
Trientalis borealis	1	10.0	.5	--	.1	.7	--	.3	.5	5.0
nd cover aracteristic:										
Litter	10	100.0	98.0	--	33.4	25.7	--	33.7	29.7	9,800.0
Dead wood	10	100.0	38.0	--	3.5	10.1	--	3.6	7.0	3,800.0
Live wood	5	50.0	4.5	--	.5	1.2	--	.5	.9	225.0
Bare rock	2	20.0	3.0	--	1.0	.8	--	1.0	.9	60.0
Bare ground	1	10.0	.5	--	.1	.1	--	.1	.1	5.0

Table 11. — Stand data summary for the aspen-birch community

Item	Number of stand	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Aster macrophyllus	13	100.0	80.9	--	21.7	19.2	--	41.5	30.2	8,092.3
Populus tremuloides (T)	13	100.0	78.8	102.0	41.8	41.1	50.2	54.2	48.4	7,884.6
Diervilla Lonicera	13	100.0	70.4	21,309.0	4.5	26.3	35.2	19.0	26.8	7,038.5
Corylus cornuta	13	100.0	69.4	13,383.3	7.4	26.4	31.2	36.8	31.5	6,938.5
Betula papyrifera (SA)	13	100.0	65.0	110.2	3.5	36.3	38.6	36.5	37.2	6,500.0
Populus tremuloides (SA)	13	100.0	62.3	102.2	4.3	34.3	33.5	36.9	35.0	6,230.8
Gramineae	13	100.0	58.6	--	3.0	14.0	--	5.8	9.9	5,861.5
Other mosses	12	92.3	59.2	--	6.9	25.5	--	7.0	16.2	5,467.5
Maianthemum canadense	13	100.0	51.4	--	1.8	11.6	--	3.5	7.5	5,138.5
Betula papyrifera (T)	13	100.0	44.8	39.9	8.2	24.3	20.0	12.5	18.9	4,476.9
Clintonia borealis	13	100.0	37.5	--	4.0	7.8	--	8.1	7.8	3,746.2
Aralia nudicaulis	13	100.0	37.2	--	6.9	8.5	--	13.2	11.0	3,715.4
Populus tremuloides (SE)	13	100.0	33.8	867.9	.6	39.5	40.6	35.3	38.4	3,384.6
Cornus canadensis	13	100.0	29.6	--	1.4	6.3	--	2.8	4.7	2,961.5
Acer spicatum	10	76.9	33.6	4,856.4	3.3	12.8	13.1	16.5	14.2	2,585.8
Abies balsamea (SE)	10	76.9	30.0	1,452.5	1.0	25.2	31.3	28.8	28.5	2,307.7
Amelanchier spp.	13	100.0	21.8	1,116.7	.8	8.1	2.1	3.2	4.4	2,176.9
Abies balsamea (T)	9	69.2	29.5	24.8	5.4	12.5	11.5	6.2	10.1	2,039.6
Alnus crispa	8	61.5	22.5	5,784.6	3.9	7.4	9.8	16.8	11.4	1,387.0
Pteridium aquilinum	10	76.9	17.7	--	6.0	4.3	--	10.5	7.4	1,360.9
Cornus rugosa	9	69.2	18.8	1,224.4	.6	6.3	3.4	3.2	4.4	1,304.7
Fragaria vesca	11	84.6	14.2	--	.8	3.5	--	1.7	2.5	1,204.1
Betula papyrifera (SE)	10	76.9	15.2	335.9	.3	12.4	8.8	10.5	10.5	1,171.6
Abies balsamea (SA)	6	46.2	24.6	43.2	1.4	13.1	13.6	13.2	13.3	1,136.1
Trientalis borealis	10	76.9	14.5	--	.4	3.0	--	.7	1.9	1,112.4
Rubus pubescens	9	69.2	14.6	--	.9	31.7	--	29.2	30.4	1,011.8
Streptopus roseus	9	69.2	14.6	--	1.0	2.9	--	2.1	2.5	1,011.8
Picea mariana (T)	9	69.2	14.1	8.8	3.1	6.1	4.7	3.7	5.0	974.6
Lonicera canadensis	10	76.9	10.8	609.0	.1	3.9	1.8	.8	2.2	828.4
Picea glauca (T)	8	61.5	12.3	6.2	3.3	5.3	3.4	5.1	4.7	757.4
Calliergonella schreberi	9	69.2	10.2	--	1.5	4.5	--	1.5	3.0	703.0
Other lichens	9	69.2	9.5	--	1.1	4.0	--	1.1	2.5	655.0
Pinus banksiana (T)	7	53.8	11.9	10.3	9.4	5.4	4.8	9.1	6.5	642.0
Linnaea borealis	8	61.5	10.4	--	.4	2.3	--	.8	1.6	639.1
Lycopodium obscurum	8	61.5	10.0	--	.6	2.0	--	1.1	1.5	615.4
Vaccinium myrtilloides	8	61.5	9.8	--	1.0	18.4	--	23.8	21.2	605.9
Galium triflorum	7	53.8	7.7	--	.3	1.8	--	.5	1.2	414.2
Vaccinium angustifolium	6	46.2	7:7	--	.5	16.5	--	11.2	13.9	355.0
Lycopodium clavatum	6	46.2	6.9	--	.6	1.2	--	1.2	1.2	319.5
Rubus strigosus	7	53.8	5.5	--	.5	14.6	--	17.6	16.0	298.2
Picea glauca (SA)	5	38.5	7.7	5.1	.2	3.5	2.8	3.1	3.2	295.9
Sorbus americana (SE)	5	38.5	6.9	156.4	.1	7.1	5.8	5.1	6.1	266.3
Pinus strobus (SA)	4	30.8	8.1	6.0	.2	3.9	2.8	2.5	3.0	248.5
Cyperaceae	5	38.5	6.0	--	.2	1.5	--	.5	1.0	230.8
Pinus strobus (T)	4	30.8	7.3	3.5	6.1	3.2	3.0	7.8	4.7	224.9
Picea mariana (SA)	5	38.5	5.5	4.0	.1	2.8	2.1	1.8	2.3	213.0
Lycopodium annotinum	4	30.8	6.8	--	.7	1.2	--	1.4	1.3	208.3
Rosa acicularis	7	53.8	3.8	--	.4	11.1	--	11.8	11.5	207.1
Viola spp.	6	46.2	4.2	--	.1	.8	--	.1	.5	195.3
Prunus pensylvanica	6	46.2	4.2	146.2	.2	1.6	.2	.7	.8	195.3
Mitella nuda	4	30.8	5.8	--	.2	1.3	--	.5	.9	177.5
Pinus strobus (SE)	3	23.1	7.3	180.8	.1	4.8	4.3	3.5	4.3	168.6
Pyrola secunda	5	38.5	4.2	--	.1	.9	--	.1	.6	162.7
Picea glauca (SE)	5	38.5	4.1	44.8	.2	4.4	2.2	7.2	4.8	156.8
Coptis groenlandica	5	38.5	3.8	--	.1	.7	--	.2	.5	147.9
Salix spp.	3	23.1	5.0	126.9	.1	1.8	.2	.2	.8	115.4
Acer rubrum (SA)	2	15.4	6.5	10.7	.3	3.7	4.8	4.9	4.5	100.6
Salix bebbiana	3	23.1	4.0	260.2	.5	1.3	.5	1.4	1.2	92.3
Lonicera hirsuta	3	23.1	3.8	307.7	.1	1.6	.8	.4	1.0	88.8
Polytrichum spp.	3	23.1	3.2	--	.2	1.2	--	.2	.6	74.6
Picea mariana (SE)	3	23.1	3.1	57.7	.2	2.8	1.6	4.1	2.8	71.0
Acer rubrum (SE)	2	15.4	4.6	188.5	.1	3.7	5.2	2.5	3.8	71.0
Dicranum spp.	4	30.8	2.2	--	.1	.8	--	.1	.5	66.3
Anemone quinquefolia	3	23.1	2.7	--	.1	.5	--	.1	.3	62.1
Melampyrum lineare	4	30.8	1.5	--	.1	.3	--	.1	.2	47.3
Prunus virginiana	4	30.8	1.5	50.0	.1	.5	.1	.3	.4	47.3
Cladonia rangiferina	3	23.1	1.9	--	.1	.7	--	.1	.4	44.4
Ribes spp.	3	23.1	1.8	--	.1	4.3	--	3.4	3.8	40.8
Thuja occidentalis (T)	2	15.4	2.3	.9	.2	.9	.5	.2	.5	35.5
Lathyrus ochroleucus	3	23.1	1.4	--	.1	.3	--	.1	.3	32.0
Viburnum rafinesquianum	2	15.4	1.9	188.5	.1	.6	.8	.4	.6	29.6
Cornus stolonifera	2	15.4	1.9	200.0	.1	.7	.2	.3	.4	29.6
Pinus resinosa (T)	3	23.1	1.2	.5	1.6	.5	.2	1.3	.7	26.6
Epilobium angustifolium	3	23.1	1.2	--	.1	.3	--	.2	.2	26.6
Petasites vitifolius	2	15.4	1.5	--	.1	.3	--	.2	.2	23.7
Osmunda claytoniana	2	15.4	1.2	--	.8	.2	--	1.4	.8	17.8
Populus grandidentata (T)	2	15.4	1.2	.5	.2	.4	.2	.2	.3	17.8
Populus grandidentata (SA)	2	15.4	1.2	1.2	.1	.6	.4	.5	.5	17.8
Pinus banksiana (SA)	2	15.4	1.2	.5	.1	.5	.2	.2	.3	17.8
Apocynum androsaemifolium	2	15.4	1.2	--	.2	.3	--	.5	.3	17.8
Chimaphila umbellata	2	15.4	.8	--	.1	2.2	--	.5	1.3	11.8
Sorbus americana (SA)	2	15.4	.8	.7	.1	.5	.2	.2	.3	11.8
Acer rubrum (T)	1	7.7	1.5	.9	.1	.6	.5	.2	.5	11.8
Hypnum crista-castrensis	2	15.4	.8	--	.2	.4	--	.2	.3	11.8
Asarum canadense	1	7.7	1.2	--	.1	.2	--	.2	.2	8.9
Hepatica americana	1	7.7	1.2	--	.1	.3	--	.1	.2	8.9
Polypodium virginianum	1	7.7	1.2	--	.2	.2	--	.3	.3	8.9
Lonicera villosa	1	7.7	1.2	19.2	.1	.3	.1	.1	.2	8.9

(Continued on next page)

Table 11 continued

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Arctostaphylos Uva-ursi	1	7.7	0.8	--	0.1	1.2	--	2.3	1.8	5.9
Pyrola virens	1	7.7	.8	--	.1	.2	--	.1	.1	5.9
Hieracium scabrum	1	7.7	.8	--	.1	.2	--	.1	.2	5.9
Vicia americana	1	7.7	.8	--	.1	.2	--	.1	.2	5.9
Dryopteris spinulosa	2	15.4	.4	--	.1	.1	--	.2	.1	5.9
Pyrola rotundifolia	1	7.7	.8	--	.1	.2	--	.1	.1	5.9
Fraxinus nigra (SA)	1	7.7	.8	0.2	.1	.4	0.2	.1	.2	5.9
Cladonia mitis	1	7.7	.8	--	.1	.2	--	.1	.1	5.9
Ribes triste	1	7.7	.8	92.3	.1	.2	.2	.1	.2	5.9
Fragaria virginiana	1	7.7	.6	--	.1	.2	--	.1	.1	4.7
Antennaria spp.	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Fraxinus nigra (SE)	1	7.7	.4	3.8	.1	.2	.1	2.7	1.0	3.0
Waldsteinia fragarioides	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Circaea alpina	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Trillium grandiflorum	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Pyrola elliptica	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Anaphalis margaritacea	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Cladonia sylvatica	1	7.7	.4	--	.1	.2	--	.1	.1	3.0
Populus balsamifera (SA)	1	7.7	.4	.3	.1	.2	.1	.2	.2	3.0
Habenaria orbiculata	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Goodyera repens	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Lycopodium complanatum	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Moneses uniflora	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Lactuca canadensis	1	7.7	.4	--	.1	.1	--	.1	.1	3.0
Ground cover characteristic:										
Litter	13	100.0	99.6	--	85.0	43.6	--	85.2	64.3	9,961.5
Dead wood	13	100.0	26.8	--	2.3	11.5	--	2.3	6.9	2,676.9
Bare rock	9	69.2	9.8	--	1.8	4.0	--	1.8	2.8	681.7
Live wood	7	53.8	4.5	--	.1	1.8	--	.1	1.0	240.2
Bare ground	3	23.1	3.2	--	.3	1.5	--	.3	.9	74.6

Table 12. – Stand data summary for the maple-aspen-birch community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Acer rubrum (SE)	15	100.0	87.7	19,806.7	4.6	44.3	80.1	52.5	59.0	8,766.7
Maianthemum canadense	15	100.0	67.3	--	2.7	19.3	--	8.2	13.7	6,733.3
Populus tremuloides (T)	15	100.0	66.3	123.3	56.3	30.1	34.5	43.6	36.2	6,633.3
Other mosses	15	100.0	60.0	--	6.6	24.2	--	6.7	15.5	6,000.0
Aster macrophyllus	15	100.0	59.7	--	14.9	16.8	--	38.4	27.5	5,966.7
Corylus cornuta	15	100.0	56.7	7,613.3	3.9	34.2	46.9	45.9	42.3	5,666.7
Acer rubrum (SA)	15	100.0	55.3	90.2	2.7	25.3	23.9	22.6	24.0	5,533.3
Betula papyrifera (SA)	15	100.0	55.3	111.9	3.6	25.5	27.3	27.9	27.1	5,533.3
Acer rubrum (T)	14	93.3	50.0	55.8	13.8	21.1	21.6	13.4	18.7	4,666.7
Betula papyrifera (T)	15	100.0	44.7	53.9	12.1	20.6	20.3	16.1	19.2	4,466.7
Clintonia borealis	15	100.0	37.3	--	4.0	10.7	--	10.9	10.7	3,733.3
Acer spicatum	12	80.0	46.3	3,766.7	2.3	27.7	29.6	33.1	30.1	3,706.7
Abies balsamea (SE)	14	93.3	39.3	1,556.7	1.8	18.5	9.8	19.9	15.9	3,671.1
Abies balsamea (SA)	11	73.3	46.0	111.4	3.6	21.9	26.5	25.9	24.9	3,373.3
Populus tremuloides (SE)	14	93.3	30.0	693.3	.7	13.5	4.1	8.9	8.7	2,800.0
Populus tremuloides (SA)	13	86.7	30.7	44.7	2.0	14.3	11.8	14.7	13.6	2,657.8
Aralia nudicaulis	15	100.0	24.3	--	4.0	6.8	--	10.1	8.5	2,433.3
Trientalis borealis	15	100.0	23.7	--	.7	6.8	--	2.3	4.5	2,366.7
Lycopodium obscurum	13	86.7	23.7	--	1.4	6.2	--	3.9	5.1	2,051.1
Cornus canadensis	14	93.3	21.7	--	1.3	6.3	--	4.2	5.2	2,022.2
Abies balsamea (T)	11	73.3	24.3	26.0	4.1	10.0	8.3	3.0	7.1	1,784.4
Diervilla Lonicera	10	66.7	23.7	1,206.7	.3	10.7	7.6	4.6	7.7	1,577.8
Gramineae	14	93.3	15.3	--	.5	4.1	--	1.3	2.7	1,431.1
Amelanchier spp.	13	86.7	15.3	683.3	.4	9.0	3.7	4.8	5.8	1,328.9
Calliergonella schreberi	13	86.7	15.0	--	2.0	5.7	--	2.1	3.9	1,300.0
Vaccinium angustifolium	12	80.0	15.0	--	1.0	43.5	--	43.1	43.3	1,200.0
Streptopus roseus	12	80.0	13.3	--	.6	3.3	--	1.6	2.5	1,066.7
Picea mariana (T)	8	53.3	18.0	17.7	4.5	7.3	6.3	4.0	5.9	960.0
Picea mariana (SA)	10	66.7	13.3	21.3	.6	5.6	4.9	5.3	5.4	888.9
Betula papyrifera (SE)	11	73.3	11.7	263.3	.3	4.9	1.5	5.7	3.9	855.6
Rubus pubescens	10	66.7	12.3	--	.8	30.2	--	28.3	29.2	822.2
Dicranum spp.	9	60.0	12.7	--	1.3	4.9	--	1.3	3.0	760.0
Viola spp.	12	80.0	9.0	--	.2	2.5	--	.7	1.7	720.0
Cornus rugosa	8	53.3	11.3	660.0	.2	5.3	3.3	2.5	3.7	604.4
Pinus strobus (SE)	9	60.0	9.3	113.3	.1	3.7	.6	1.7	2.0	560.0
Lonicera canadensis	12	80.0	7.0	293.3	.1	4.8	2.6	1.3	3.1	560.0
Alnus crispa	8	53.3	9.0	580.0	.5	3.9	2.5	4.1	3.6	480.0
Pinus strobus (T)	8	53.3	8.7	6.7	14.9	3.4	2.9	12.7	6.4	462.2
Lycopodium annotinum	8	53.3	8.3	--	.6	2.1	--	1.9	1.9	444.4
Picea glauca (T)	8	53.3	8.0	4.2	1.6	3.2	2.0	1.3	2.2	426.7
Sorbus americana (SE)	7	46.7	9.0	176.7	.2	4.4	1.3	2.5	2.7	420.0
Cyperaceae	7	46.7	9.0	--	.4	1.9	--	1.1	1.5	420.0
Pteridium aquilinum	8	53.3	7.0	--	2.8	2.1	--	6.5	4.4	373.3
Quercus rubra (SE)	4	26.7	14.0	400.0	.6	5.3	.8	4.1	3.4	373.3
Other lichens	7	46.7	7.3	--	.5	2.5	--	.5	1.5	342.2
Picea glauca (SA)	8	53.3	6.3	6.6	.2	3.0	1.7	1.6	2.3	337.8
Lycopodium clavatum	7	46.7	5.7	--	.4	1.5	--	1.5	1.6	264.4
Coptis groenlandica	7	46.7	5.3	--	.3	1.3	--	.9	1.2	248.9
Linnaea borealis	6	40.0	4.3	--	.3	1.3	--	1.1	1.3	173.3
Pinus banksiana (T)	6	40.0	4.0	3.9	2.1	1.9	1.0	2.1	1.6	160.0
Polytrichum spp.	8	53.3	3.0	--	.1	1.2	--	.1	.6	160.0
Galium triflorum	7	46.7	3.3	--	.1	1.0	--	.3	.7	155.6
Sorbus americana (SA)	6	40.0	3.7	4.0	.1	1.7	1.3	.9	1.4	146.7
Picea glauca (SE)	6	40.0	3.7	66.7	.1	1.7	.3	.9	1.0	146.7
Anemone quinquefolia	5	33.3	3.3	--	.1	.9	--	.1	.5	111.1
Vaccinium myrtilloides	6	40.0	2.7	--	.2	5.0	--	3.7	4.4	106.7
Gaultheria procumbens	4	26.7	3.7	--	.4	6.4	--	5.5	5.9	97.8
Rubus strigosus	4	26.7	3.3	--	.7	7.6	--	11.9	9.7	88.9
Quercus rubra (SA)	3	20.0	4.0	4.5	.1	1.6	1.0	.5	1.1	80.0
Picea mariana (SE)	3	20.0	3.3	80.0	.1	1.3	.9	2.2	1.5	66.7
Salix bebbiana	4	26.7	2.3	40.0	.3	1.1	.3	1.6	1.1	62.2
Viburnum rafinesquianum	3	20.0	3.0	280.0	.1	1.6	1.9	1.6	1.7	60.0
Petasites vitifolius	3	20.0	2.3	--	.1	.7	--	.3	.5	46.7
Fraxinus nigra (SE)	2	13.3	2.7	90.0	.1	1.2	.5	1.3	1.1	35.6
Populus grandidentata (T)	3	20.0	1.3	1.9	.5	.6	.5	.4	.5	26.7
Fragaria vesca	3	20.0	1.3	--	.1	.4	--	.2	.3	26.7
Dryopteris spinulosa	2	13.3	1.7	--	.2	.3	--	.5	.5	22.2
Melampyrum lineare	3	20.0	1.0	--	.1	.3	--	.1	.2	20.0
Polypodium virginianum	3	20.0	1.0	--	.1	.3	--	.1	.3	20.0
Lycopodium complanatum	3	20.0	1.0	--	.1	.4	--	.1	.3	20.0
Quercus rubra (T)	1	6.7	2.3	2.9	.6	.9	.7	.7	.8	15.6
Apocynum androsaemifolium	2	13.3	1.0	--	.2	.2	--	.3	.3	13.3
Rosa acicularis	2	13.3	1.0	--	.1	3.2	--	4.0	3.7	13.3
Osmunda claytoniana	2	13.3	1.0	--	.4	.2	--	1.1	.7	13.3
Gaultheria hispidula	2	13.3	.7	--	.1	4.0	--	3.5	3.7	8.9
Pinus strobus (SA)	2	13.3	.7	.3	.1	.3	.1	.3	.3	8.9
Athyrium filix-femina	1	6.7	1.3	--	.3	.4	--	1.1	.7	8.9
Impatiens capensis	2	13.3	.7	--	.1	.1	--	.1	.1	8.9
Fraxinus nigra (SA)	2	13.3	.7	.9	.1	.3	.2	.3	.3	8.9
Pinus resinosa (T)	1	6.7	1.3	.5	2.0	.5	.3	2.3	1.1	8.9
Gymnocarpium Dryopteris	1	6.7	1.0	--	.1	.2	--	.1	.1	6.7
Uvularia sessilifolia	1	6.7	.7	--	.1	.1	--	.1	.1	4.4
Sorbus americana (T)	1	6.7	.7	.3	.1	.3	.1	.1	.2	4.4
Populus grandidentata (SE)	1	6.7	.7	6.7	.1	.3	.1	.2	.2	4.4
Thuja occidentalis (SE)	1	6.7	.7	6.7	.1	.3	.1	.1	.1	4.4
Pyrola secunda	1	6.7	.7	--	.1	.3	--	.1	.2	4.4
Prunus virginiana	1	6.7	.7	6.7	.1	.7	.1	.3	.3	4.4
Pyrola rotundifolia	1	6.7	.3	--	.1	.1	--	.1	.1	2.2

(Continued on next page)

Table 12 continued

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Monotropa uniflora	1	6.7	0.3	--	0.1	0.1	--	0.1	0.1	2.2
Populus grandidentata (SA)	1	6.7	.3	0.2	.1	.1	0.1	.1	.1	2.2
Cladonia rangiferina	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Oryopteris Phegopteris	1	6.7	.3	--	.1	.1	--	.2	.1	2.2
Lathyrus ochroleucus	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Thuja occidentalis (T)	1	6.7	.3	.1	.1	.1	.1	.1	.1	2.2
Hypnum crista-castrensis	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Sphagnum spp.	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Epilobium angustifolium	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Mitella nuda	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Equisetum spp.	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Solidago spp.	1	6.7	.3	--	.1	.1	--	.1	.1	2.2
Alnus rugosa	1	6.7	.3	13.3	.1	.3	.1	.1	.2	2.2
Tilia americana (SE)	1	6.7	.3	3.3	.1	.2	.1	.1	.1	2.2
Fraxinus nigra (T)	1	6.7	.3	.4	.1	.2	.1	.1	.1	2.2
Polygonum cilinode	1	6.7	.0	--	.1	.0	--	.1	.1	.0
Ground cover characteristic:										
Litter	15	100.0	99.3	--	83.4	40.4	--	83.9	62.1	9,933.3
Oead wood	15	100.0	37.3	--	4.2	15.0	--	4.3	9.6	3,733.3
Bare rock	9	60.0	7.0	--	.7	2.6	--	.8	1.6	420.0
Live wood	9	60.0	5.3	--	.3	2.1	--	.4	1.2	320.0
Bare ground	4	26.7	2.7	--	.1	1.1	--	.1	.6	71.1

Table 13. — Stand data summary for the white pine community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Pinus strobus (T)	6	100.0	90.0	188.5	125.0	44.2	56.5	71.7	57.7	9,000.0
Diervilla Lonicera	6	100.0	77.5	12,525.0	2.6	43.8	59.2	44.0	49.2	7,750.0
Aster macrophyllus	6	100.0	72.5	--	20.6	22.8	--	58.3	40.7	7,250.0
Maianthemum canadense	6	100.0	61.7	--	1.9	19.7	--	7.2	13.7	6,166.7
Abies balsamea (SE)	6	100.0	53.3	15,333.3	1.3	38.5	57.2	45.2	47.0	5,333.3
Abies balsamea (T)	6	100.0	41.7	91.0	11.7	20.0	19.3	8.0	16.0	4,166.7
Gramineae	6	100.0	40.8	--	1.4	12.8	--	4.7	8.5	4,083.3
Aralia nudicaulis	6	100.0	38.3	--	4.2	12.0	--	13.8	13.0	3,833.3
Other mosses	5	83.3	45.0	--	4.8	17.8	--	4.7	11.2	3,750.0
Corylus cornuta	6	100.0	35.8	3,066.7	1.3	18.8	19.8	20.7	19.7	3,583.3
Abies balsamea (SA)	4	66.7	53.3	165.5	5.9	31.5	37.2	38.7	35.8	3,555.6
Amelanchier spp.	7	116.7	24.2	891.7	.4	14.7	6.3	10.3	11.5	2,819.4
Pinus strobus (SE)	6	100.0	26.7	2,366.7	.3	19.3	12.8	11.0	14.2	2,666.7
Pinus resinosa (T)	5	83.3	24.2	24.3	15.9	11.7	8.3	10.0	10.2	2,013.9
Linnaea borealis	5	83.3	21.7	--	.7	6.5	--	2.3	4.5	1,805.6
Acer spicatum	5	83.3	20.0	1,583.3	1.8	9.8	6.3	18.8	15.7	1,666.7
Cornus canadensis	5	83.3	17.5	--	1.0	5.5	--	4.7	5.0	1,458.3
Betula papyrifera (T)	6	100.0	14.2	15.8	3.5	6.8	4.7	1.8	4.5	1,416.7
Betula papyrifera (SA)	4	66.7	20.8	18.5	.4	10.8	8.8	6.8	8.8	1,388.9
Calliergonella schreberi	4	66.7	19.2	--	4.2	7.7	--	4.5	5.8	1,277.8
Vaccinium myrtilloides	4	66.7	15.0	--	1.6	24.3	--	35.5	30.0	1,000.0
Populus tremuloides (SE)	5	83.3	11.7	308.3	.3	8.5	4.3	8.0	7.0	972.2
Populus tremuloides (T)	5	83.3	10.8	10.0	6.0	4.8	3.0	3.3	3.8	902.8
Pinus strobus (SA)	3	50.0	15.8	7.7	.4	7.5	5.8	8.3	7.2	791.7
Lonicera canadensis	5	83.3	9.2	375.0	.1	5.2	2.8	1.5	3.2	763.9
Picea glauca (T)	6	100.0	7.5	6.3	2.1	3.7	1.5	1.2	2.3	750.0
Cornus rugosa	3	50.0	15.0	816.7	.5	6.3	4.2	5.2	5.0	750.0
Betula papyrifera (SE)	4	66.7	10.8	225.0	.1	5.8	1.7	3.7	3.8	722.2
Acer rubrum (SA)	2	33.3	17.5	17.7	.5	7.8	9.5	7.7	8.3	583.3
Acer rubrum (SE)	2	33.3	17.5	1,475.0	.5	12.5	16.8	16.7	15.3	583.3
Pinus banksiana (T)	5	83.3	6.7	5.7	3.7	3.2	1.3	2.2	2.2	555.6
Vaccinium angustifolium	4	66.7	8.3	--	.3	22.2	--	15.3	18.8	555.6
Picea glauca (SE)	4	66.7	6.7	75.0	.2	7.2	3.7	9.5	6.5	444.4
Sorbus americana (SE)	3	50.0	8.3	116.7	.1	6.3	3.7	4.5	4.8	416.7
Dicranum spp.	3	50.0	8.3	--	.6	2.8	--	.7	1.7	416.7
Other lichens	3	50.0	8.3	--	.8	3.0	--	.7	1.7	416.7
Clintonia borealis	3	50.0	8.3	--	.4	2.7	--	2.2	2.3	416.7
Populus tremuloides (SA)	3	50.0	7.5	16.7	.6	4.2	2.5	2.5	3.0	375.0
Anemone quinquefolia	3	50.0	6.7	--	.2	2.3	--	.5	1.3	333.3
Acer rubrum (T)	2	33.3	10.0	9.0	1.7	4.3	2.8	.8	2.8	333.3
Pteridium aquilinum	4	66.7	5.0	--	.5	1.7	--	1.7	1.5	333.3
Alnus crispa	3	50.0	5.8	441.7	.3	2.5	1.3	3.2	3.3	291.7
Trientalis borealis	2	33.3	8.3	--	.2	3.0	--	1.0	1.8	277.8
Rosa acicularis	4	66.7	4.2	--	.3	24.5	--	28.0	26.2	277.8
Fragaria vesca	2	33.3	7.5	--	.2	2.2	--	.5	1.3	250.0
Lycopodium obscurum	3	50.0	3.3	--	.2	1.2	--	.8	1.0	166.7
Rubus pubescens	2	33.3	4.2	--	.1	13.0	--	5.8	9.5	138.9
Picea glauca (SA)	3	50.0	2.5	2.7	.1	1.5	.5	1.0	1.0	125.0
Picea mariana (SA)	2	33.3	3.3	7.2	.2	1.8	1.0	.7	1.2	111.1
Streptopus roseus	2	33.3	3.3	--	.1	1.2	--	.3	.8	111.1
Antennaria spp.	1	16.7	5.0	--	.1	1.7	--	.3	1.0	83.3
Picea mariana (T)	2	33.3	2.5	4.7	1.4	1.2	.8	.8	1.0	83.3
Melampyrum lineare	2	33.3	2.5	--	.1	.8	--	.2	.5	83.3
Gaultheria procumbens	1	16.7	3.3	--	.1	7.3	--	7.2	7.3	55.6
Pyrola secunda	1	16.7	3.3	--	.1	1.0	--	.5	.8	55.6
Cladonia mitis	1	16.7	3.3	--	.5	1.0	--	.5	.8	55.6
Sorbus americana (SA)	2	33.3	1.7	.5	.1	1.0	.3	.5	.7	55.6
Polytrichum spp.	2	33.3	1.7	--	.1	.7	--	.2	.3	55.6
Lathyrus ochroleucus	2	33.3	1.7	--	.1	.5	--	.3	.3	55.6
Salix bebbiana	2	33.3	1.7	25.0	.1	1.0	.2	.3	.5	55.6
Cyperaceae	1	16.7	3.3	--	.1	1.0	--	.3	.7	55.6
Rubus strigosus	2	33.3	1.7	--	.1	3.7	--	2.7	3.2	55.6
Viola spp.	2	33.3	1.7	--	.1	.7	--	.1	.4	55.6
Arctostaphylos Uva-ursi	1	16.7	2.5	--	.1	2.3	--	1.2	1.8	41.7
Picea mariana (SE)	1	16.7	2.5	75.0	.1	1.3	.2	1.2	.8	41.7
Viburnum rafinesquianum	1	16.7	.8	16.7	.1	.5	.1	.1	.2	13.9
Vicia americana	1	16.7	.8	--	.1	.3	--	.1	.2	13.9
Prunus pensylvanica	1	16.7	.8	8.3	.1	.3	.1	.1	.2	13.9
Lonicera hirsuta	1	16.7	.8	58.3	.1	.5	.3	.2	.3	13.9
Clematis virginiana	1	16.7	.8	--	.1	.3	--	.2	.2	13.9
Galium triflorum	1	16.7	.8	--	.1	.3	--	.1	.2	13.9
Cladonia rangiferina	1	16.7	.8	--	.1	.3	--	.1	.2	13.9
Pinus resinosa (SE)	1	16.7	.8	8.3	.1	.3	.1	.3	.2	13.9
Thuja occidentalis (SA)	1	16.7	.8	2.2	.1	.5	.2	.3	.3	13.9
Chimaphila umbellata	1	16.7	.8	--	.1	2.8	--	1.0	1.8	13.9
Fragaria virginiana	1	16.7	.8	--	.1	.3	--	.1	.2	13.9
Pinus resinosa (SA)	1	16.7	.8	.3	.1	.3	.2	.3	.3	13.9
Coptis groenlandica	1	16.7	.8	--	.1	.3	--	.2	.2	13.9
Rubus parviflorus	1	16.7	.0	--	.1	.0	--	3.2	3.2	.0
Lycopodium clavatum	1	16.7	.0	--	.1	.0	--	.1	.1	.0
Ground cover characteristic:										
Litter	6	100.0	99.2	--	84.4	45.8	--	85.3	65.5	9,916.7
Dead wood	6	100.0	32.5	--	2.7	15.2	--	2.7	8.8	3,250.0
Live wood	4	66.7	6.7	--	.6	3.2	--	.5	1.8	444.4
Bare rock	3	50.0	7.5	--	.3	2.7	--	.2	1.7	375.0

Table 14. — Stand data summary for the red pine community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Pinus resinosa (T)	4	100.0	78.7	156.7	146.9	37.0	38.5	48.5	41.5	7,875.0
Pinus strobus (T)	4	100.0	76.3	89.5	58.5	34.2	39.0	40.7	37.7	7,625.0
Dicranum spp.	4	100.0	55.0	--	9.1	14.5	--	9.0	11.7	5,500.0
Pinus strobus (SE)	4	100.0	51.3	3,300.0	1.9	36.7	28.2	32.5	32.5	5,125.0
Vaccinium angustifolium	4	100.0	48.8	--	7.1	41.7	--	50.2	45.7	4,875.0
Other mosses	4	100.0	47.5	--	3.0	12.5	--	3.0	7.8	4,750.0
Maianthemum canadense	4	100.0	43.8	--	1.7	45.0	--	37.5	41.3	4,375.0
Calliergonella schreberi	4	100.0	42.5	--	10.8	11.7	--	11.0	11.5	4,250.0
Other lichens	4	100.0	30.0	--	1.3	7.3	--	1.5	4.3	3,000.0
Amelanchier spp.	4	100.0	28.8	1,700.0	.4	28.0	23.5	17.5	23.0	2,875.0
Gaultheria procumbens	3	75.0	36.3	--	3.1	28.5	--	17.2	23.0	2,718.8
Acer rubrum (SE)	3	75.0	33.8	4,525.0	.8	23.5	42.7	16.5	27.5	2,531.3
Aster macrophyllus	3	75.0	31.3	--	6.4	13.8	--	29.0	21.0	2,343.8
Vaccinium myrtilloides	3	75.0	27.5	--	4.9	18.2	--	23.8	21.0	2,062.5
Pinus strobus (SA)	2	50.0	40.0	22.5	.6	14.2	17.0	17.0	16.0	2,000.0
Corylus cornuta	3	75.0	23.8	1,437.5	.5	22.5	28.8	29.7	26.7	1,781.3
Melampyrum lineare	3	75.0	21.3	--	.7	10.2	--	5.0	7.5	1,593.8
Cladonia rangiferina	4	100.0	15.0	--	2.3	4.0	--	2.3	3.3	1,500.0
Gramineae	2	50.0	26.3	--	1.2	8.8	--	3.8	6.3	1,312.5
Betula papyrifera (T)	3	75.0	16.3	19.7	2.3	7.5	5.8	.8	4.5	1,218.8
Cornus canadensis	3	75.0	15.0	--	1.6	8.5	--	14.2	11.5	1,125.0
Picea mariana (SE)	3	75.0	15.0	462.5	1.4	14.5	16.7	30.0	20.5	1,125.0
Picea mariana (SA)	2	50.0	21.3	10.2	.2	7.3	6.8	4.8	6.5	1,062.5
Cladonia mitis	3	75.0	12.5	--	1.7	3.3	--	1.8	2.5	937.5
Polytrichum spp.	4	100.0	8.8	--	.8	2.3	--	.8	1.8	875.0
Pinus resinosa (SA)	2	50.0	16.3	6.5	.3	5.8	4.5	6.3	5.5	812.5
Betula papyrifera (SA)	2	50.0	16.3	6.5	.2	5.5	4.5	5.3	5.3	812.5
Pinus banksiana (T)	2	50.0	15.0	9.8	7.1	6.0	6.0	5.3	5.8	750.0
Diervilla Lonicera	3	75.0	8.8	225.0	.1	8.5	4.0	2.5	4.8	656.3
Aralia nudicaulis	3	75.0	8.8	--	.5	3.5	--	2.3	2.8	656.3
Alnus crispa	2	50.0	11.3	750.0	.4	9.8	11.5	20.0	14.0	562.5
Betula papyrifera (SE)	3	75.0	7.5	362.5	.3	5.3	4.5	3.8	4.5	562.5
Acer rubrum (T)	2	50.0	10.0	5.0	1.8	4.3	3.0	1.5	3.0	500.0
Populus tremuloides (SE)	3	75.0	5.0	87.5	.1	4.0	1.8	1.0	2.0	375.0
Cyperaceae	3	75.0	5.0	--	.2	2.5	--	1.0	1.8	375.0
Comptonia peregrina	2	50.0	7.5	287.5	.1	7.8	6.0	3.5	5.8	375.0
Acer rubrum (SA)	1	25.0	12.5	6.0	.2	4.8	6.0	5.0	5.3	312.5
Quercus rubra (T)	2	50.0	6.3	2.8	.3	2.5	2.0	.3	1.8	312.5
Abies balsamea (SA)	1	25.0	12.5	5.0	.1	4.3	3.0	2.8	3.3	312.5
Quercus rubra (SE)	1	25.0	12.5	325.0	.3	5.5	2.0	4.3	4.0	312.5
Pinus resinosa (SE)	3	75.0	3.8	75.0	.2	3.5	2.5	6.3	4.3	281.3
Abies balsamea (T)	2	50.0	5.0	2.5	.3	2.3	1.3	.3	1.3	250.0
Picea mariana (T)	2	50.0	5.0	5.5	2.6	2.5	1.0	1.5	2.0	250.0
Thuja occidentalis (SA)	1	25.0	8.8	4.5	.2	3.0	2.8	4.3	3.3	218.8
Juniperus communis	1	25.0	7.5	487.5	.2	21.5	24.2	24.7	23.5	187.5
Sorbus americana (SE)	2	50.0	3.8	37.5	.1	2.8	.8	.8	1.5	187.5
Pinus banksiana (SA)	1	25.0	7.5	3.0	.1	2.8	2.8	2.5	2.8	187.5
Chimaphila umbellata	2	50.0	3.8	--	.1	6.5	--	1.8	4.0	187.5
Picea glauca (SE)	2	50.0	2.5	25.0	.3	2.3	.5	4.3	2.3	125.0
Picea glauca (T)	1	25.0	5.0	1.0	.3	1.8	1.3	.5	1.3	125.0
Abies balsamea (SE)	2	50.0	2.5	25.0	.1	2.3	.5	.8	1.3	125.0
Quercus rubra (SA)	1	25.0	5.0	1.3	.1	1.8	1.3	1.5	1.5	125.0
Salix bebbiana	2	50.0	2.5	100.0	.1	2.3	1.3	2.3	2.0	125.0
Thuja occidentalis (T)	1	25.0	5.0	3.0	.8	2.3	1.3	.5	1.3	125.0
Arctostaphylos Uva-ursi	1	25.0	3.8	--	1.0	4.5	--	7.3	5.8	93.8
Sphagnum spp.	1	25.0	3.8	--	.6	1.0	--	.8	.8	93.8
Pteridium aquilinum	1	25.0	2.5	--	.6	1.5	--	5.3	3.3	62.5
Picea glauca (SA)	1	25.0	2.5	.8	.1	1.0	.5	.8	.8	62.5
Streptopus roseus	1	25.0	2.5	--	.1	.8	--	.3	.5	62.5
Linnaea borealis	1	25.0	2.5	--	.1	1.8	--	.5	1.3	62.5
Clintonia borealis	1	25.0	1.3	--	.1	.8	--	.3	.5	31.3
Goodyera tesselata	1	25.0	1.3	--	.1	.8	--	.3	.5	31.3
Lycopodium clavatum	1	25.0	1.3	--	.1	.3	--	.3	.3	31.3
Anemone quinquefolia	1	25.0	1.3	--	.1	.3	--	.1	.2	31.3
Trientalis borealis	1	25.0	1.3	--	.1	.8	--	.3	.5	31.3
Hypnum crista-castrensis	1	25.0	1.3	--	.1	.3	--	.1	.2	31.3
Polypodium virginianum	1	25.0	1.3	--	.1	1.0	--	.3	.5	31.3
Ground cover characteristic:										
Litter	4	100.0	98.8	--	63.8	26.7	--	63.5	45.0	9,875.0
Bare rock	4	100.0	31.3	--	3.3	8.3	--	3.5	5.5	3,125.0
Dead wood	4	100.0	26.3	--	2.3	7.0	--	2.0	4.8	2,625.0
Live wood	2	50.0	5.0	--	1.2	1.0	--	1.3	1.3	250.0
Bare ground	1	25.0	1.3	--	.1	.3	--	.1	.2	31.3

Table 15. — Stand data summary for the budworm-damaged community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Abies balsamea (SE)	10	100.0	76.0	3,645.0	4.5	44.5	51.5	60.8	52.3	7,600.0
Abies balsamea (SA)	10	100.0	75.5	128.2	3.2	48.3	60.4	54.5	54.5	7,550.0
Maianthemum canadense	10	100.0	59.0	--	2.5	17.1	--	8.7	12.9	5,900.0
Calliergonella schreberi	10	100.0	57.0	--	12.4	17.8	--	12.3	15.1	5,700.0
Other mosses	10	100.0	51.5	--	6.1	17.1	--	6.2	11.6	5,150.0
Cornus canadensis	9	90.0	48.0	--	5.5	12.1	--	14.5	13.1	4,320.0
Aster macrophyllus	9	90.0	46.5	--	10.3	13.1	--	30.5	21.9	4,185.0
Betula papyrifera (T)	9	90.0	44.3	59.5	12.0	19.9	20.4	15.5	18.6	3,987.0
Picea mariana (T)	8	80.0	44.3	65.2	17.6	20.4	21.6	18.8	20.3	3,544.0
Diervilla Lonicera	9	90.0	36.5	2,025.0	.4	24.2	20.4	13.9	19.3	3,285.0
Linnaea borealis	10	100.0	32.0	--	1.9	8.6	--	6.4	7.7	3,200.0
Betula papyrifera (SA)	10	100.0	31.7	40.1	1.7	21.0	19.7	23.0	21.3	3,170.0
Abies balsamea (T)	9	90.0	33.3	35.2	6.0	22.6	20.7	15.2	19.4	2,997.0
Populus tremuloides (T)	8	80.0	35.2	57.1	31.0	14.0	15.3	22.8	17.4	2,816.0
Corylus cornuta	9	90.0	30.5	3,355.0	1.6	20.9	29.9	34.5	28.3	2,745.0
Populus tremuloides (SE)	9	90.0	29.0	865.0	.5	14.7	12.5	7.9	11.6	2,610.0
Acer spicatum	9	90.0	26.5	1,425.0	.9	20.8	23.0	30.3	24.8	2,385.0
Betula papyrifera (SE)	9	90.0	25.5	1,475.0	.6	13.7	17.2	10.0	13.7	2,295.0
Gramineae	9	90.0	25.0	--	.8	6.6	--	2.7	4.6	2,250.0
Picea mariana (SA)	8	80.0	26.6	20.6	.9	17.3	11.8	15.8	15.0	2,128.0
Aralia nudicaulis	9	90.0	23.5	--	3.3	7.2	--	11.9	9.4	2,115.0
Dicranum spp.	7	70.0	29.5	--	3.2	8.4	--	3.2	5.8	2,065.0
Clintonia borealis	9	90.0	20.5	--	2.3	4.5	--	6.5	5.5	1,845.0
Lonicera canadensis	9	90.0	15.5	790.0	.2	14.9	15.5	11.5	13.9	1,395.0
Picea glauca (T)	8	80.0	16.6	10.7	5.6	6.5	4.6	6.7	6.0	1,328.0
Acer rubrum (SE)	6	60.0	22.0	1,175.0	1.1	10.7	11.6	9.5	10.6	1,320.0
Rubus strigosus	6	60.0	21.5	--	7.9	25.8	--	31.0	28.5	1,290.0
Pinus banksiana (T)	6	60.0	20.2	18.6	13.0	7.4	7.4	11.7	8.9	1,212.0
Trientalis borealis	9	90.0	13.0	--	.3	3.4	--	.6	2.2	1,170.0
Rubus pubescens	7	70.0	16.5	--	1.1	32.6	--	26.4	29.4	1,155.0
Viola spp.	8	80.0	11.5	--	.3	3.0	--	.7	2.1	920.0
Fragaria vesca	7	70.0	13.0	--	.8	3.5	--	2.6	3.2	910.0
Other lichens	7	70.0	12.5	--	.9	3.9	--	.9	2.4	875.0
Amelanchier spp.	7	70.0	10.5	215.0	.1	7.9	3.5	2.4	4.7	735.0
Lycopodium clavatum	6	60.0	10.0	--	.8	2.3	--	2.0	2.2	600.0
Pyrola secunda	6	60.0	8.5	--	.5	2.5	--	1.7	2.1	510.0
Sorbus americana (SE)	5	50.0	10.0	160.0	.2	5.1	2.1	1.8	3.1	500.0
Picea glauca (SE)	7	70.0	7.0	115.0	.1	4.3	1.6	1.9	2.6	490.0
Populus tremuloides (SA)	6	60.0	7.5	3.9	.1	6.2	4.1	2.3	4.2	450.0
Picea mariana (SE)	6	60.0	6.5	185.0	.6	3.9	2.8	6.9	4.5	390.0
Polygonum cilinode	3	30.0	12.0	--	.8	5.0	--	4.4	4.7	360.0
Galium triflorum	7	70.0	4.5	--	.2	1.5	--	.9	1.2	315.0
Vaccinium angustifolium	6	60.0	5.0	--	.3	12.6	--	13.5	13.1	300.0
Coptis groenlandica	3	30.0	7.5	--	.4	1.3	--	.8	1.1	225.0
Polytrichum spp.	6	60.0	3.5	--	.3	1.1	--	.2	.7	210.0
Picea glauca (SA)	5	50.0	4.1	1.8	.1	2.4	.9	1.4	1.8	205.0
Thuja occidentalis (T)	2	20.0	10.0	10.5	2.7	7.2	8.1	8.0	7.8	200.0
Hylocomium splendens	4	40.0	5.0	--	1.0	1.4	--	.9	1.1	200.0
Vaccinium myrtilloides	6	60.0	3.0	--	.2	9.8	--	9.8	9.7	180.0
Lycopodium obscurum	4	40.0	4.5	--	.2	.8	--	.6	.7	180.0
Streptopus roseus	4	40.0	3.5	--	.2	.8	--	.6	.7	140.0
Rosa acicularis	4	40.0	3.5	--	.2	7.5	--	6.9	7.3	140.0
Acer rubrum (SA)	3	30.0	4.5	3.6	.1	2.1	1.3	.7	1.4	135.0
Mitella nuda	3	30.0	4.5	--	.1	1.0	--	.3	.6	135.0
Acer rubrum (T)	4	40.0	3.1	2.8	.6	1.2	.7	.6	.8	124.0
Alnus crispa	3	30.0	4.0	435.0	.4	2.1	2.8	4.0	2.9	120.0
Pinus strobus (SE)	4	40.0	3.0	30.0	.1	1.5	.3	.5	.8	120.0
Chimaphila umbellata	3	30.0	3.5	--	.1	6.0	--	4.0	5.0	105.0
Lonicera hirsuta	2	20.0	4.0	75.0	.1	2.8	1.1	.7	1.5	80.0
Pyrola rotundifolia	3	30.0	2.5	--	.1	.8	--	.2	.5	75.0
Hypnum crista-castrensis	3	30.0	2.0	--	.3	.5	--	.3	.5	60.0
Lathyrus ochroleucus	3	30.0	2.0	--	.1	.5	--	.4	.4	60.0
Cyperaceae	4	40.0	1.5	--	.1	.4	--	.1	.3	60.0
Salix bebbiana	2	20.0	2.0	20.0	.1	1.1	.2	.2	.5	40.0
Cornus rugosa	2	20.0	2.0	370.0	.1	1.4	1.9	1.5	1.6	40.0
Thuja occidentalis (SA)	1	10.0	3.0	1.3	.1	1.8	.9	1.8	1.5	30.0
Pinus strobus (T)	2	20.0	1.5	2.0	.7	.6	.3	.4	.5	30.0
Lycopodium complanatum	2	20.0	1.5	--	.3	.5	--	1.6	1.0	30.0
Rubus parviflorus	1	10.0	2.5	--	.6	3.1	--	6.3	4.7	25.0
Waldsteinia fragarioides	2	20.0	1.0	--	.1	.3	--	.1	.2	20.0
Lycopodium annotinum	1	10.0	2.0	--	.3	.3	--	.6	.5	20.0
Pyrola elliptica	2	20.0	1.0	--	.1	.2	--	.1	.2	20.0
Melampyrum lineare	2	20.0	1.0	--	.1	.3	--	.1	.2	20.0
Quercus rubra (SE)	1	10.0	2.0	25.0	.1	.7	.3	.2	.4	20.0
Vicia americana	2	20.0	1.0	--	.1	.3	--	.2	.2	20.0
Thuja occidentalis (SE)	1	10.0	1.5	15.0	.1	.6	.2	.1	.3	15.0
Pyrola asarifolia	1	10.0	1.0	--	.1	.2	--	.1	.1	10.0
Prunus pensylvanica	1	10.0	1.0	20.0	.1	2.5	1.1	.3	1.3	10.0
Anemone quinquefolia	1	10.0	1.0	--	.1	.2	--	.1	.1	10.0
Cladonia rangiferina	1	10.0	1.0	--	.1	.3	--	.1	.2	10.0
Equisetum spp.	1	10.0	1.0	--	.1	.2	--	.1	.1	10.0
Ribes spp.	1	10.0	1.0	--	.3	1.0	--	.7	.8	10.0
Petasites vitifolius	1	10.0	.5	--	.1	.1	--	.1	.1	5.0
Uvularia sessilifolia	1	10.0	.5	--	.1	.1	--	.1	.1	5.0
Habenaria orbiculata	1	10.0	.5	--	.1	.1	--	.1	.1	5.0

(continued on next page)

Table 15 continued

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Goodyera repens	1	10.0	0.5	--	0.1	0.1	--	0.1	0.1	5.0
Populus grandidentata (SA)	1	10.0	.5	0.6	.1	.3	0.1	.3	.2	5.0
Salix spp.	1	10.0	.5	5.0	.1	.5	.1	.4	.3	5.0
Galium boreale	1	10.0	.5	--	.1	.1	--	.1	.1	5.0
Pinus resinosa (T)	1	10.0	.5	.1	.1	.2	.1	.4	.2	5.0
Cladonia sylvatica	1	10.0	.5	--	.1	.2	--	.1	.1	5.0
Viburnum rafinesquianum	1	10.0	.5	30.0	.1	.2	.2	.2	.2	5.0
Sorbus americana (SA)	1	10.0	.5	.3	.1	.3	.1	.2	.2	5.0
Epigaea repens	1	10.0	.5	--	.2	.1	--	.5	.3	5.0
Sphagnum spp.	1	10.0	.5	--	.4	.2	--	.4	.3	5.0
Pinus resinosa (SE)	1	10.0	.5	5.0	.1	.2	.1	.1	.1	5.0
Pinus banksiana (SA)	1	10.0	.5	.3	.1	.3	.1	.1	.2	5.0
Gaultheria hispidula	1	10.0	.5	--	.1	1.4	--	1.5	1.5	5.0
Apocynum androsaemifolium	1	10.0	.0	--	.1	.0	--	.1	.1	.0
Actaea rubra	1	10.0	.0	--	.1	.0	--	.1	.1	.0
Epilobium angustifolium	1	10.0	.0	--	.1	.0	--	.1	.1	.0
Pteridium aquilinum	1	10.0	.0	--	.1	.0	--	.1	.1	.0
Ground cover characteristic:										
Litter	10	100.0	99.5	--	70.2	33.2	--	70.0	51.4	9,950.0
Dead wood	10	100.0	36.5	--	4.5	12.0	--	4.4	8.5	3,650.0
Bare rock	5	50.0	6.5	--	.5	2.1	--	.5	1.4	325.0
Live wood	4	40.0	4.0	--	.3	1.6	--	.2	.9	160.0
Bare ground	2	20.0	2.0	--	.1	.5	--	.1	.2	40.0

Table 16. — Stand data summary for the fir-birch community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Abies balsamea (SA)	8	100.0	94.7	260.1	8.4	56.3	74.6	70.4	67.0	9,475.0
Other mosses	8	100.0	85.2	--	11.5	27.5	--	11.5	19.4	8,525.0
Abies balsamea (T)	8	100.0	77.2	153.5	26.0	35.9	43.8	27.1	35.6	7,725.0
Abies balsamea (SE)	8	100.0	75.0	9,877.1	6.1	46.7	58.2	67.6	57.5	7,500.0
Acer spicatum	8	100.0	70.4	6,689.6	4.2	52.5	70.5	80.9	68.0	7,037.5
Betula papyrifera (T)	8	100.0	61.0	106.6	27.0	29.1	26.4	31.4	29.0	6,100.0
Calliergonella schreberi	8	100.0	45.0	--	9.3	13.4	--	9.4	11.3	4,500.0
Betula papyrifera (SA)	8	100.0	43.5	76.6	3.1	24.5	16.1	19.5	20.0	4,350.0
Cornus canadensis	8	100.0	35.9	--	2.8	15.6	--	17.7	16.7	3,587.5
Betula papyrifera (SE)	8	100.0	28.1	1,854.1	.5	19.9	16.9	9.5	15.5	2,812.5
Corylus cornuta	7	87.5	29.6	1,395.9	.8	20.1	13.1	10.6	14.7	2,592.2
Sorbus americana (SE)	8	100.0	24.7	545.9	.5	19.1	15.1	11.7	15.2	2,475.0
Picea mariana (T)	7	87.5	27.5	31.4	9.3	12.2	8.6	9.3	10.2	2,406.3
Maianthemum canadense	7	87.5	25.0	--	.7	11.4	--	6.1	8.8	2,187.5
Aster macrophyllus	7	87.5	22.7	--	3.7	8.5	--	19.7	14.2	1,990.6
Linnaea borealis	7	87.5	21.0	--	1.0	8.0	--	5.8	7.0	1,837.5
Viola spp.	7	87.5	19.6	--	.5	7.5	--	2.8	5.4	1,717.2
Thuja occidentalis (T)	6	75.0	18.5	22.6	11.4	8.3	7.8	13.2	9.9	1,387.5
Dicranum spp.	5	62.5	21.3	--	1.5	6.0	--	1.4	3.8	1,328.1
Lonicera canadensis	6	75.0	15.9	743.8	.2	11.3	7.8	3.5	7.5	1,190.6
Aralia nudicaulis	6	75.0	14.6	--	1.2	5.0	--	5.4	5.3	1,096.9
Clintonia borealis	5	62.5	17.5	--	1.8	5.6	--	7.8	6.8	1,093.8
Galium triflorum	7	87.5	11.6	--	.2	4.4	--	1.0	2.9	1,017.2
Picea glauca (T)	7	87.5	9.8	7.9	4.5	4.8	2.9	5.1	4.1	853.1
Rubus strigosus	4	50.0	15.4	--	4.0	25.7	--	27.2	26.5	768.8
Diervilla Lonicera	7	87.5	8.8	337.5	.1	6.1	5.0	2.1	4.4	765.6
Populus tremuloides (T)	4	50.0	15.2	11.4	4.5	8.4	9.3	12.2	10.0	762.5
Picea mariana (SA)	6	75.0	9.4	8.9	.4	5.5	2.1	2.9	3.6	703.1
Other lichens	6	75.0	9.1	--	.3	2.6	--	.3	1.6	684.4
Trientalis borealis	6	75.0	8.8	--	.3	4.6	--	3.6	4.1	656.3
Thuja occidentalis (SA)	4	50.0	12.1	14.6	.6	6.6	3.1	4.5	4.8	606.3
Rubus pubescens	5	62.5	8.8	--	.5	27.4	--	26.0	26.7	546.9
Lycopodium obscurum	4	50.0	10.0	--	.9	3.3	--	3.9	3.6	500.0
Streptopus roseus	6	75.0	6.3	--	.3	2.1	--	1.3	1.6	468.8
Gramineae	5	62.5	7.5	--	.2	2.5	--	.9	1.8	468.8
Lycopodium annotinum	4	50.0	9.1	--	1.1	5.8	--	11.1	8.4	456.3
Populus tremuloides (SE)	4	50.0	8.8	202.1	.2	4.3	2.0	1.8	2.8	437.5
Thuja occidentalis (SE)	4	50.0	8.5	1,479.1	.4	4.6	4.8	6.5	5.4	425.0
Lycopodium clavatum	5	62.5	5.4	--	.8	1.8	--	3.5	2.6	335.9
Hypnum crista-castrensis	5	62.5	5.0	--	.4	1.5	--	.3	1.0	312.5
Coptis groenlandica	4	50.0	6.3	--	.2	1.9	--	.8	1.4	312.5
Populus tremuloides (SA)	3	37.5	7.1	3.8	.1	4.0	1.9	1.9	2.6	267.2
Vaccinium myrtilloides	4	50.0	5.0	--	.4	12.2	--	9.1	10.6	250.0
Pyrola secunda	3	37.5	6.3	--	.2	2.3	--	.8	1.6	234.4
Picea glauca (SA)	4	50.0	4.4	2.9	.1	2.6	1.0	.9	1.6	218.8
Amelanchier spp.	4	50.0	4.4	87.5	.1	2.8	1.0	.6	1.5	218.8
Fragaria vesca	3	37.5	5.4	--	.4	1.6	--	1.6	1.6	201.6
Hylocomium splendens	3	37.5	4.4	--	.9	1.3	--	1.0	1.0	164.1
Picea mariana (SE)	3	37.5	3.1	162.5	.1	1.6	2.0	1.5	1.8	117.2
Pyrola virens	3	37.5	2.9	--	.1	1.0	--	.3	.6	107.8
Polytrichum spp.	3	37.5	2.5	--	.2	.8	--	.3	.5	93.8
Cyperaceae	3	37.5	2.3	--	.1	.8	--	.5	.6	84.4
Picea glauca (SE)	2	25.0	2.8	27.1	.1	1.4	.3	.4	.8	68.8
Lonicera hirsuta	1	12.5	5.3	83.4	.1	2.8	.5	.3	1.1	65.6
Gymnocarpium Oryopteris	2	25.0	1.9	--	.1	1.0	--	.4	.6	46.9
Sorbus americana (SA)	2	25.0	1.9	3.5	.1	1.0	.4	.3	.6	46.9
Goodyera repens	2	25.0	1.9	--	.1	.6	--	.1	.4	46.9
Cladonia sylvatica	2	25.0	1.9	--	.2	.6	--	.1	.5	46.9
Cornus rugosa	2	25.0	1.6	58.4	.1	.9	.5	.1	.5	40.6
Mitella nuda	2	25.0	1.3	--	.1	1.1	--	1.1	1.3	31.3
Alnus crispa	2	25.0	1.3	25.0	.1	1.0	.4	.3	.5	31.3
Prunus pensylvanica	2	25.0	1.3	12.5	.1	.9	.1	.1	.3	31.3
Impatiens capensis	1	12.5	2.5	--	.3	.8	--	1.0	.9	31.3
Acer rubrum (SE)	1	12.5	2.5	62.5	.1	1.1	.4	.8	.8	31.3
Circaea alpina	1	12.5	1.9	--	.1	.6	--	.1	.4	23.4
Pinus strobus (T)	1	12.5	1.9	2.5	.6	.8	.5	.8	.6	23.4
Chimaphila umbellata	1	12.5	1.3	--	.1	3.1	--	1.0	2.1	15.6
Vaccinium angustifolium	1	12.5	1.3	--	.1	3.1	--	2.4	2.8	15.6
Petasites vitifolius	2	25.0	.6	--	.1	.3	--	.4	.3	15.6
Rubus parviflorus	2	25.0	.6	--	.6	1.8	--	8.0	4.9	15.6
Taxus canadensis	1	12.5	1.3	31.3	.1	1.6	1.1	.4	1.0	15.6
Moneses uniflora	1	12.5	1.3	--	.1	.4	--	.3	.3	15.6
Lathyrus ochroleucus	1	12.5	1.0	--	.1	.4	--	.3	.4	12.5
Apocynum androsaemifolium	1	12.5	.6	--	.1	.3	--	.1	.2	7.8
Pinus strobus (SE)	1	12.5	.6	6.3	.1	.3	.1	.1	.1	7.8
Fraxinus nigra (SE)	1	12.5	.6	6.3	.1	.4	.1	.3	.3	7.8
Cynoglossum boreale	1	12.5	.6	--	.1	.3	--	.3	.3	7.8
Goodyera tesselata	1	12.5	.6	--	.1	.5	--	.1	.3	7.8
Athyrium filix-femina	1	12.5	.6	--	.1	.3	--	.1	.1	7.8
Pinus banksiana (T)	1	12.5	.6	.4	.4	.3	.1	.6	.4	7.8
Sorbus americana (T)	1	12.5	.6	.3	.1	.3	.1	.1	.2	7.8
Pteridium aquilinum	1	12.5	.6	--	.1	.1	--	.4	.3	7.8
Ribes spp.	1	12.5	.6	--	.1	1.6	--	1.3	1.4	7.8
Cladonia rangiferina	1	12.5	.6	--	.1	.1	--	.1	.1	7.8
Sambucus spp.	1	12.5	.6	18.7	.1	.5	.1	.9	.5	7.8
Dryopteris spinulosa	1	12.5	.6	--	.1	.1	--	.3	.3	7.8
Ground cover characteristic:										
Litter	8	100.0	98.1	--	70.6	31.6	--	70.7	51.3	9,812.5
Dead wood	8	100.0	36.3	--	4.4	11.6	--	4.4	7.8	3,625.0
Live wood	5	62.5	6.3	--	.5	2.0	--	.5	1.3	390.6
Bare rock	3	37.5	1.9	--	.1	.4	--	.1	.3	70.3
Bare ground	1	12.5	1.3	--	.1	.5	--	.1	.3	15.6

Table 17. – Stand data summary for the white-cedar community

Item	Number of stands	Percent presence	Average frequency	Average density	Basal area or cover	Relative frequency	Relative density	Relative dominance	Importance value	Commonness Index
Species:										
Thuja occidentalis (T)	9	100.0	91.7	214.1	82.7	40.8	50.7	48.7	46.7	9,166.7
Other mosses	9	100.0	80.6	--	10.3	29.4	--	10.2	19.9	8,055.6
Abies balsamea (SE)	9	100.0	76.1	14,594.4	1.7	38.2	60.4	37.7	45.4	7,611.1
Acer spicatum	9	100.0	68.9	5,661.1	4.3	48.8	49.4	59.9	52.9	6,888.9
Betula papyrifera (T)	9	100.0	48.3	74.7	28.3	21.1	16.7	17.4	18.4	4,833.3
Thuja occidentalis (SA)	7	77.8	59.4	169.2	6.2	34.2	37.1	39.3	36.9	4,623.5
Abies balsamea (T)	8	88.9	47.8	76.6	16.7	19.4	18.0	10.4	16.1	4,246.9
Abies balsamea (SA)	7	77.8	49.4	177.0	4.8	27.7	30.3	27.6	28.4	3,845.7
Thuja occidentalis (SE)	9	100.0	33.9	2,161.1	1.2	16.8	14.2	27.7	19.6	3,388.9
Maianthemum canadense	9	100.0	31.7	--	1.1	12.3	--	7.4	10.0	3,166.7
Sorbus americana (SE)	8	88.9	35.0	816.7	.7	19.0	9.1	18.6	15.6	3,111.1
Cornus canadensis	9	100.0	23.9	--	1.1	10.0	--	7.4	8.8	2,388.9
Trientalis borealis	9	100.0	22.8	--	.9	8.7	--	4.9	6.7	2,277.8
Aster macrophyllus	7	77.8	23.3	--	2.1	10.9	--	21.4	16.1	1,814.8
Viola spp.	8	88.9	20.0	--	.7	7.3	--	3.7	5.3	1,777.8
Clintonia borealis	8	88.9	20.0	--	1.6	8.1	--	12.1	10.2	1,777.8
Betula papyrifera (SA)	7	77.8	22.8	42.8	1.9	11.9	8.3	9.2	10.0	1,771.6
Betula papyrifera (SE)	7	77.8	22.2	966.7	.2	11.7	10.8	6.1	9.6	1,728.4
Lonicera canadensis	9	100.0	15.6	661.1	.1	13.9	13.1	11.1	12.7	1,555.6
Aralia nudicaulis	8	88.9	17.2	--	2.3	5.6	--	10.7	8.0	1,530.9
Taxus canadensis	5	55.6	27.2	4,316.7	1.0	14.1	19.8	11.3	15.1	1,512.3
Mitella nuda	6	66.7	21.7	--	1.1	7.8	--	6.8	7.3	1,444.4
Corylus cornuta	8	88.9	16.1	950.0	.6	12.0	10.9	11.6	11.6	1,432.1
Picea glauca (T)	8	88.9	14.4	16.2	11.4	6.2	4.0	7.2	5.8	1,284.0
Streptopus roseus	7	77.8	13.3	--	.9	4.8	--	3.9	4.3	1,037.0
Calliergonella schreberi	6	66.7	14.4	--	1.6	4.4	--	1.7	3.1	963.0
Picea glauca (SE)	7	77.8	11.1	161.1	.1	5.1	1.6	3.4	3.3	864.2
Pinus strobus (SE)	4	44.4	18.3	777.8	.2	6.0	1.7	3.9	3.8	814.8
Populus tremuloides (T)	4	44.4	16.7	38.8	19.4	6.9	5.7	10.8	7.7	740.7
Rubus pubescens	6	66.7	8.9	--	.6	54.7	--	54.4	54.6	592.6
Diervilla Lonicera	5	55.6	9.4	316.7	.1	6.3	4.2	3.4	4.8	524.7
Hylocomium splendens	4	44.4	10.0	--	.6	3.0	--	.6	1.8	444.4
Pinus strobus (T)	4	44.4	7.8	15.2	7.0	3.0	2.2	4.3	3.3	345.7
Gymnocarpium Dryopteris	4	44.4	6.1	--	.6	2.0	--	2.9	2.4	271.6
Rubus parviflorus	3	33.3	6.7	--	1.5	17.6	--	32.1	24.9	222.2
Populus tremuloides (SE)	3	33.3	6.1	138.9	.1	2.8	2.2	1.9	2.3	203.7
Hypnum crista-castrensis	4	44.4	3.9	--	.1	1.2	--	.1	.6	172.8
Pyrola secunda	4	44.4	3.9	--	.1	2.3	--	1.0	1.7	172.8
Dicranum spp.	3	33.3	5.0	--	.3	1.4	--	.2	.8	166.7
Galium triflorum	3	33.3	4.4	--	.1	1.0	--	.2	.7	148.1
Gramineae	3	33.3	4.4	--	.1	2.2	--	.9	1.7	148.1
Dryopteris spinulosa	3	33.3	4.4	--	1.3	1.3	--	4.2	2.8	148.1
Lycopodium obscurum	3	33.3	4.4	--	.3	2.4	--	2.7	2.6	148.1
Other lichens	3	33.3	3.9	--	.1	1.3	--	.2	.7	129.6
Cyperaceae	2	22.2	5.0	--	.2	1.1	--	.3	.8	111.1
Impatiens capensis	2	22.2	5.0	--	.5	1.2	--	1.3	1.3	111.1
Amelanchier spp.	3	33.3	3.3	44.4	.1	2.4	.9	.8	1.3	111.1
Linnaea borealis	3	33.3	3.3	--	.1	2.4	--	.8	1.6	111.1
Lycopodium annotinum	3	33.3	2.8	--	.1	1.0	--	.7	.9	92.6
Picea mariana (T)	3	33.3	2.8	3.7	1.0	1.1	.6	.7	.8	92.6
Lycopodium lucidulum	3	33.3	2.8	--	.2	1.9	--	2.6	2.1	92.6
Sorbus americana (T)	2	22.2	3.9	1.9	.2	1.6	1.1	.1	.9	86.4
Pyrola virens	3	33.3	2.2	--	.1	.8	--	.8	.7	74.1
Picea glauca (SA)	3	33.3	2.2	1.4	.1	1.4	.4	.9	1.0	74.1
Sorbus americana (SA)	3	33.3	1.7	1.4	.1	1.1	.3	.3	.7	55.6
Goodyera repens	2	22.2	1.7	--	.1	.6	--	.2	.3	37.0
Coptis groenlandica	2	22.2	1.7	--	.1	.6	--	.1	.3	37.0
Polytrichum spp.	2	22.2	1.7	--	.1	.6	--	.1	.3	37.0
Moneses uniflora	2	22.2	1.1	--	.1	.9	--	.3	.6	24.7
Chimaphila umbellata	2	22.2	1.1	--	.1	2.7	--	.2	1.6	24.7
Picea mariana (SA)	2	22.2	1.1	2.3	.1	.6	.2	.1	.4	24.7
Mertensia paniculata	1	11.1	1.7	--	.1	.3	--	.2	.2	18.5
Alnus crispa	1	11.1	1.7	55.6	.1	.9	.7	1.0	.9	18.5
Botrychium virginianum	1	11.1	1.7	--	.1	.4	--	.2	.3	18.5
Oxalis montana	1	11.1	1.1	--	.1	.4	--	.4	.4	12.3
Cornus rugosa	1	11.1	1.1	11.1	.1	.8	.1	.1	.3	12.3
Circaea alpina	1	11.1	1.1	--	.1	.4	--	.4	.4	12.3
Acer rubrum (SE)	1	11.1	.6	5.6	.1	.2	.1	.1	.1	6.2
Cystopteris fragilis	1	11.1	.6	--	.1	.3	--	.1	.2	6.2
Anemone quinquefolia	1	11.1	.6	--	.1	.2	--	.3	.3	6.2
Habenaria orbiculata	1	11.1	.6	--	.1	.1	--	.4	.3	6.2
Lycopodium complanatum	1	11.1	.6	--	.1	.2	--	.1	.1	6.2
Ribes americana	1	11.1	.6	27.8	.1	.3	.2	.1	.2	6.2
Salix bebbiana	1	11.1	.6	5.6	.1	.3	.1	.1	.1	6.2
Pinus strobus (SA)	1	11.1	.6	1.3	.1	.3	.1	.1	.2	6.2
Populus tremuloides (SA)	1	11.1	.6	.3	.1	.2	.1	.1	.1	6.2
Ribes triste	1	11.1	.6	11.1	.1	.3	.1	.1	.1	6.2
Athyrium filix-femina	1	11.1	.6	--	.1	.1	--	.2	.1	6.2
Rubus strigosus	1	11.1	.6	--	.1	1.1	--	1.9	1.6	6.2
Pinus resinosa (T)	1	11.1	.6	1.0	.6	.2	.1	.4	.2	6.2
Clematis virginiana	1	11.1	.6	--	.1	.1	--	.1	.1	6.2
Vaccinium angustifolium	1	11.1	.6	--	.1	1.6	--	.2	.9	6.2
Picea mariana (SE)	1	11.1	.6	5.6	.1	.4	.1	.2	.2	6.2
Pinus banksiana (SA)	1	11.1	.6	1.2	.1	.2	.1	.1	.1	6.2
Pteridium aquilinum	1	11.1	.0	--	.1	.0	--	.6	.6	.0
Ground cover characteristic:										
Litter	9	100.0	100.0	--	82.5	39.0	--	82.3	60.6	10,000.0
Dead wood	9	100.0	45.0	--	3.9	16.2	--	3.9	10.0	4,500.0
Live wood	6	66.7	4.4	--	.2	1.7	--	.1	1.0	296.3
Bare rock	4	44.4	2.8	--	.2	1.0	--	.2	.6	123.5
Bare ground	1	11.1	1.1	--	.1	.3	--	.1	.2	12.3

Table 18. — Families represented by more than one species in the sample. The last two columns represent the average within family percent presence of occurrence in stands and average within family percent frequency occurrence in sample points or plots

Family	Number of species	Percent presence	Percent frequency
Ericaceae	15	13.3	2.4
Rosaceae	12	18.9	3.1
Pinaceae	8	34.9	12.7
Polypodiaceae	8	8.2	1.0
Compositae	7	11.4	5.0
Caprifoliaceae	7	31.2	8.7
Liliaceae	5	41.1	14.7
Lycopodiaceae	5	24.9	3.5
Betulaceae	4	58.5	20.2
Salicaceae	4	24.2	6.4
Cladoniaceae	4	15.3	3.6
Ranunculaceae	4	12.2	1.5
Cornaceae	3	37.7	11.3
Hypnaceae	3	43.7	14.3
Orchidaceae	3	6.6	.4
Saxifragaceae	3	5.1	.8
Aceraceae	2	43.8	19.2
Araliaceae	2	39.6	9.4
Rubiaceae	2	15.6	1.6
Fabaceae	2	8.5	.5
Onagraceae	2	3.3	.2
Boraginaceae	2	.9	.1

Community Comparisons

Figures 11 through 17 depict the importance of the ıst prevalent species in the tree, sapling, seedling, tall ıub, low shrub, herb, and moss-lichen classes *among* 12 community types by size of circle. From small to ıge, they indicate the following four ranges of per- ıt of maximum density or ground cover: 0-25, 26-50, 51-75, 76-100. Similarly, importance *within* each community is indicated by shading, as follows: ¼ shaded = 0-25, ½ shaded = 26-50, ¾ shaded = 51-75, fully shaded = 76-100. Thus, by comparing circle size across the page one can determine the relative importance of the species among the communities, and by comparing amount of shading down the page one can determine the relative importance of species within each community.

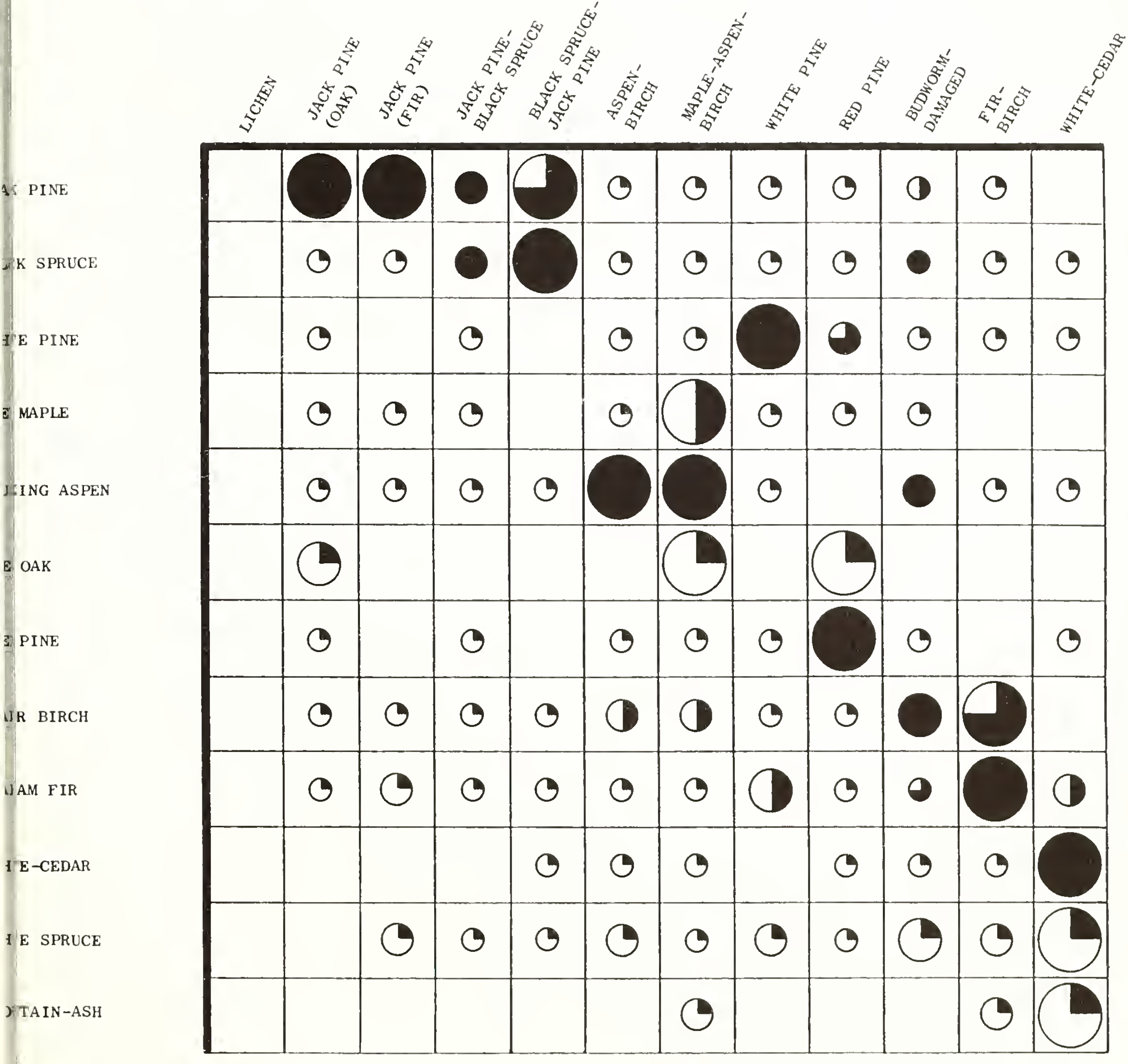

Figure 11. — Importance of tree species density (tree size class) among and within communities.

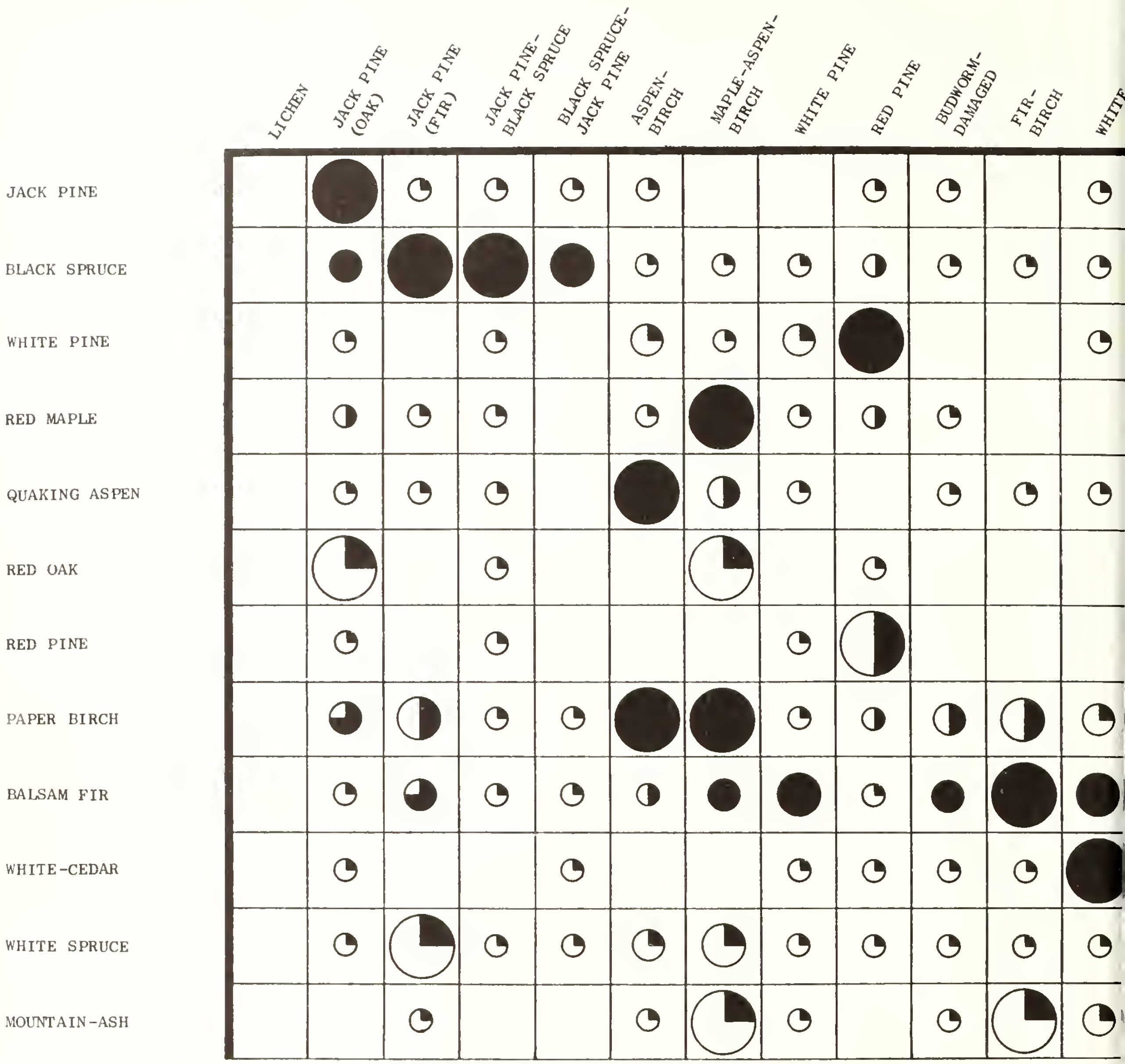

Figure 12. – Importance of tree species density (sapling size class) among and within communities.

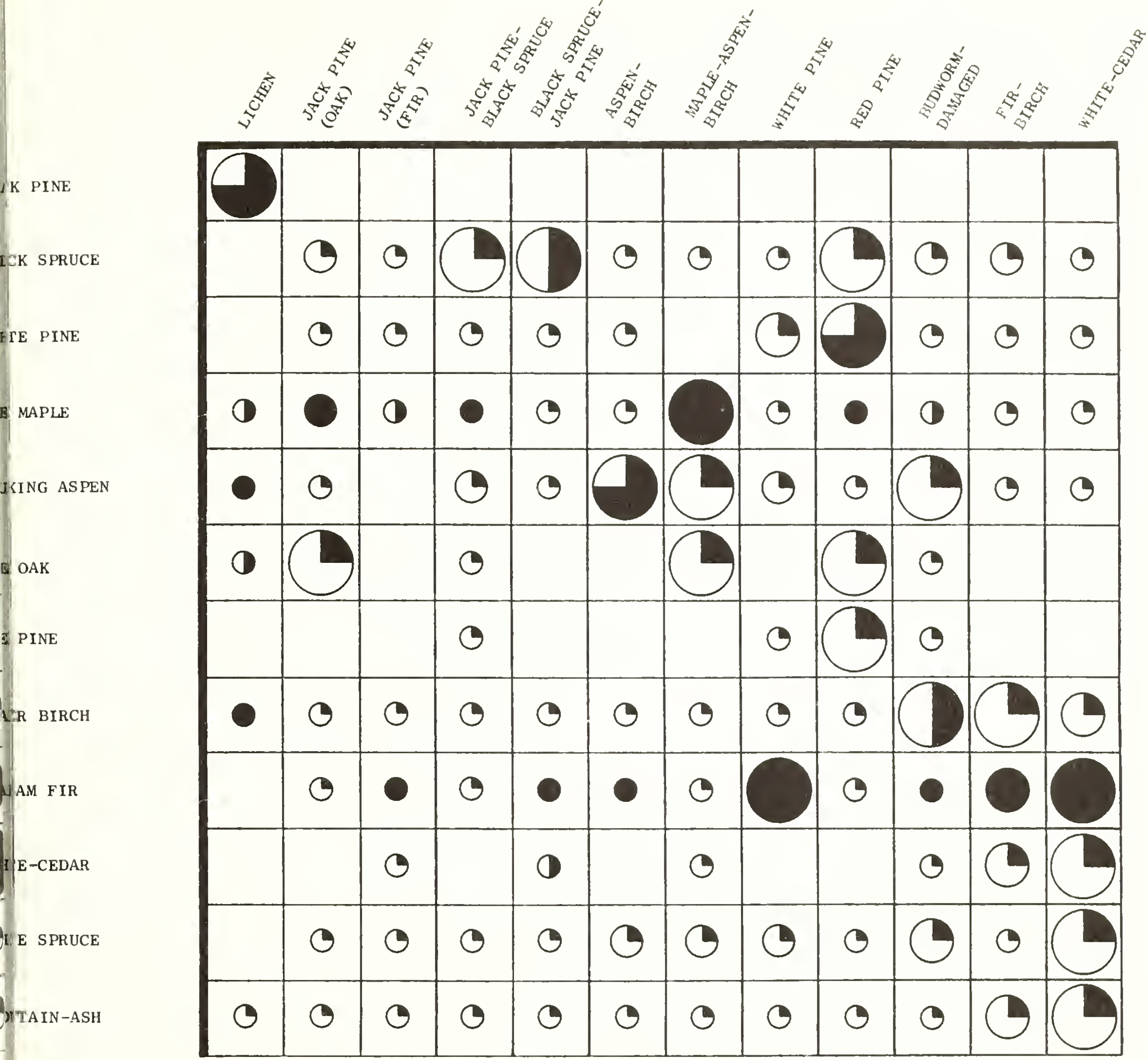

Figure 13. - Importance of tree species density (seedling size class) among and within communities.

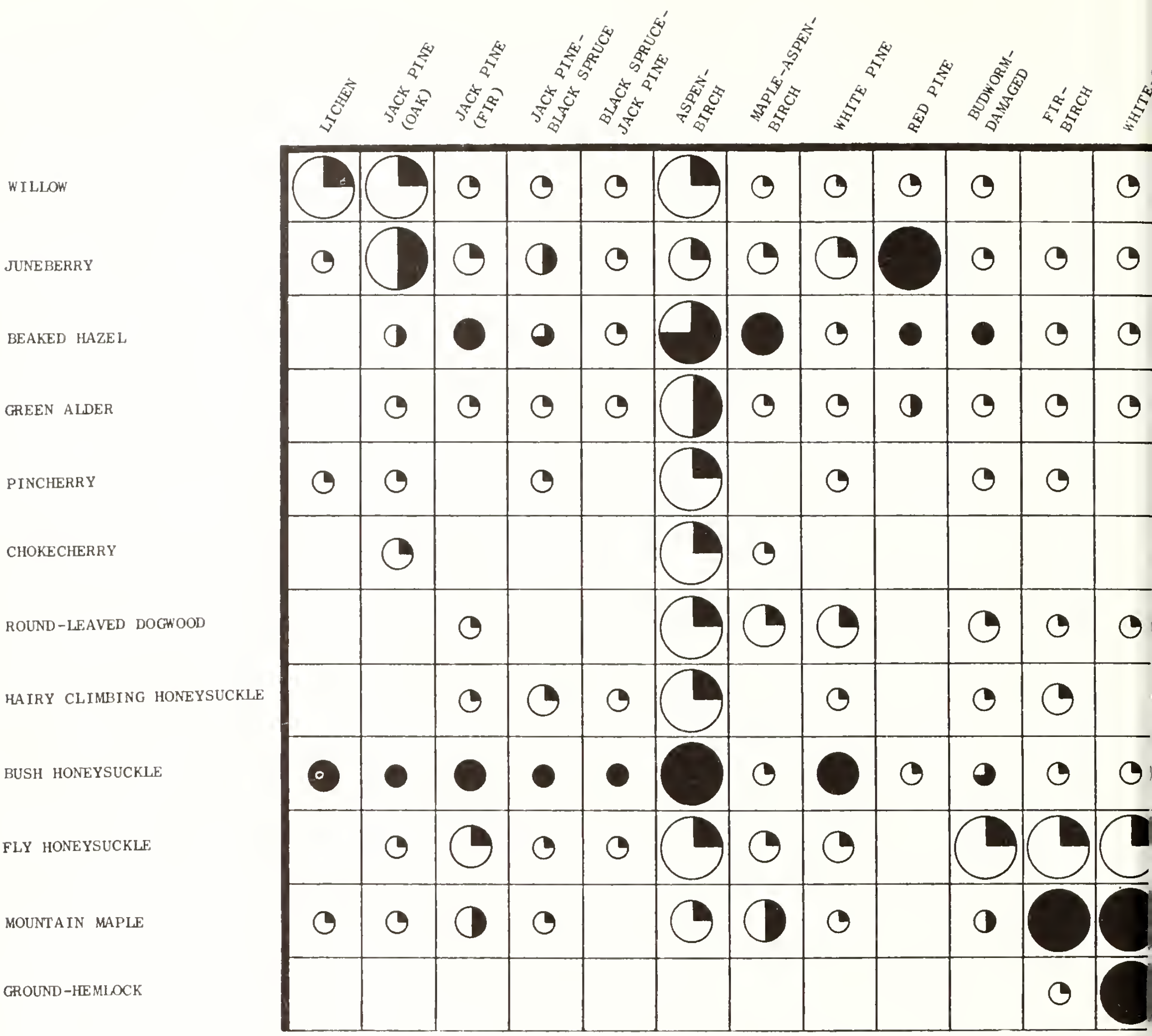

Figure 14. — Importance of tall shrub species density among and within communities.

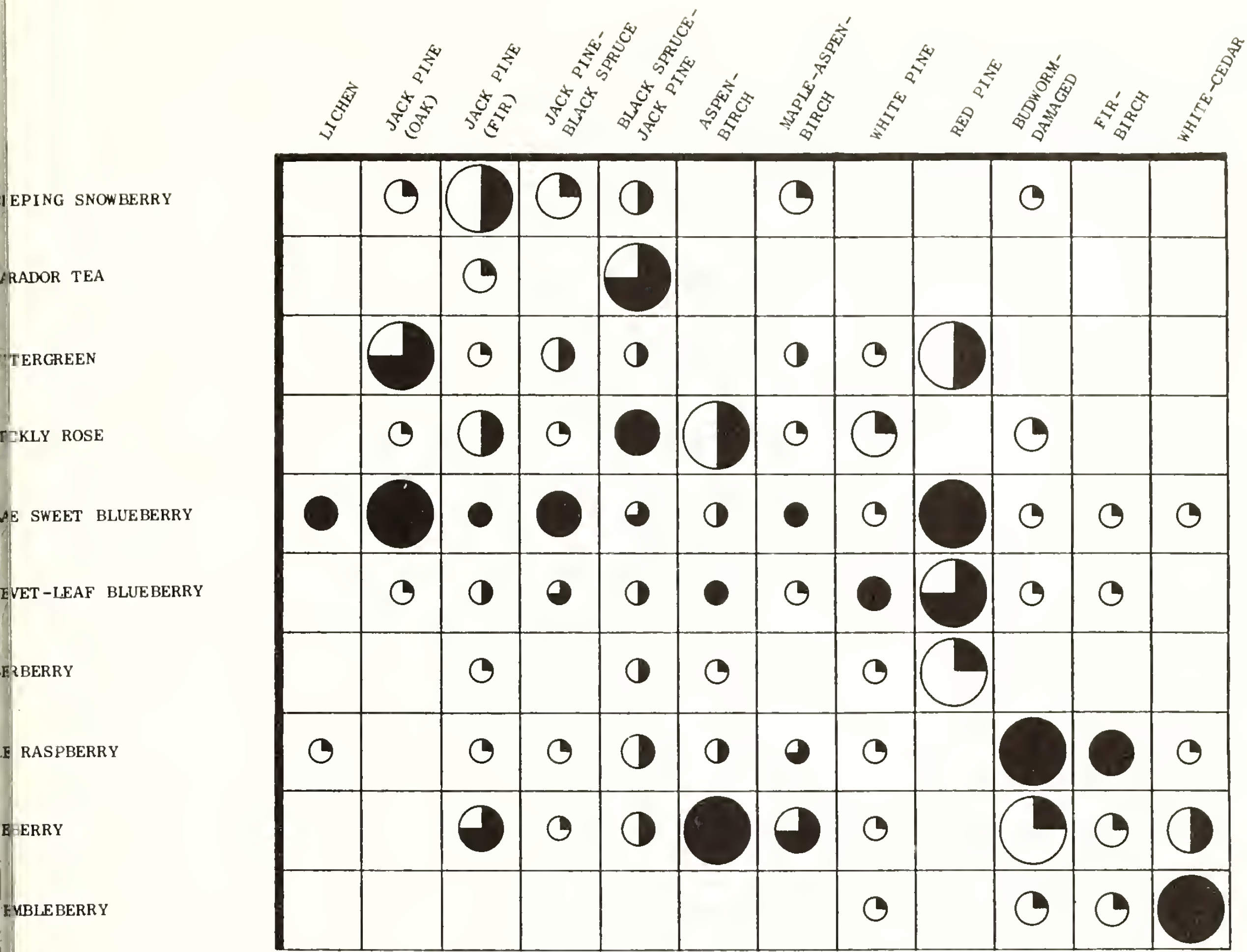

Figure 15. – Importance of low shrub species percent cover among and within communities.

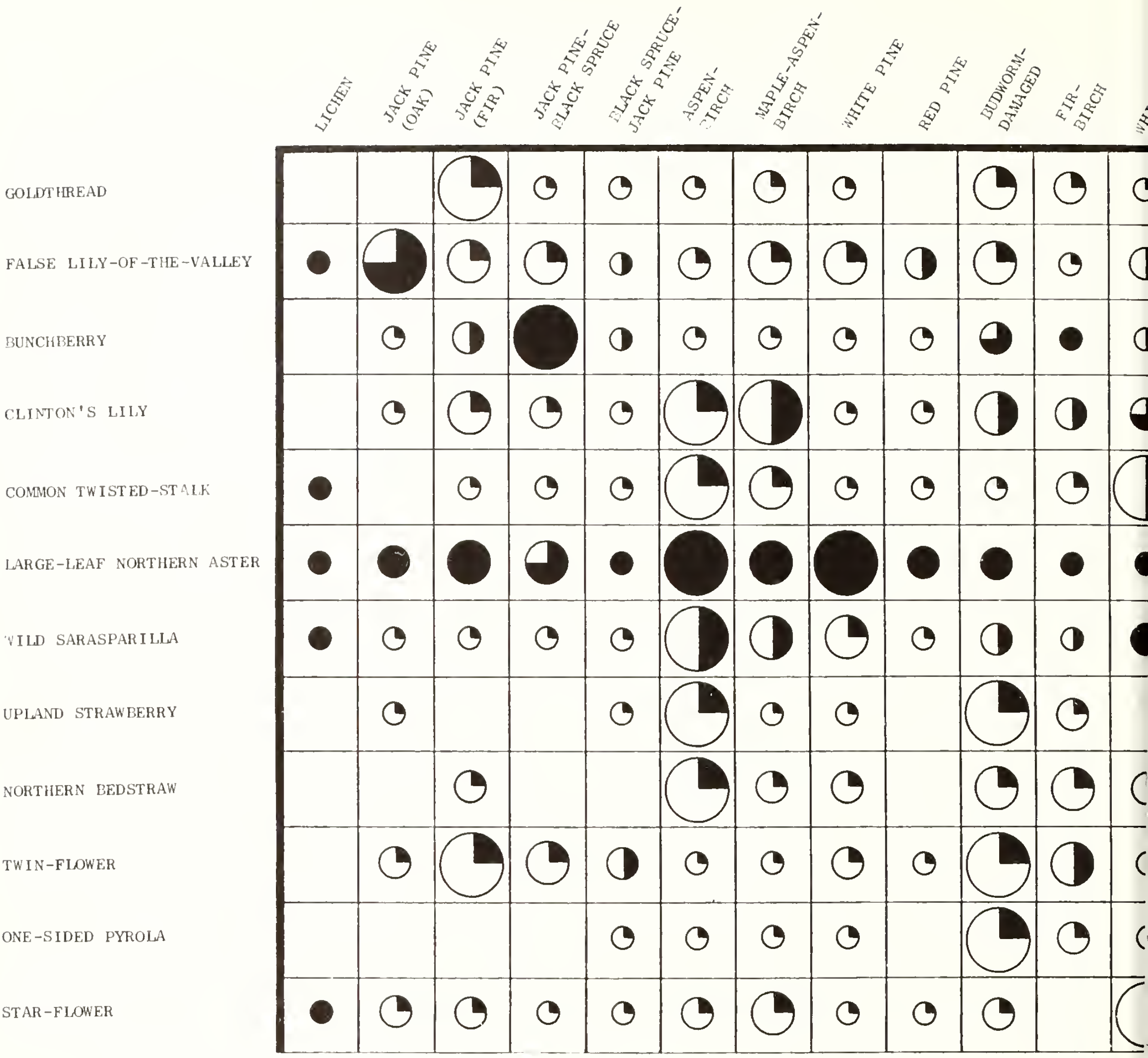

Figure 16. — Importance of herb species percent cover among and within communities.

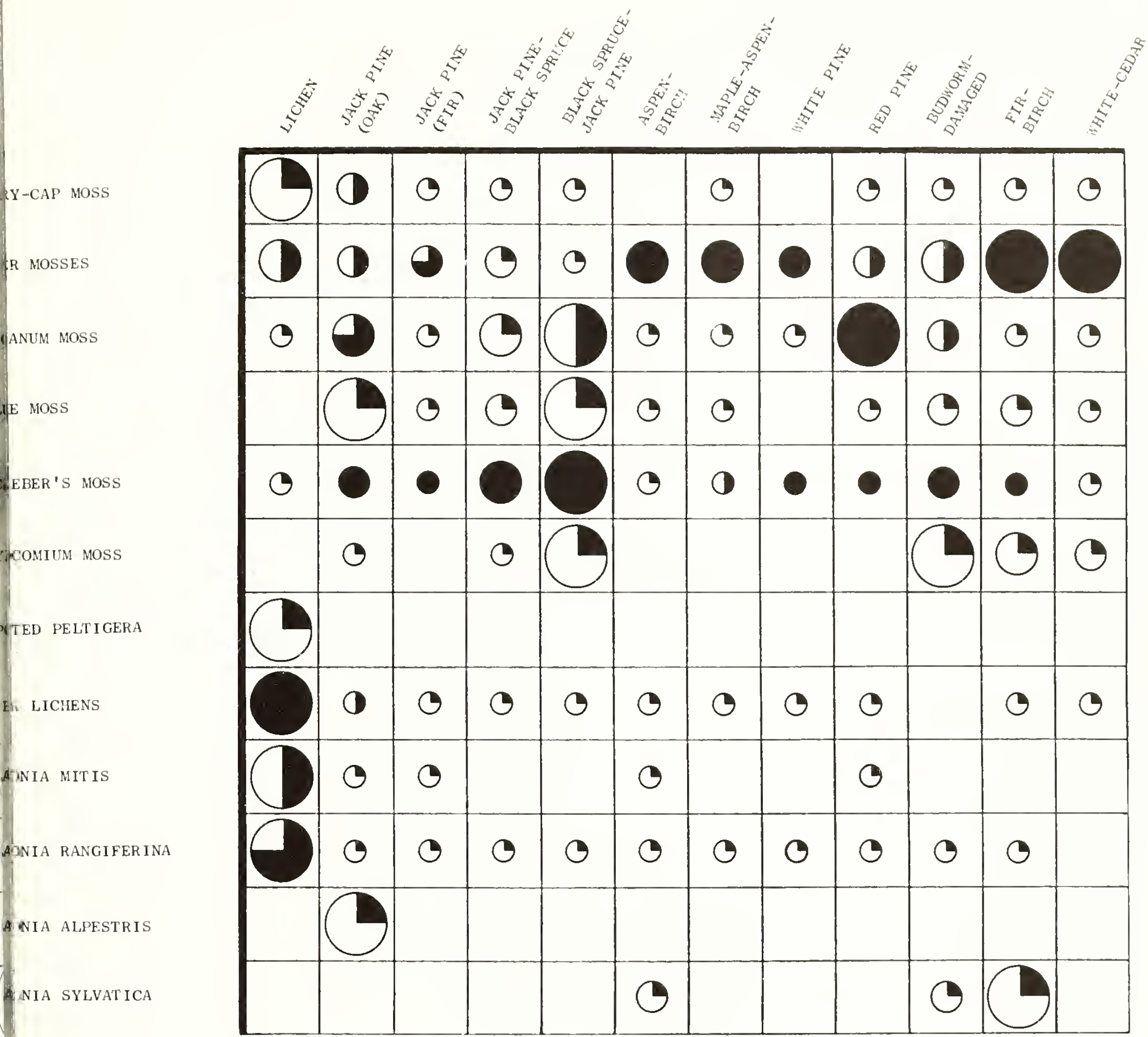

Figure 17. – Importance of moss and lichen species percent cover among and within communities.

SOME RECENT RESEARCH PAPERS
OF THE
NORTH CENTRAL FOREST EXPERIMENT STATION

Proceedings of the Ninth Lake States Forest Tree Improvement Conference, August 22-23, 1969. USDA Forest Serv. Res. Pap. NC-47, 34 p. 1970.

A Water Curtain for Controlling Experimental Forest Fires, by Von J. Johnson. USDA Forest Serv. Res. Pap. NC-48, 7 p., illus. 1970.

Wilderness Ecology: A Method of Sampling and Summarizing Data for Plant Community Classification, by Lewis F. Ohmann and Robert R. Ream. USDA Forest Serv. Res. Pap. NC-49, 14 p., illus. 1971.

Predicting Lumber Grade Yields for Standing Hardwood Trees, by Charles L. Stayton, Richard M. Marden, and Glenn L. Gammon. USDA Forest Serv. Res. Pap. NC-50, 8 p. 1971.

Tables of Compound-Discount Interest Rate Multipliers for Evaluating Forestry Investments, by Allen L. Lundgren. USDA Forest Serv. Res. Pap. NC-51, 142 p., illus. 1971.

Ecological Studies of the Timber Wolf in Northeastern Minnesota, by L. David Mech and L. D. Frenzel, Jr. (Editors). USDA Forest Serv. Res. Pap. NC-52, 62 p., illus. 1971.

Pest Susceptibility Variation in Lake States Jack-Pine Seed Sources, by James P. King. USDA Forest Serv. Res. Pap. NC-53, 10 p., illus. 1971.

Influence of Stand Density on Stem Quality in Pole-size Northern Hardwoods, by Richard M. Godman and David J. Books. USDA Forest Serv. Res. Pap. NC-54, 7 p., illus. 1971.

The Dynamic Forces and Moments Required in Handling Tree-length Logs, by John A. Sturos. USDA Forest Serv. Res. Pap. NC-55, 8 p., illus. 1971.

Growth and Yield of Black Spruce on Organic Soils in Minnesota, by Donald A. Perala. USDA Forest Serv. Res. Pap. NC-56, 16 p., illus. 1971.

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971

William F. Johnston

Management GUIDE For the BLACK SPRUCE type in the Lake States

NORTH CENTRAL FOREST EXPERIMENT STATION • FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

This management guide applies only to the black spruce forest type in the Lake States where the species grows in pure stands or in mixed stands where it predominates. The guide does not apply to stands where black spruce is an important but not the predominant tree species, such as in the mixed conifer swamp type, the white spruce-balsam fir type, and the jack pine type.

Forests of the black spruce type produce pulpwood and Christmas trees in the Lake States where they occupy 2 million acres of commercial forest land — the largest acreage of the type south of Canada. The most extensive stands are in northern Minnesota, which has two-thirds of the black spruce type in the Lake States. The remainder occurs in Upper Michigan, and to a lesser extent, in northern Wisconsin.

The management practices recommended here are based on research and experience. Unique situations and further research findings may require modification of the recommendations. The forest manager must therefore exercise good judgment in using this guide and must be alert to improved ways of handling the black spruce type.

The author is a Silviculturist for the Station at its Northern Conifers Laboratory in Grand Rapids, Minnesota. The Laboratory is maintained in cooperation with the University of Minnesota. Grateful acknowledgment is due the several industrial, State, and Federal foresters in the Lake States who improved this guide by making helpful review comments.

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(Maintained in cooperation with the University of Minnesota)

Manuscript approved for publication April 13, 1971.

MANAGEMENT GUIDE FOR THE BLACK SPRUCE TYPE IN THE LAKE STATES

William F. Johnston

SOIL-SITE RELATIONS

The black spruce[1] type is found mainly on ·ganic soil in the Lake States, but it also occurs ı mineral soil. Growth rate varies greatly on ·ganic soil sites. Height of dominant trees at) years ranges from about 50 feet on the best tes to less than 15 feet on the poorest. Mature ands commonly yield 30 cords per acre on ɔod sites, whereas many stands on poor sites ever produce merchantable quantities of ılpwood. Many poor-site stands, however, are ırvested for small Christmas trees.

Growth rate on organic soil apparently is lated to the amount of nutrients received in ound water flowing from adjacent mineral ɔil. Thus the best sites are immediately down-ope from mineral soil areas. On these sites e soil is usually only a few feet deep, dark own to blackish, and moderately well decom-ɔsed. In contrast, the poorest sites tend to be ward the center and along the lower margin organic soil areas. On these sites the soil is ten several feet deep and topped by a thick cumulation of poorly decomposed, yellowish-own sphagnum moss.

The black spruce type is common on miner-soil only on the Laurentian Shield in north-stern Minnesota and in a few isolated areas of Upper Michigan. Here black spruce grows on gravelly and bouldery loam and on shallow soil over bedrock, where it usually is mixed with other species, but occasionally forms a pure type. Growth is best where the slope is gentle and moisture is plentiful, either from a shallow water table or seepage. South of the Shield, black spruce is occasionally found on sandy soil with a high water table.

[1]*For scientific names of plants mentioned in* *xt see page 12.*

ASSOCIATED VEGETATION

Tamarack, northern white-cedar, and balsam fir are the main tree species associated with black spruce on organic soil in the Lake States; jack pine, quaking aspen, paper birch, and white spruce are the main associates on mineral soil. Black ash, red maple, American elm, balsam poplar, eastern white pine, and red pine are other common tree associates, especially in the transition zone between organic and mineral soil.

Black spruce stands are bushy on the best sites on organic soil. Tall shrubs such as speckled alder and red-osier dogwood are common, as are grasses and numerous other herbs (fig. 1). The ground cover is a mosaic of various mosses and litter. In contrast, stands on poorer sites have only low shrubs such as Labrador-tea and leather-leaf plus various sedges (fig. 2). Here the ground cover is characterized by feather mosses except on the poorest sites, where sphagnum moss predominates (fig. 3).

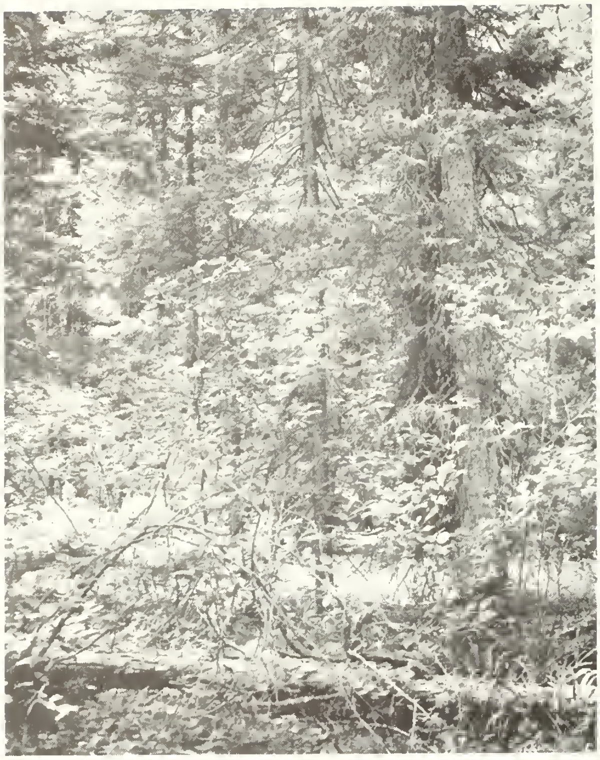

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Figure 1. — This brushy stand of black spruce is typical of those occupying the best sites on organic soil. As shown here, a conspicuous understory of tall shrubs such as speckled alder is usually present.

F-5198

Figure 2. — This nonbrushy stand of bla spruce is typical of those occupying mediu to poor sites on organic soil. As shown he practically no understory is present exce for some low shrubs such as Labrador-t

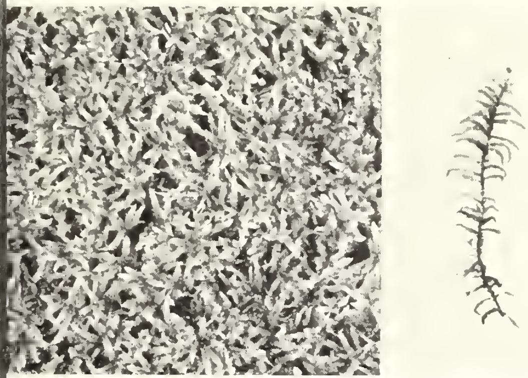
REPRODUCTION

Black spruce is a dependable seeder. Stands 40 or more years old have a nearly continuous seed supply because the persistent cones shed seed for at least 4 years after ripening and seed crops seldom fail. A mature stand produces an average of perhaps 200,000 seeds — about ½ pound — per acre per year. Although most of this seed falls in or near the stand, recent reproduction surveys indicate that natural seeding is effective up to 4 chains (1 chain = 66 feet) downwind from the edge of a stand.

Seedling establishment requires a moist but unsaturated seedbed free from competing vegetation. Establishment is generally successful if the surface layer is: (1) removed, either by fire or machine; (2) compacted, as in a skid road; or (3) composed of living sphagnum moss. Most types of sphagnum moss are good seedbe although some types outgrow black spru seedlings and smother them. Other mosse particularly the feather mosses, dry up a die after clearcutting and become extreme poor seedbeds (fig. 3). Thus seedbed cond tions are usually much improved by removi or compacting such mosses.

Vegetative reproduction of black spruce common on the poorer sites on organic s where sphagnum moss is the predomina ground cover. Here the moss often grows ov segments of the lowest branches and induc the development of adventitious roots. The buried branch segments, or layers, thus resu in new trees. Much of the advance growth r maining after clearcutting is of layer origi Some of these trees grow well, but seedlings a preferred for reproducing black spruce.

POOR SEEDBEDS: Feather mosses

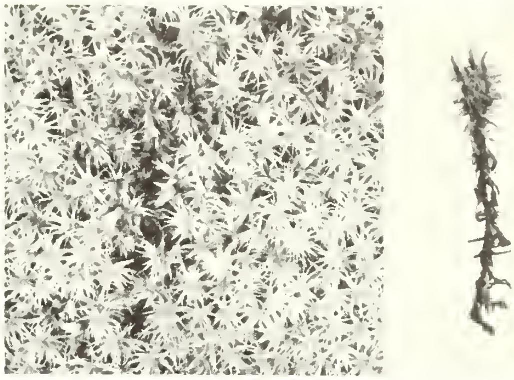


Calliergonella schreberi

Hypnum crista-castrensis

Hylocomium splendens

POOR SEEDBEDS: Dicranum mosses



Dicranum rugosum

GOOD SEEDBEDS: Sphagnum mosses

Sphagnum spp.

F-519899, 519900-519904

Figure 3. — These mosses are common seedbeds in black spruce stands, particularly on nonbrushy sites. All except sphagnum make poor seedbeds because they die and dry out following clearcutting. The photos are all ½ natural size.

STAND DEVELOPMENT

Most black spruce stands in the Lake States are or were once even-aged because wildfires burned periodically in abnormally dry years, long before logging and fire protection began. Black spruce reproduces successfully after a fire because the standing trees retain adequate seed in their cones and the seedlings grow much faster in the open burned area than under a living overstory.

In areas undisturbed by fire for a century or more, black spruce stands become uneven-aged because new trees begin to fill in as overstory trees die. Black spruce is not as tolerant of shade as two of its common competitors, northern white-cedar and balsam fir, and s may be succeeded by them in the absence o fire.

All-aged stands of black spruce are commo in the Lake States only on the poorest sites o organic soil. This is probably because such site have a low fire hazard and the trees are con tinuously reproduced from layers.

YIELD AND GROWTH

The yield and 10-year net growth of pulp wood in any black spruce stand can be dete mined given its site index, age, and basal are (tables 1 and 2). Site index is obtained from th

Table 1.—*Yields of black spruce stands in the Lake States by site index, age, and basal area*[1]
(In cords per acre)

SITE INDEX 45

Age (years)	Height of dominants and co-dominants (feet)	Basal area per acre (square feet)					
		60	80	100	120	140	160
60	51	13.7	18.1	22.4	26.6	30.9	--
80	60	14.8	19.6	24.2	28.8	33.4	37.9
100	66	15.6	20.5	25.4	30.2	35.0	39.7
120	71	16.0	21.1	26.2	31.1	36.1	41.0
140	74	16.4	21.6	26.7	31.8	36.9	41.9
160	76	16.7	22.0	27.2	32.4	37.5	42.6
SITE INDEX 35							
60	40	10.4	13.7	17.0	20.2	23.4	--
80	47	11.3	14.8	18.4	21.8	25.3	28.8
100	51	11.8	15.5	19.2	22.9	26.5	30.1
120	55	12.2	16.0	19.8	23.6	27.4	31.1
140	58	12.4	16.4	20.3	24.1	28.0	31.8
160	60	12.7	16.7	20.6	24.6	28.4	32.3
SITE INDEX 25							
60	28	7.2	9.5	11.7	14.0	--	--
80	33	7.8	10.2	12.7	15.1	17.5	--
100	37	8.2	10.7	13.3	15.8	18.3	20.8
120	39	8.4	11.1	13.7	16.3	18.9	21.5
140	41	8.6	11.3	14.0	16.7	19.3	22.0
160	43	8.7	11.5	14.2	17.0	19.6	22.3

1/ Yields, which include trees 3.6 inches d.b.h. and larger, were obtained from Table 5 of Perala, Donald A., 1971. Growth and yield of black spruce on organic soils in Minnesota. USDA Forest Serv. Res. Pap. NC-56.

Table 2.—*Ten-year net growth of black spruce stands in the Lake States by site index, age, and basal area*[1]

(In cords per acre)

Age (years)	Basal area per acre (square feet)					
	60	80	100	120	140	160
SITE INDEX 45						
60	9.6	9.0	7.4	5.1	2.3	--
80	8.1	8.0	7.0	5.3	3.1	0.5
100	7.1	7.3	6.8	5.6	3.9	1.8
120	6.4	6.8	6.6	5.8	4.6	2.9
140	5.9	6.4	6.5	6.0	5.1	3.8
160	5.5	6.2	6.4	6.1	5.6	4.8
SITE INDEX 35						
60	7.3	6.8	5.6	3.8	1.8	--
80	6.2	6.1	5.3	4.0	2.4	0.4
100	5.4	5.6	5.1	4.2	3.0	1.4
120	4.9	5.2	5.0	4.4	3.4	2.2
140	4.5	4.9	4.9	4.5	3.9	2.9
160	4.2	4.7	4.8	4.6	4.2	3.6
SITE INDEX 25						
60	5.0	4.7	3.9	2.7	--	--
80	4.2	4.2	3.7	2.8	1.6	--
100	3.7	3.8	3.5	2.9	2.0	1.0
120	3.4	3.6	3.4	3.0	2.4	1.5
140	3.1	3.4	3.4	3.1	2.7	2.0
160	2.9	3.2	3.3	3.2	2.9	2.5

1/ Growth, which includes trees 3.6 inches d.b.h. and larger, was obtained from Table 8 of Perala, Donald A., 1971. Growth and yield of black spruce on organic soils in Minnesota. USDA Forest Serv. Res. Pap. NC-56.

and's average total height and age (fig. 4). The eld of any stand can be projected 10 years by mply adding its net growth (table 2) to its esent yield (table 1).

DAMAGING AGENTS

Breakage and uprooting of trees by wind e the most important causes of mortality in der stands of black spruce. Wind breakage more frequent in stands with butt rot, which ecomes common after about 100 years on or-nic soil and 70 years on mineral soil. Both reakage and uprooting occur mainly along and edges exposed to the prevailing wind and stands opened up by partial cutting. By using the rotations and cutting methods recommended in this guide, wind-caused mortality should be minimal.

The most serious pest of black spruce is dwarf mistletoe. Besides causing witches'-broom, it kills many trees and reduces volume growth on others. Dwarf mistletoe is probably best controlled by broadcast burning.

Fortunately, the other pests of black spruce seldom cause serious damage. Needle rusts may discolor and defoliate some trees enough to disqualify them for Christmas trees. Insects such as the spruce budworm, eastern spruce beetle, and certain sawflies occasionally attack

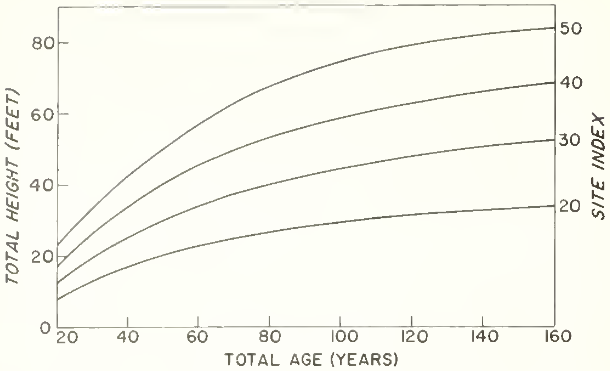


Figure 4. — Site index curves for black spruce stands in the Lake States. (Obtained from Figure 1 of Perala, Donald A., 1971. Growth and yield of black spruce on organic soils in Minnesota. USDA Forest Serv. Res. Pap. NC-56.)

black spruce. Snowshoe hares sometimes debark and browse reproduction, and red squirrels can spoil Christmas trees by clipping off twigs with cones. Black spruce is browsed occasionally by moose but rarely by white-tailed deer.

Good fire protection now results in little loss, but wildfire is always a serious potential enemy because black spruce trees are easily killed.

Poorly constructed or maintained roads have killed black spruce or reduced its growth on thousands of acres of organic soil in the Lake States by impeding the normal movement of water. Beaver damming of man-made drainage ditches has similar effects. Road-caused damage can be minimized by constructing and maintaining adequate collector and discharge ditches, and by using large culverts that are correctly positioned and maintained. Removal of beaver dams and judicious control of beaver can avert damage to valuable timber and the unsightliness of dying trees.

MANAGEMENT OBJECTIVES

The overall objective in managing the black spruce type should be to produce a high sustained yield of pulpwood and other forest values as efficiently as possible. The poorest sites, however, should be managed mainly for Christmas trees under present conditions. Practices to enhance water, wildlife, and scenery are largely unknown in the black spruce type, but these values should not be ignored. Although little is known about how these values are affected by harvesting old stands and growing new ones, the type can probably be managed best in fairly large, even-aged stands, as occurred under virgin conditions.

More specifically, since pulpwood is the main product, the objective should be to manage the type in even-aged stands large enough for efficient, mechanized harvesting. The highest possible sustained yield of water, wildlife, and scenic values will likely be obtained by having pulpwood harvest areas well distributed throughout the forest and over time. The most important specific objective in managing water is to keep normal drainageways open, as noted under Damaging Agents. Wildlife and scenic values can be improved on pulpwood harvest areas by: (1) having their boundaries follow natural site or forest type lines and (2) removing heavy slash cover, particularly by broadcast burning, and otherwise leaving the areas neat. The resulting openings produce different and/or more abundant browse and other wildlife food than mature black spruce stands.

KEY TO RECOMMENDATIONS

Recommendations for managing variou black spruce stands are given in the followin key, which contains a series of alternative statements accompanied by detailed explanations So, with accurate knowledge of a stand, th forest manager can find and carry out the cor rect recommended practice(s).

How to Use the Key

Starting with the first pair of like-numbere statements, select the one statement that bette describes the stand in question. Read the ac companying explanation and follow the dotte line to the right where a final recommendation a partial recommendation plus a number, or a number alone is given. If a number is given repeat the selection process until a final recom mendation is reached. The overall recom mendation is the sum of the partial recommenda tions arrived at while going through the key.

The Key

1. **Site index 23 or less** .... GROW CHRISTMAS TREES

Many stands on such sites can be partially cut for Christmas trees about once every decade (fig. 5). Wind damage is rare because the trees are much shorter and often more open grown than in pulpwood stands. Also, trees of acceptable quality are almost never abundant enough to result in overcutting the stand. If Christmas trees are not harvested about every 10 years some may become unmarketable. For example, additional height growth or twig clipping by red squirrels can spoil tree form. Since succeeding crops come from the remaining stand, it should be protected as much as possible during each cutting.

1. **Site index over 23** .... GROW PULPWOOD 2

2. **Stand immature** .... CUT NO TREES

Intermediate cutting is not recommended for black spruce due to its low economic return and the risk of increasing wind-caused mortality.

2. **Stand mature** .... CLEARCUT STAND 3

The rotation required to produce pulpwood ranges from about 60 to 130 years. Based on culmination of mean annual growth, rotations would be shorter for stands with high basal areas than for those with low basal areas. Stands on poor sites or with excessive numbers of trees may require rotations up to 130 years before yields or tree sizes are large enough to harvest efficiently. Rotations for stands on mineral soil should not exceed 70 years because butt rot becomes common at this age.

The shape and size of the area to be clearcut should depend mainly on the long-term cost of harvesting and reproducing either progressive strips seeded naturally, or large patches to entire stands seeded artificially (cf. figs. 6 and 7). Since a stand can usually be managed by more than one method, the overall recommendation for that stand should be determined before deciding what shape and size of area to clearcut.

3. **Dwarf mistletoe scarce** 4

This means dwarf mistletoe is apparently absent or is established so lightly it will not become a problem during the next rotation.

3. **Dwarf mistletoe abundant** ....

BROADCAST BURN SLASH (see p. 10) 9

The clearcut area should include a zone 2 chains (1 chain = 66 feet) *beyond* the margin of the infection center(s).

4. **Residual black spruce stems abundant** 5

This means enough stems are present to form a new stand or to reduce the growth of new reproduction.

4. **Residual black spruce stems scarce** 6

5. **Residual stems young and fast growing** . . . . . . SAVE RESIDUAL STEMS

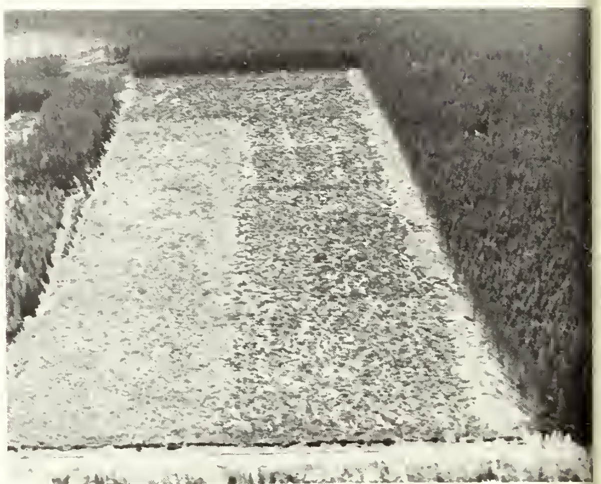
Residual stems should be saved to reproduce the stand only if: (1) 60 percent or more of the milacres[2] in the clearcut area will contain at least one, young, fast growing stem *after* harvesting and (2) the cost of saving such stems does not exceed the cost of obtaining new reproduction of equal size. Obviously, the stand must be harvested carefully and slash removed where it covers needed stems.

5. **Residual stems old and slow growing** . . . .
BROADCAST BURN SLASH (see p. 10) 9

[2] *A milacre is 1/1000 acre or about 44 square feet.*

F-519905

Figure 5. — This stand of black spruce is typical of those on poor sites that have been partially cut for Christmas trees. Note the stumps of harvested trees in the foreground.



F-519897

Figure 6. — These two strips, each about 4 chains wide and ¼ mile long, were clearcut and broadcast burned 4 years apart; future strips will progress into the mature stand at the right. Note the unburned, slash-free alley next to the stand.

F-519147

Figure 7. — This 98-acre patch was clearcut, broadcast burned, and direct seeded. Note the unburned, slash-free alley next to the surrounding forest.

6. **Brush scarce** 7
This means brush is absent or will not become dense enough to reduce the growth of reproduction. In deciding whether brush is scarce or not (cf. figs. 1 and 2), it is important to realize that brush density usually increases greatly after clearcutting.

6. **Brush abundant** BROADCAST BURN SLASH (see p. 10) 9

7. **Sphagnum seedbeds well distributed** 8
This means patches of sphagnum suitable for seedling establishment occur in at least 60 percent of the milacres in the clearcut area, or at a square spacing not exceeding about 10 feet.

7. **Sphagnum seedbeds poorly distributed** ....
BROADCAST BURN SLASH (see p. 10) 9

8. **Slash cover light** 9
This means slash (expected or actual) will not hinder satisfactory reproduction or be an important fire hazard. Stands with low yields and those harvested by the full tree system, for example, may leave only a light cover of slash.

8. **Slash cover heavy** 9
BROADCAST BURN SLASH (see p. 10) 9

9. **Seed source within range** .... USE NATURAL SEEDING
If the clearcut area is surrounded by a mature stand of black spruce, natural seeding can be relied on up to 4 chains from the windward side of the area and up to 2 chains from the leeward side. Thus a strip perpendicular to the prevailing wind direction (the recommended orientation) can be up to 6 chains wide with natural seeding from both sides, or 4 chains wide with seeding only from the windward side. Also, the outer portion of large patches can often be reproduced by natural seeding, thus importantly reducing the area requiring direct seeding. A milacre stocking of 60 percent within 2 to 4 years after cutting is considered satisfactory reproduction.

9. **Seed source out of range** .... USE DIRECT SEEDING
Black spruce is generally direct seeded at a rate of about ¼ pound (100,000 seeds) per acre to obtain a milacre stocking of at least 60 percent. Seed need not be stratified but should be treated with approved repellents for birds and rodents, and then sown between March and mid-May of the first year following burning or cutting. A hand seeder with filler such as sawdust is efficient for seeding small areas. Snowmobile or aerial seeding is more efficient for large areas.

BROADCAST BURNING TECHNIQUES

Research and experience in north-central Minnesota have proven that black spruce slash can be broadcast burned safely, effectively, and economically on organic soil sites. Burning on such sites should be equally successful in Michigan and Wisconsin after forest managers gain some local experience.

If burning is recommended in the key, the stand must be harvested in such a way that the resulting clearcut area can be burned safely and efficiently. The main requirements for setting up and conducting a successful broadcast burn are:

1. Make sides of clearcut area smooth and reasonably straight.

2. Leave a slash-free alley about ½ chain wide between the slash-covered area and the surrounding area (figs. 6 and 7).

3. Distribute the slash as completely and evenly as possible inside the slash-covered area.

4. Cut all unmerchantable trees near the edge of the slash-covered area.

5. Burn slash within a year after harvesting.

6. Burn when the fire will consume most slash but not cause a control problem.

Burning has been successful from June to October, with about half the burns occurring in August. Burning has usually been done 3 to 10 days since 0.1 inch of rain, and when minimum relative humidity was 30 to 60 percent, maximum air temperature 60° to 90° F., and maximum wind speed 5 to 15 miles per hour. Burning to kill back brush or improve nonsphagnum seedbeds requires drier and hotter conditions than burning to just consume slash or kill residual trees, which simultaneously eradicates dwarf mistletoe. Experience indicates this more severe burning usually requires at least 7 days since rain, relative humidity less than 45 percent, and an air temperature of at least 80° F.

On mineral soil sites, broadcast burning must be severe enough to expose mineral soil if natural or direct seeding is planned. However, local conditions and experience may indicate that mechanical ground preparation such as scarification is more efficient than burning.

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COMMON AND SCIENTIFIC NAMES OF PLANTS MENTIONED IN TEXT

Common name	Scientific name
Alder, speckled	*Alnus rugosa* (Du Roi) Spreng.
Ash, black	*Fraxinus nigra* Marsh.
Aspen, quaking	*Populus tremuloides* Michx.
Birch, paper	*Betula papyrifera* Marsh.
Dogwood, red-osier	*Cornus stolonifera* Michx.
Elm, American	*Ulmus americana* L.
Fir, balsam	*Abies balsamea* (L.) Mill.
Labrador-tea	*Ledum groenlandicum* Oeder
Leather-leaf	*Chamaedaphne calyculata* (L.) Moench
Maple, red	*Acer rubrum* L.
Mistletoe, dwarf	*Arceuthobium pusillum* Peck
Mosses:	
Feather	Main species are:
	Calliergonella schreberi (BSG.) Grout
	Hylocomium splendens (Hedw.) BSG.
	Hypnum crista-castrensis Hedw.
Sphagnum	*Sphagnum* spp.
Pines:	
Jack	*Pinus banksiana* Lamb.
Red	*Pinus resinosa* Ait.
Eastern white	*Pinus strobus* L.
Poplar, balsam	*Populus balsamifera* L.
Rust, needle	*Chrysomyxa* spp.
Spruces:	
Black	*Picea mariana* (Mill.) B. S. P.
White	*Picea glauca* (Moench) Voss
Tamarack	*Larix laricina* (Du Roi) K. Koch
White-cedar, northern	*Thuja occidentalis* L.

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The Dynamic Forces and Moments Required in Handling Tree-length Logs, by John A. Sturos. USDA Forest Serv. Res. Pap. NC-55, 8 p., illus. 1971.

Growth and Yield of Black Spruce on Organic Soils in Minnesota, by Donald A. Perala. USDA Forest Serv. Res. Pap. NC-56, 16 p., illus. 1971.

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Site-Index COMPARISONS for TREE SPECIES in NORTHERN MINNESOTA

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NORTH CENTRAL FOREST EXPERIMENT STATION · FOREST SERVICE
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(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication May 11, 1971.

SITE-INDEX COMPARISONS FOR TREE SPECIES IN NORTHERN MINNESOTA

Willard H. Carmean and Alexander Vasilevsky

Forest trees in northern Minnesota grow on large variety of soils having great differences ı tree-site quality. Faced with this profusion [species, soils, and sites, a forest manager often ıs difficulty deciding which tree species to favor ı a given type of land. The problem of fitting ıe proper tree species to the proper site is freıently encountered in tree planting, stand conersion, thinning, and timber stand improvement.

Selecting the proper tree for the site requires etailed knowledge of the relative productivity the site for several alternative tree species. lethods must be available for estimating site ıality for the different tree species. In addition, eld information is needed for various species rowing on lands of differing site qualities, and ıowledge is needed about present and future arket values for the variety of forest products ıat might be produced. Thus the first step in ıoosing among alternative tree species is to timate the site quality of the land for each of ıese species. This information can then be used determine and compare the volume and value products the land is capable of producing when ocked with these alternative tree species.

The most commonly used method for estimatg site quality is based on tree age and height easurements taken from dominant and codomiant trees growing in fully stocked, undisturbed, en-aged stands. These measurements are used ith site-index curves to estimate how tall trees ill be at an index age — usually 50 years for stern hardwoods and conifers (Carmean 1970). owever, many stands suitable for site-index timation do not contain the species of tree for hich site information is desired. In these stands, e can estimate site index from the tree species ıat are present, then use species-comparison aphs to convert site index of the measured ecies to site index of the desired species. becies-comparison graphs have been published r the Southern Appalachians (Doolittle 1958), ıe Piedmont (Nelson and Beaufait 1957, Olson and Della-Bianca 1959), Vermont (Curtis and Post 1962), Connecticut and Massachusetts (Foster 1959), Idaho (Deitschman and Green 1965), and California (Wiant and Porter 1966). In this study, similar methods were used for developing species-comparison graphs for several tree species found in northern Minnesota.

THE DATA

We examined forest survey[1] and soil-site[2] plot records for 20 counties in northern and northeastern Minnesota. On each of these plots site index estimates were available based upon age and height measurements of dominant and codominant trees; very often site-index estimates were available for several tree species growing on a single plot. All plots having site estimates for two or more tree species were selected for study.

We next carefully screened all data for suitability in estimating site index. Many forest survey plots were discarded because records revealed the stands were poorly stocked, uneven aged, or too young for dependable site-index estimation. Most of the forest survey plots retained for further analysis had age and height measurements based on only one or two trees of each species, but in some cases measurements were taken from three or four dominant and codominant trees.

Site-index estimates for each tree species were made using standard harmonized site-index curves (table 1). Site curves for basswood and

[1] *Appreciation is extended to the Minnesota Department of Iron Range Resources and Rehabilitation for assistance in collecting and compiling field data.*

[2] *Appreciation is extended to the USDA Soil Conservation Service, St. Paul, Minnesota, for the use of data from their soil-site plots.*

Table 1.—Species studied and curves used for estimating site index in northern Minnesota

Species	Standard site index curves (reference)
Quaking aspen (Populus tremuloides Michx.)	(Gevorkiantz 1956b)
Paper birch (Betula papyrifera Marsh.)	(Cooley 1958)
Red oak (Quercus rubra L.)	(Gevorkiantz 1957f)
Basswood (Tilia americana L.)	(Gevorkiantz 1957f)
Black ash (Fraxinus nigra Marsh.)	(Gevorkiantz 1957f)
Jack pine (Pinus banksiana Lamb.)	(Gevorkiantz 1956a)
Red pine (Pinus resinosa Ait.)	(Gevorkiantz 1957e)
White pine (Pinus strobus L.)	(Gevorkiantz 1957d)
White spruce (Picea glauca (Moench) Voss)	(Gevorkiantz 1957c)
Black spruce (Picea mariana (Mill.) B.S.P.)	(Gevorkiantz 1957b)
Balsam fir (Abies balsamea (L.) Mill.)	(Gevorkiantz 1956c)
White-cedar (Thuja occidentalis L.)	(Gevorkiantz 1957a)
Tamarack (Larix laricina (Du Roi) K. Koch)	(Gevorkiantz 1957g)

black ash do not exist, so the site index curves for red oak were used for these species. All of the site curves are based on total tree age except the white spruce and balsam fir curves, which are based on breast-height age. Thus, in the case of white spruce and balsam fir we added 10 years to d.b.h. age for good sites (S.I. 50 and greater), and 15 years for poorer sites (S.I. less than 50). This procedure insured that comparable site index values based on total tree age were used for all tree species.

ANALYSIS AND RESULTS

Our first step was to record site index values for all possible paired species combinations. Then scatter diagrams were prepared relating site indices of the two paired species. In many cases, we found there were only a few paired observations, the range of site index was limited, or the data were erratic with little relationship between the site indices of the paired species. However, in many cases site index relationships were evident and so these species combinations were selected for further analysis.

No curvilinear trends were apparent, so linear regression equations were computed using site index of one species as the dependent variable, and site index of the associated species as the independent variable (table 2). Because eith of the paired species can be considered as th dependent variable, two separate equations we computed for each of the species comparison These equations accounted for 40 to 65 perce (r^2) of the site index variation associated wi the various species comparisons.

The regression equations (table 2) could b used for directly calculating site index of or species based on measured site index of th associated species. However, when such calcu lations are made, the equation used should b the one in which measured site index is the in dependent variable. That is, these equatio should only be solved forward and not backwar For example, one might measure site index i a paper birch stand and then wish to estima site index for quaking aspen. In this case th first equation (table 2) should be used becau site index for quaking aspen is the value to b estimated (dependent variable).

The objective of our study was to derive sit index ratios or species-comparison graphs th can be used for estimating site index for tre species based upon measured site index of speci actually present in the stand. However, sit index ratios or species-comparison graphs impl that the regressions on which they are based ca be solved forward or backward. Such a procedu

Table 2.—Regression equations and statistics for site-index comparisons of northern Minnesota forest species. Also shown are equations that average the trends portrayed by the two equations listed for each paired species combination

Species: Dependent variable (Y)	Species: Independent variable (X)	Site index range: Y (feet)	Site index range: X (feet)	Number of paired observations	Equations	Coefficient of determination (r^2)	Standard error of estimate (feet)
Quaking aspen	Paper birch	43-90	37-82	106	Y=24.36 + 0.67(X)	0.51	6.2
Paper birch	Quaking aspen	37-82	43-90	106	Y= 9.87 + .75(X)	.51	6.6
					SI QA= 8.50 + .95(SI PB)		
Quaking aspen	Basswood	40-80	37-80	16	Y=22.41 + .75(X)	.45	8.1
Basswood	Quaking aspen	37-80	40-80	16	Y=20.44 + .59(X)	.45	7.2
					SI QA= 0.60 + 1.11(SI Ba)		
Paper birch	Red oak	40-85	40-76	32	Y=29.01 + .58(X)	.44	7.0
Red oak	Paper birch	40-76	40-85	32	Y=10.43 + .76(X)	.44	8.0
					SI PB=11.20 + .98(SI RO)		
Jack pine	Red pine	43-72	40-75	66	Y=23.85 + .63(X)	.40	5.7
Red pine	Jack pine	40-75	43-72	66	Y=19.38 + .64(X)	.40	5.8
					SI JP= 2.80 + .995(SI RP)		
Red pine	White pine	37-72	41-70	58	Y=18.84 + .68(X)	.47	4.8
White pine	Red pine	41-70	37-72	58	Y=15.90 + .69(X)	.47	4.8
					SI RP= 3.57 + .95(SI WP)		
White pine	White spruce	31-67	32-68	23	Y=20.06 + .60(X)	.62	5.0
White spruce	White pine	32-68	31-67	23	Y=-1.30 + 1.03(X)	.62	6.6
					SI WP=10.90 + .78(SI WS)		
Red pine	White spruce	43-70	36-67	15	Y=26.58 + .56(X)	.65	4.0
White spruce	Red pine	36-67	43-70	15	Y=-11.87 + 1.17(X)	.65	5.8
					SI RP=18.90 + .70(SI WS)		
Balsam fir	White cedar	32-68	21-38	19	Y=24.47 + .92(X)	.43	6.4
White cedar	Balsam fir	21-38	32-68	19	Y= 4.87 + .47(X)	.43	4.6
					SI BF=11.80 + 1.36(SI WC)		
Balsam fir	Black ash	34-68	25-62	21	Y=18.69 + .81(X)	.53	7.0
Black ash	Balsam fir	25-62	34-68	21	Y= 7.04 + .65(X)	.53	6.3
					SI BF= 6.60 + 1.11(SI BA)		
Tamarack	Black spruce	10-67	10-49	67	Y= 7.48 + .95(X)	.52	8.1
Black spruce	Tamarack	10-49	10-67	67	Y=11.56 + .54(X)	.52	6.1
					SI Ta=-3.70 + 1.30(SI BS)		

not statistically acceptable, thus we looked for ier means to derive these ratios and graphs.

First we calculated trend graphs using each the two equations available for each species mbination (table 2). These trend graphs conmed that somewhat different site-index trends e obtained depending upon which species is ed as the dependent variable. The two trend aphs coincide at the average site index for ch species, thus both equations will show the me site-index relationships at average site lex. But the trend graphs diverge with inased distance from average site index, until irkedly different site-index predictions are obned at very good or very poor sites. Thus, nsiderable error in site prediction might result the wrong equation is used for very good or ry poor sites. But which equation should be used?

There are no reasons to favor one equation over the other. Accordingly, we calculated new equations that averaged the trends shown by the two equations in each paired species combination. These graphically determined average equations (table 2) can be solved forward or backward and thus are suitable for calculating site-index ratios or species-comparison graphs.

Species-comparison graphs for each species combination were next prepared using these average equations. All of these graphs showed definite site-index differences between the compared species. In some cases site-index differences were relatively consistent regardless of site quality (fig. 1); in other cases site-index differences varied with site quality (fig. 2). These observed site-index relations also are expressed

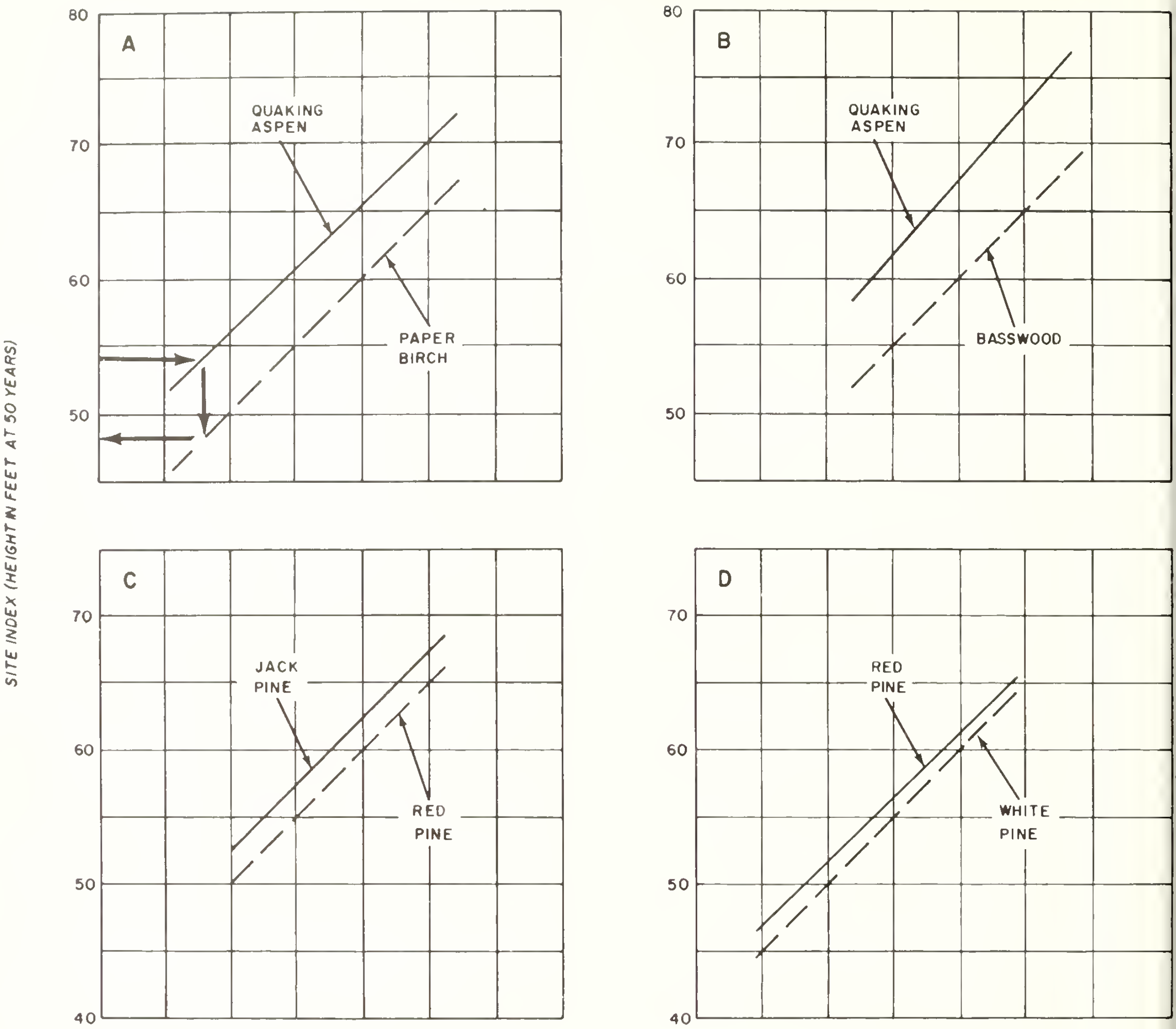

Figure 1.—Species-comparison graphs for hardwood and conifer species of northern Minnesota that have relatively consistent site-index differences at all site qualities. These graphs can be used to estimate site index for certain tree species based on site-index measurements of other tree species present in the forest stand. For example: Suppose you would like to know the site index for paper birch on a certain area, but there are no paper birch trees available for the required tree height and age measurements. However, there are suitable quaking aspen trees present and height and age measurements indicate that their site index is 54. So, on graph A start at 54 on the site-index scale and read right to the quaking aspen line, then read straight down to the paper birch line; then read left to the site-index scale where estimated site index for paper birch is found to be 48. The reverse of this procedure also can be used; for example, site index 48 for paper birch indicates a site index of 54 for quaking aspen.

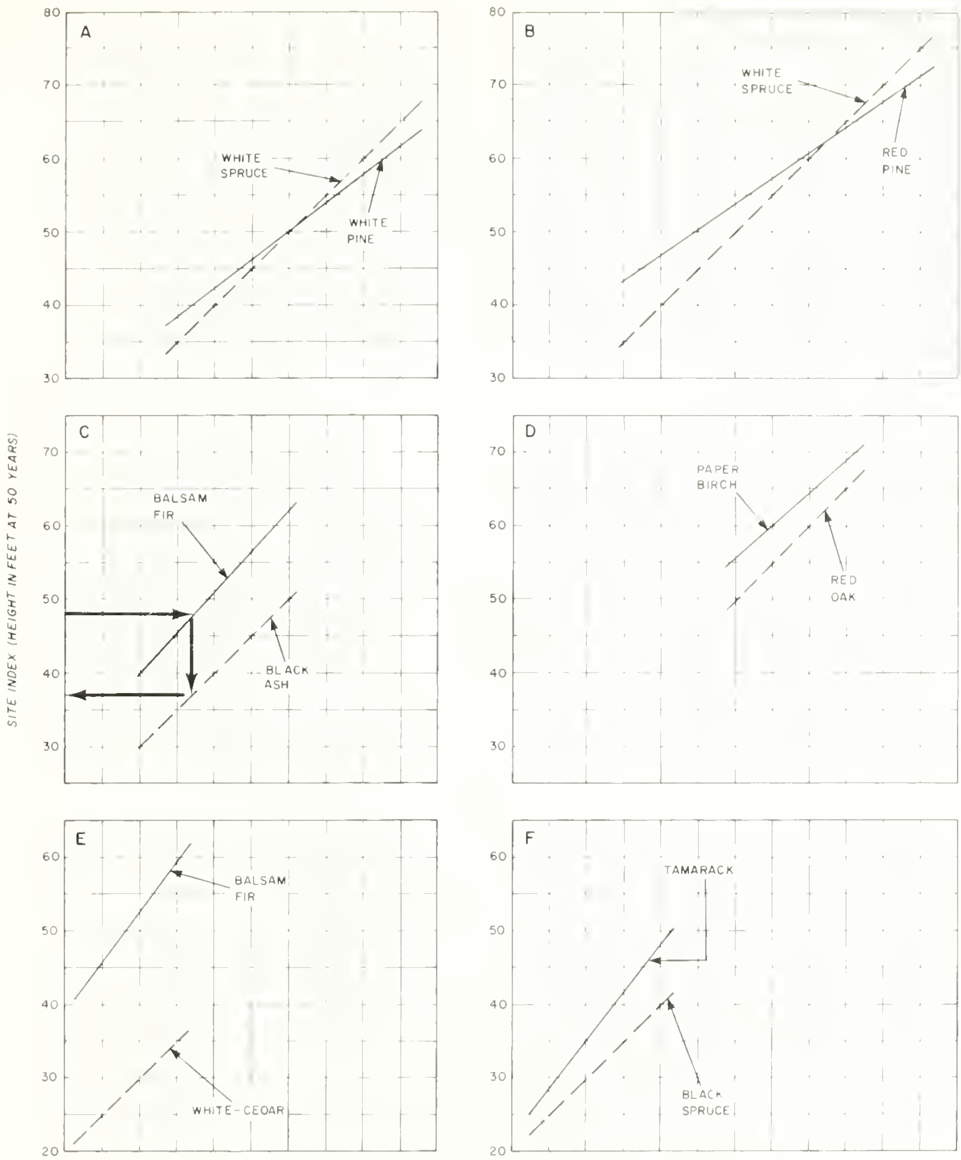

Figure 2.—Species-comparison graphs for hardwood and conifer species of northern Minnesota having site-index differences that vary with site quality. These graphs can be used to estimate site index for certain tree species based on site-index measurements of other tree species present in the forest stand. For example: Suppose you would like to know the site index for black ash on a certain area, but there are no black ash trees available for the required tree height and age measurements. However, there are suitable balsam fir trees present and height and age measurements indicate that their site index is 48. So, on graph C start at 48 on the site-index scale and read right to the balsam fir line, then read straight down to the black ash line; then read left to the site-index scale where estimated site index for black ash is found to be 37. The reverse of this procedure also can be used; for example, site index 37 for black ash indicates a site index of 48 for balsam fir.

by site-index ratios between each of the paired species at different site qualities (table 3). Ratios are listed only for the range of site index well represented by plot data. In addition, ratios and species-comparison graphs were restricted to the range of site index in which trend graphs, calculated by the two species-comparison equations, differed no more than 5 feet.

Four of the species combinations have similar site-index ratios for all levels of site quality (table 3). For these combinations the average site index ratios can be used at all levels of site quality for determining site index from the associated species. The species-comparison graph showing the site-quality relationships of these four species combinations (fig. 1) also can be used for convenience in estimating site indices.

Six of the species combinations have different site-index ratios for different levels of site quality (table 3). For example, the white pine - white spruce combination has an average site-index ratio of 1.00, but ratios of 0.93 and 1.05 were obtained for poorer and better sites, respectively. Thus these species have similar site indices for the average sites in our study. However, we can expect white pine to have a higher site index than white spruce on poorer sites, while wh spruce will have a higher site index than wh pine on better sites. The site-index ratios list for the different site qualities can be used direct calculations of site index when site inc of the associated species is known. Also t species-comparison graphs (fig. 2) can be us to estimate site index based on measured s index of other tree species present in the sta

DISCUSSION

Our results show that much unexplained var tion remains in the site-index correlations tween the various tree species (table 2). T various regressions account for 40 to 65 perc (r^2) of the total variation of site index about t computed trend lines. Also the standard err of estimate are rather large (4.0 to 8.1 fee thus we cannot place too much confidence the actual position of the trend lines shown figures 1 and 2.

Several reasons may account for this un plained variation. Although we rejected pl that were obviously poorly stocked or unev aged in our initial data screening, some of

Table 3.—Site-index ratios for paired species combinations at different site qualities

Species 1	Species 2	Average site index (feet) Sp 1	Sp 2	Site-index ratios (Sp 1: Sp 2) at Sp 1 site index of: 30	40	50	60	70	80	Average site-index ratio at Sp 1-Sp 2 average site indices
Quaking aspen	Paper birch	62.8	57.2	--	--	0.88	0.90	0.93	--	1/ 0.91
Quaking aspen	Basswood	68.5	61.1	--	--	--	.89	.89	0.89	1/ .89
Paper birch	Red oak	62.2	57.5	--	--	.87	.92	.95	--	2/ .92
Jack pine	Red pine	60.3	58.0	--	--	.95	.96	.97	--	1/ .96
Red pine	White pine	55.5	54.1	--	--	.96	.98	.99	--	1/ .97
White pine	White spruce	50.5	50.7	--	0.93	1.00	1.05	--	--	2/ 1.00
Red pine	White spruce	57.7	55.7	--	.76	.89	.98	1.05	--	2/ .97
Balsam fir	White cedar	50.7	28.7	--	.52	.56	.59	--	--	2/ .57
Balsam fir	Black ash	51.6	40.8	--	.75	.78	.80	--	--	2/ .79
Tamarack	Black spruce	38.0	32.2	0.87	.84	.83	--	--	--	2/ .85

1/ Site-index ratios are relatively consistent at all site qualities. Therefore, use the average site-index ratios to estimate site index when the site index of the associated species is known. The species-comparison graph (fig. 1) also can be used for convenience in estimating site indices.

2/ Site-index ratios are different for different site qualities. Therefore, use the listed Sp 1 site-index ratios, or use the species comparison graphs (fig. 2) to estimate site index when the site index of the associated species is known.

rvey plots used might still have been in stands at were not completely satisfactory for site-dex determination. Also, some of the trees easured for site index may have had early ppression or past injuries, and errors may have curred in ring counting of diffuse porous hard-oods or in measuring tree heights. In addition, most of the plots only one or two trees were easured for site index. This is a small number trees for site-index estimation even on care-lly selected research plots, because much vari-ion often occurs among trees measured for site dex. It is also possible that the harmonized e index curves used in this study (table 1) may t be suitable for application in northern Min-sota; trees growing on certain northern Minne-ta soils may have height-growth patterns dif-ent from those portrayed in the standard site-lex curves. Estimating site index for basswood d black ash from red oak site-index curves rtainly is not advisable, and we need new site rves for these species. Finally, unexplained riation in site index may be associated with netic differences in tree-height growth (and site lex) among clones of aspen (Zahner and Craw-rd 1963).

Despite these limitations we have found signi-ant site-index relations among various tree ecies in northern Minnesota. These results e helpful guides in selecting the most suitable e species for various sites. Accordingly, the ative positions of the trend lines in figures and 2 are more important than the actual edicted differences in site index.

We can generalize that on all sites quaking pen has a higher site index than paper birch g. 1-A) and basswood (fig. 1-B); jack pine has site index slightly higher than red pine (fig. C); and red pine may have a site index slightly gher than white pine (fig. 1-D). These rela-ns are only predicted for the listed range of es that we observed in northern Minnesota, d better or poorer sites elsewhere may show fferent relations. For example, site index for sswood on very good sites might exceed site lex for quaking aspen.

We also can generalize that on poor sites both ite pine (fig. 2-A) and red pine (fig. 2-B) l have higher site indices than white spruce. owever, on better sites white spruce site index parently exceeds that of white and red pine. On all sites observed balsam fir site index is much higher than black ash (fig. 2-C); however, the sites we observed are relatively poor, and black ash might grow faster on better sites. On all sites paper birch site index exceeds that for red oak; however, differences apparently are not as great on better sites (fig. 2-D), and possibly red oak also will grow faster on better sites. Balsam fir has a much higher site index than white-cedar on all sites (fig. 2-E); tamarack also has a much higher site index than black spruce on all sites (fig. 2-F), and possibly these differences are even more pronounced on better sites.

Site-index comparisons are a necessary first step in choosing the best species for a given site. The comparisons we have made (figs. 1 and 2) will help foresters to select the most productive tree on various portions of their forest lands in northern Minnesota. However, tree species in addition to those presented here also might be considered for management in northern Minnesota – for example, certain northern hardwood species on the better sites.

Other factors that should be considered in choosing among alternative tree species include tree height growth before and after index age (50 years), total yield produced, and the value of this yield. For example, on good sites quaking aspen might have a somewhat higher site index than basswood or red oak. However, aspen is a short-lived tree and thus height and volume growth may slow markedly after 50 years of age. In contrast, the longer-lived basswood and red oak maintain height, diameter, and volume growth well after 50 years, and thus may ultimately produce more volume than aspen. Finally, red oak and basswood are often valuable for high-quality veneer and saw logs, while aspen is chiefly used for pulp and fiber. Even though all three species might produce similar total volume on certain sites, we might still favor red oak and basswood because they can produce a greater total value of yield.

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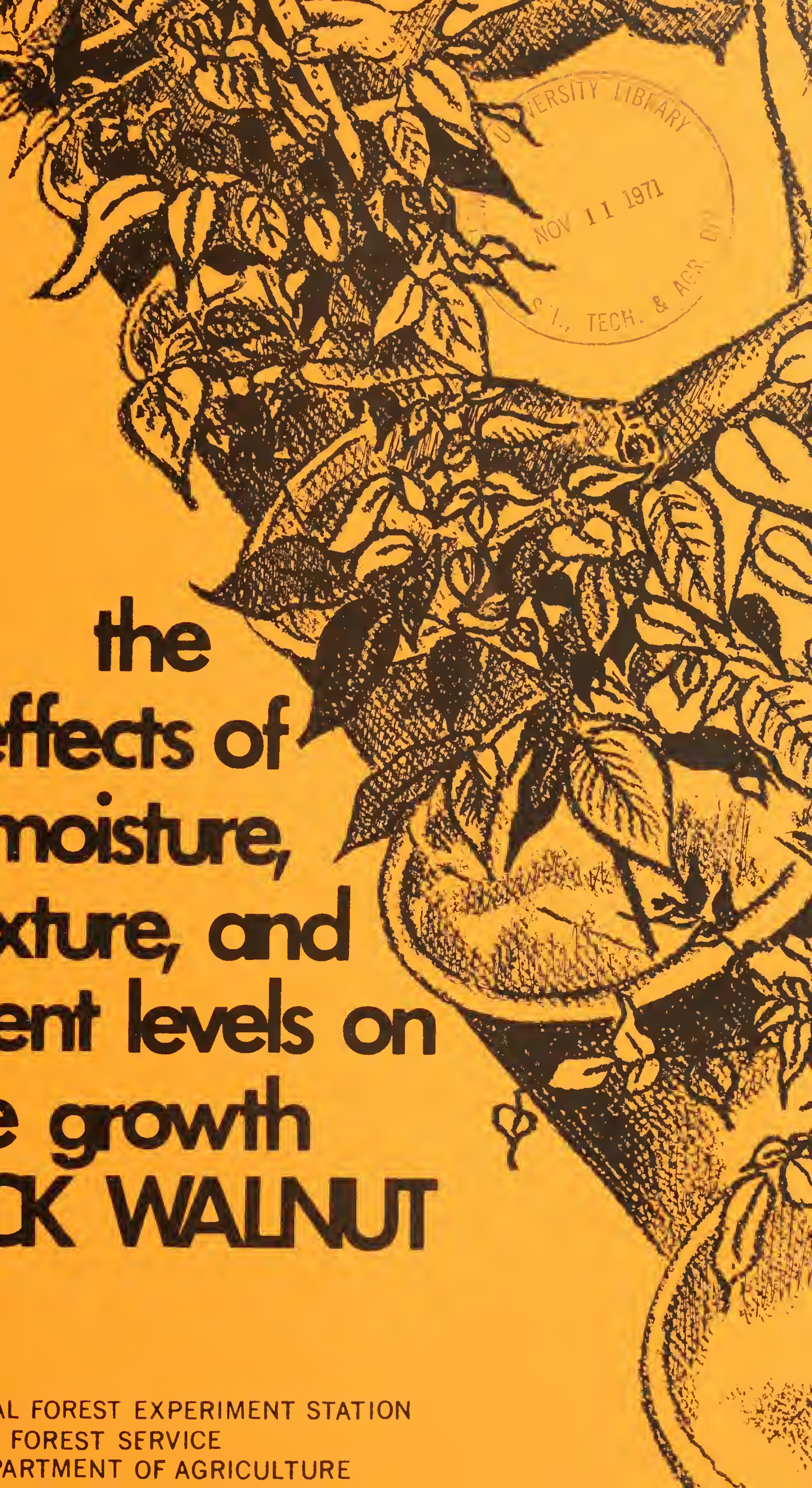

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dickson

the effects of soil moisture, texture, and nutrient levels on the growth f BLACK WALNUT

NORTH CENTRAL FOREST EXPERIMENT STATION
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(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication May 11, 1971.

THE EFFECTS OF SOIL MOISTURE, TEXTURE, AND NUTRIENT LEVELS ON THE GROWTH OF BLACK WALNUT

Richard E. Dickson

In recent years intensive management (includ-ng fertilization) of high value hardwoods has ecome an accepted forestry practice. The re-ponse of trees or tree seedlings to fertilizer epends on the soil's inherent nutrient level, exture, structure, and moisture, and the rate, ime, placement, and kind of fertilization.

A study was designed to determine the re-ponse of black walnut seedlings to fertilization hen grown in two Iowa soils of different tex-ure, and to evaluate the interactions between ater regimes and fertilizer rates.

PROCEDURES

Two soils, two soil moisture regimes, and three utrient levels, were tested in a complete fac-orial design with three replications. The treat-ents were randomly assigned to pots kept in single greenhouse bay. The treatment data ere subjected to analysis of variance and Dun-an's Multiple Range Test.

Soils

Samples of Ames clay loam (27 percent sand, 8 percent silt, and 25 percent clay) and Thur-an sand (92 percent sand, 4 percent silt, and percent clay) were collected from Boone and tory Counties, Iowa. The initial pH of the clay nd sandy soil was 4.7 and 5.1 respectively, and d not change materially during the course of e experiment.

After thorough mixing, 11.80 kilograms of clay or 14.53 kilograms[1] of sand were placed in 3-gallon plastic pots. The field capacity and wilting point percentages were 40.0 and 12.6 percent for clay, and 25.0 and 2.7 percent for sand.

Soil Moisture Regimes

The two soil moisture regimes, field capacity and wilting point, were regulated by periodic weighing and rewatering of the entire soil-plant-pot system. After the amount of water required for a regime was lost from the system, the pot was rewatered to field capacity by weight for the start of another cycle.

The field capacity pots were rewatered every 2 or 3 days depending on the rate of water loss from the system. These pots were allowed to dry to approximately 75 percent of the available water then rewatered to field capacity.

The wilting point pots were allowed to dry from field capacity until the weight of the system reached that calculated for the 15 bar wilting point before rewatering for another cycle. Each wilting point cycle took approximately 20 days.

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[1] *These were the ovendry weights of each soil needed to provide 3.3 kilograms of available water per pot. Available water is the weight of water in the soil from the 1/3 bar field capacity to the 15 bar wilting point.*

Fertilizer Levels

The three treatments were: (1) no fertilizer; (2) N, P, K, at 137, 38 and 143 pounds/acre respectively (1X) added 27 days after planting; (3) N, P, K at same rates and time as treatment (2) plus N, P, K at double the initial level 30 days after initial fertilization – for a total 3X concentration (N, P, K at 411, 114, 429 pounds/acre).

Fertilizer levels were generated by adding 800 milliliters of a complete, concentrated Johnson's nutrient solution to each pot.[2]

Planting and Harvesting

Five germinating walnut seeds were planted on January 3, 1969, in each 3-gallon pot. The seedlings were thinned to three per pot as soon as the first true leaves appeared. All pots were watered and maintained at or near field capacity from planting time through the start of the experimental growth period on January 30, 1969. Net height growth was determined by measuring the plants at the start and end of the experimental growth period. The plants were harvested on April 30, 1969, separated into leaf, stem, and root for drying at 70° C. in a force draft oven for 48 hours before dry weight determination. Shoot/root ratios were based on the ovendry weight of the parts.

Nutrient Determination

Nitrogen was determined on a 100 mg subsample of leaf material by micro-kjeldahl distillation. The cations and P were determined on a 500 mg subsample after wet-ashing with concentrated HNO_3 and $HC10_4$.[3] The concentrations of K, Ca, and Mg in leaf material were determined by atomic absorption. Phosphorus was determined colorimetrically by the ammonium-molybdate stannous chloride method.[4]

RESULTS AND DISCUSSION

The soil moisture treatments had the greatest effect on growth, producing highly significant differences in both height and dry weight of tops and roots (table 1). The soil and fertilizer treatments were less effective. There was no main effect of soils on height growth nor of fertilizers on root dry weight. Significant interactions occurred only where soil moisture was involved. All three treatments, soils, soil moisture, and fertilizers, had a significant effect on leaf, nutrient content (table 2).

Table 1.—Significance of treatment and interaction effects of soil texture, soil moisture, and fertilization on the growth of walnut

Source of variation	Height growth	Dry weight: Tops	Dry weight: Roots	Dry weight: Total	Shoot/root ratio
Replication	--	--	--	--	--
Treatment	xx	xx	xx	xx	xx
Soils	--	xx	x	xx	xx
Soil moisture	xx	xx	xx	xx	xx
Fertilizers	xx	xx	--	x	xx
Soils x soil moisture	--	xx	xx	xx	xx
Soil x fertilizer	--	--	--	--	xx
Soil moisture x fertilizer	--	xx	xx	xx	xx
Soils x soil moisture x fertilizer	--	xx	--	--	xx

-- Nonsignificant.
x Significant at the 5 percent level.
xx Significant at the 1 percent level.

Table 2.—Significance of treatment and interaction effects of soil texture, soil moisture, and fertilization on leaf dry weight and leaf nutrient content

Source of variation	Leaf dry weight	Percent Dry Weight: N	P	K	Ca	Mg
Replication	--	--	--	--	--	--
Treatment	xx	xx	xx	xx	xx	xx
Soils	xx	xx	xx	xx	xx	x
Soil moisture	xx	xx	xx	xx	--	x
Fertilizer	xx	xx	xx	xx	xx	xx
Soils and soil mixture	xx	xx	--	--	xx	xx
Soils and fertilizer	--	xx	xx	xx	--	--
Soil moisture x fertilizer	xx	xx	xx	--	--	x
Soils x soil moisture x fertilizer	xx	xx	xx	--	xx	xx

-- Nonsignificant.
x Significant at the 5 percent level.
xx Significant at the 1 percent level.

[2] *Johnson, C. M.,* et al. *Comparative chlorine requirements of different plant species. Plant and Soil 8: 337-355. 1957.*

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Height Growth

Height growth was less responsive to treatment than dry weight because much of the height growth was completed in the 30 days before the treatments started. The greatest height growth was obtained with plants grown under the field capacity soil moisture treatment plus the highest fertilizer application rate (table 3). Comparison of the main effects of the various treatments shows that most of the height growth was obtained with the first nutrient addition (table 4). For both soils and with comparable fertilizer treatments, the field capacity seedlings were significantly taller than the wilting point seedlings. No difference occurred between the soils in their effect on height growth with similar soil moisture and nutrient treatments; however, dry weight was significantly affected.

Dry Weight

Significant increases in total dry weight resulted from fertilization only in association with the field capacity treatment. The greatest yield (both dry weight and height) was obtained with the highest fertility level in sand at field capacity (table 3, fig. 1). There was no significant difference in total dry weight between the medium and high fertility levels. The lower yields from the clay soil may reflect some aeration problems in the heavier soil.

Table 4.—Individual effects and interactions of soil texture, soil moisture, and fertilization on the growth of black walnut

Treatment[1/]	Height growth	Dry weight: Tops	Dry weight: Roots	Total dry weight	Shoot/root
	Centimeters	Grams	Grams	Grams	
Soils					
Clay	4.8	12.77	26.57	39.34	0.515
Sand	4.6	17.46	33.98	51.44	.860
Water					
FC	5.8	20.81	47.00	67.81	.438
WP	3.7	9.41	13.55	22.96	.939
Clay:					
FC	5.5	16.45	37.48	53.93	.443
WP	4.2	9.08	15.66	24.74	.588
Sand:					
FC	6.0	25.17	56.51	81.68	.434
WP	3.3	9.75	11.44	21.19	1.290
Nutrients					
0	3.3	11.16	27.16	38.32	.422
1	5.5	16.02	30.56	46.58	.790
3	5.4	18.16	33.08	51.24	.852
Clay:					
0	3.2	9.68	21.48	31.17	.445
1	5.8	12.94	26.87	39.81	.530
3	5.6	15.67	31.36	47.03	.572
Sand:					
0	3.4	12.63	32.85	45.48	.400
1	5.2	19.10	34.26	53.36	1.050
3	5.3	20.63	34.82	55.45	1.130

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

Table 3.—Effects of soil texture, soil moisture, and fertilization on the growth of black walnut

Treatment Code[1/]	Height growth	Dry weight: Leaves[2/]	Dry weight: Stems	Dry weight: Total tops	Dry weight: Roots	Total dry weight	Shoot/root
	Centimeters	Grams	Grams	Grams	Grams	Grams	
Clay:							
FC-0	3.8	8.13	4.03	12.16	25.80	37.96	0.471
FC-1	6.3	11.98	4.64	16.62	39.13	55.75	.425
FC-3	6.5	14.84	5.73	20.57	47.52	68.09	.483
WP-0	2.7	5.19	2.00	7.19	17.17	24.36	.419
WP-1	5.2	7.06	2.21	9.27	14.61	23.88	.634
WP-3	4.6	8.42	2.63	11.05	15.19	26.24	.727
Sand:							
FC-0	4.0	9.93	4.84	14.77	42.40	57.17	.348
FC-1	6.3	20.08	7.92	28.00	62.32	90.32	.449
FC-3	7.6	24.91	7.83	32.74	64.80	97.54	.505
WP-0	2.7	7.69	2.81	10.50	23.30	33.80	.451
WP-1	4.2	8.01	2.21	10.22	6.20	16.42	1.650
WP-3	3.0	6.77	1.75	8.52	4.83	13.35	1.760

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs./acre); 3 = (N, P, K - 411, 114, 429 lbs./acre).

2/ No statistical analysis was made on differences among stem weights. Values covered by the same vertical line are not significantly different at the 5 percent level.

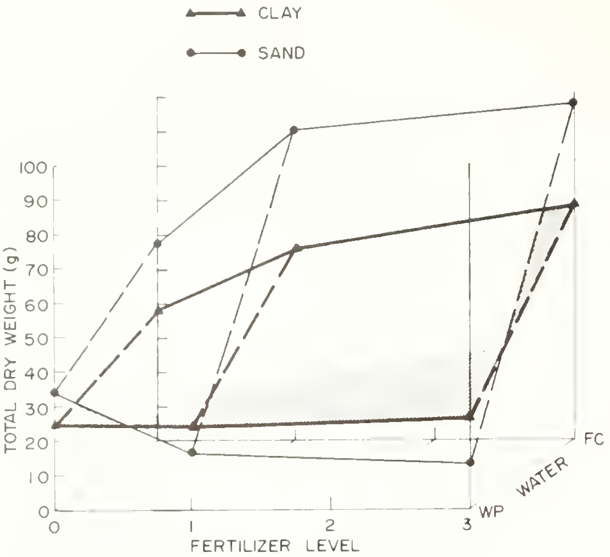

Figure 1.—The effects of soil texture, soil moisture, and fertilization on total dry weight production of black walnut.

Fertilization of the sandy soil under the wilting point treatment reduced seedling growth. This was reflected in the strong fertilizer x soil moisture interactions. The decrease in total dry weight was the result of the severe reduction in root growth (fig. 2). There was no significant decrease in top growth. In this sandy soil with its relatively low exchange capacity, most of the added nutrients would remain as free ions in the soil solution. When water was removed from the system, the osmotic concentration of the soil solution could increase until the roots were damaged.

This osmotic potential can be roughly calculated by using the total molarity of the added macronutrient salts, and by assuming total ionization, no adsorption on the soil particle, and no salts already present in the soil. With these assumptions the first addition of fertilizer would provide 0.120 mole of osmotically active salt and the second addition 0.240 mole for a total of 0.360 mole. At field capacity in the clay and sand there were 4.8 and 3.7 kilograms of water respectively (total weight of soil and water at field capacity minus oven dry weight of soil). Similarly, at the wilting point the clay still retained 1.5 kilograms and the sand 0.4 kilogram of water. the osmotic pressure at field capacity and at wilting point would then be (in bars):

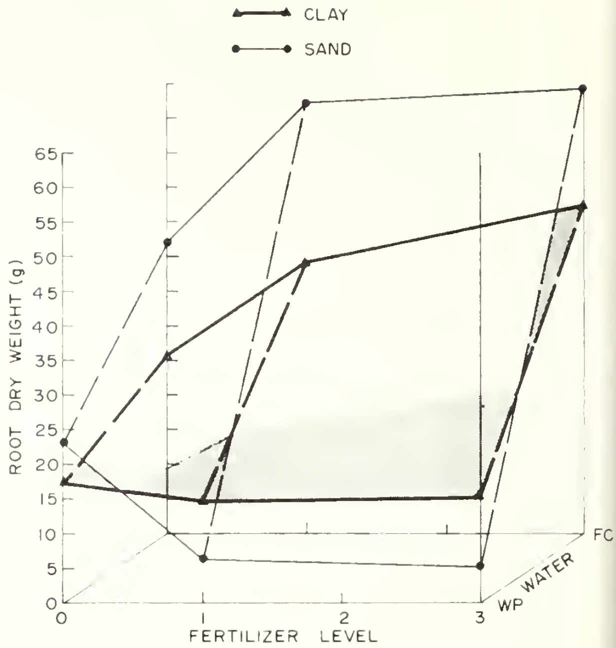

Figure 2.—The effects of soil texture, soil moisture, and fertilization on root dry weight of black walnut.

	Clay		*Sand*	
	FC	*WP*	*FC*	*WP*
Fertilizer 1	0.62	1.98	0.80	7.42
Fertilizer 3	1.09	5.93	2.40	22.24

In addition to these osmotic values, the soil matric potential (15 bars) would add to the stress at wilting point. The combined values of osmotic pressure and soil matric values clearly show that the total soil moisture stress was much greater in sand than in clay at the calculated wilting point. In line with this, wilting of the walnut seedlings was much more pronounced in the sandy soil than in clay as the soil moisture approached the 15 bar wilting point.

Shoot/Root Ratio

Changes in the relative weights of tops and roots can best be expressed as changes in the shoot/root ratio. Shoot/root ratios were effected little by fertilization in the well watered soil. Under the wilting point treatment, however, fertilization increased shoot/root ratios in both clay and sandy soils. For the clay soil under the wilting point treatment, fertilization increased top growth and decreased root growth. This

:hange in dry weight distribution produced a significant increase in shoot/root ratio only be-:ween the extreme fertilizer treatments. For the sandy soil under the wilting point treatment, 'ertilization decreased both top and root weights; however, root weights were decreased much more :han top weights resulting in the high shoot/root ratios.

Water Use Efficiency

Fertilization appears to increase the water use efficiency, assuming that evaporation from the oil surface did not change much within a paricular soil moisture treatment (table 5). The mount of water used to produce a given amount f dry matter decreased in all soil moisture treatnents as fertility level increased, except in the and wilting point treatment. There fertilization esulted in a greater decrease in dry weight than n evapotranspiration, thus increasing the water se ratio.

Nutrient Uptake

/ITROGEN AND PHOSPHORUS

Under moist growing conditions total dry veight increased 79 percent in clay and 71 perent in sand when the high fertility level was ompared to the low fertility level (table 3).

'able 5.—Effects of soil texture, soil moisture, and fertilization on total dry weight and water use by black walnut

Treatment code 1/	Total dry weight	Evapo-transpiration	Water use ratio grams H_2O/grams dry weight
	Grams	Kilograms	
Clay:			
FC-0	37.96	23.79	627
FC-1	55.75	26.71	479
FC-3	68.09	28.08	412
WP-0	24.36	13.27	545
WP-1	23.88	12.72	533
WP-3	26.24	12.76	486
Sand:			
FC-0	57.17	31.27	547
FC-1	90.32	36.93	409
FC-3	97.54	35.87	368
WP-0	33.80	15.05	445
WP-1	16.42	12.73	775
WP-3	13.35	11.93	894

1/ FC = field capacity; WP = wilting point; 0 = no ıtrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); ' = (N, P, K - 411, 114, 429 lbs/acre).

Along with this increase in dry weight, the N concentrations in the leaves increased with the fertilizer additions in both clay and sand, while the P concentrations increased to a significant degree only in the sand (table 6). In general, for broad-leaved plants leaf concentrations of N under 2 percent and of P under 0.1 percent would indicate deficiency levels.

Table 6.—Effects of soil texture, soil moisture, and fertilization on dry weight and concentration of nitrogen, phosphorus, potassium, calcium, and magnesium of walnut leaves

Treatment 1/	Dry wt. leaves	Percent dry weight: N	P	K	Ca	Mg
	Grams					
Clay:						
FC-0	8.13ab 2/	1.80a	.111bc	1.01a	1.10bc	.37a
FC-1	11.98b	2.25	.101ab	1.05a	1.33c	.50b
FC-3	14.84b	2.69b	.130c	1.17a	1.40c	.50b
WP-0	5.19a	1.75a	.089ab	1.37a	.86ab	.30a
WP-1	7.06a	2.67b	.086ab	1.19a	.61a	.37a
WP-3	8.42ab	2.77b	.079a	1.30a	1.29c	.51b
Sand:						
FC-0	9.93a	1.60	.117ab	1.26a	1.32ab	.42a
FC-1	20.08	2.06a	.127bc	1.55	1.12a	.34a
FC-3	24.91	3.20b	.291	2.11b	1.41b	.42a
WP-0	7.69a	2.22a	.097a	1.24a	1.10a	.42a
WP-1	8.01a	3.51bc	.152c	1.95b	1.55b	.54
WP-3	6.77a	3.73c	.149c	2.22b	1.90	.67

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

2/ Values followed by the same subscript letter within a soil texture are not significantly different at the 5 percent level.

The N uptake did not appear to be hampered by drought conditions. A decrease in available water usually decreases growth before it affects nutrient uptake. Such growth restrictions resulted in higher leaf concentrations in the smaller plants as illustrated by N concentrations in plants grown in sand under the wilting point water regime when compared to those grown at field capacity. Phosphorus uptake, on the other hand, was considerably reduced when the plants were grown under recurring drought conditions. Both concentrations (table 6) and total contents (table 7) decreased in leaves from a WP treatment when compared to the corresponding FC treatment at the highest fertility level.

POTASSIUM, CALCIUM, AND MAGNESIUM

The concentration and total content of K, Ca, and Mg in leaves were affected by all three variables: soil type, water regimes, and nutrient

Table 7.—Effects of soil texture, soil moisture, and fertilization on dry weight and total content of nitrogen, phosphorus, potassium, calcium, and magnesium of walnut leaves

Treatment 1/	Dry wt. leaves	N	P	K	Ca	Mg
	Grams	mg.	mg.	mg.	mg.	mg.
Clay:						
FC-0	8.13ab 2/	144ab	9ab	85a	90ab	30ab
FC-1	11.98b	269c	12b	128abc	162cd	60cd
FC-3	14.84b	400	19	171c	208d	74d
WP-0	5.19a	91a	4a	71a	44a	16a
WP-1	7.06a	188abc	6ab	83a	68ab	25ab
WP-3	8.42ab	233bc	7ab	110ab	108bc	42bc
Sand:						
FC-0	9.93a	158a	11a	123ab	130a	41a
FC-1	20.08	415	26	310	227	68
FC-3	24.91	794	72	525	352	103
WP-0	7.69a	171ab	7a	96a	85a	32a
WP-1	8.01a	282c	12a	157b	124a	43a
WP-3	6.77a	251abc	10a	152b	128a	46a

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

2/ Values followed by the same subscript letter within a soil texture are not significantly different at the 5 percent level.

levels. In general, concentrations were higher in plants grown in sand than in clay (table 6). Leaf nutrient concentration also increased as the fertility levels increased, although this was not true for K in the clay and for Mg in the sand in the field capacity treatments. Where leaf nutrient concentrations did not increase with fertilization, total content did because of the greater dry weight production (table 7).

Even though the water and fertilizer treatments did affect the cation concentrations in the leaves, it is very doubtful that these changes in concentration had any effect on growth. The concentrations of mineral nutrients in a leaf can vary over a fairly wide range and have no influence on growth as long as these concentrations remain within the adequate portion of a critical nutrient level curve (that portion of the curve between the critical and toxic concentration).[5] In almost all cases, the levels in the walnut leaves appear to be within the adequate range for these cations.

SUMMARY AND CONCLUSIONS

All treatments had a significant effect on the growth and nutrient uptake of the black walnut seedlings. The dry weight of the walnut seedlings increased significantly with fertilization in both clay and sandy soils, but only under the well watered conditions. Dry weight of the seedlings grown under the wilting point treatment did not increase with fertilization. In fact, in the sandy soil with the wilting point treatment, root growth was significantly less in the fertilized treatments than in the unfertilized treatment. In this soil and under these growing conditions, even low rates of fertilization were detrimental to the growth of walnut seedlings under recurring drought conditions. This highly significant soil moisture-fertilizer interaction can be very important in nutrient studies and in field fertilization work. High rates of applied fertilizer might have no effect on growth or actually retard growth of walnut in the field if adequate water were not available. Fertilization could also increase root growth given enough soil moisture, thus tapping a greater soil volume from which additional water and nutrients could be utilized. In this study soil volume was restricted and there was no drainage from the potted soil; therefore, all of the nutrients were maintained within the root zone. Much higher rates of fertilization or more frequent applications than were used in this experiment might be necessary in the field before growth differences of this magnitude could be obtained, particularly on a sandy soil where nutrient leaching could occur.

[5] *Smith, P. F. Mineral analysis of plant tissues. Plant Physiol. Annu. Rev. 13: 81-108. 1962.*

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Wilderness Ecology: A Method of Sampling and Summarizing Data for Plant Community Classification, by Lewis F. Ohmann and Robert R. Ream. USDA Forest Serv. Res. Pap. NC-49, 14 p., illus. 1971.

Predicting Lumber Grade Yields for Standing Hardwood Trees, by Charles L. Stayton, Richard M. Marden, and Glenn L. Gammon. USDA Forest Serv. Res. Pap. NC-50, 8 p. 1971.

Tables of Compound-Discount Interest Rate Multipliers for Evaluating Forestry Investments, by Allen L. Lundgren. USDA Forest Serv. Res. Pap. NC-51, 142 p. 1971.

Ecological Studies of the Timber Wolf in Northeastern Minnesota, by L. David Mech and L. D. Frenzel, Jr. (Editors). USDA Forest Serv. Res. Pap. NC-52, 62 p., illus. 1971.

Pest Susceptibility Variation in Lake States Jack-Pine Seed Sources, by James P. King. USDA Forest Serv. Res. Pap. NC-53, 10 p., illus. 1971.

Influence of Stand Density on Stem Quality in Pole-size Northern Hardwoods, by Richard M. Godman and David J. Books. USDA Forest Serv. Res. Pap. NC-54, 7 p., illus. 1971.

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Impact of Insects on Multiple-Use Values of North-Central Forests: An Experimental Rating Scheme, by Norton D. Addy, Harold O. Batzer, William J. Mattson, and William E. Miller. USDA Forest Serv. Res. Pap. NC-57, 8 p., illus. 1971.

Growth and Yield of Quaking Aspen in North-Central Minnesota, by Bryce E. Schlaegel. USDA Forest Serv. Res. Pap. NC-58, 11 p., illus.

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ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

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PAPER NC-67
1971

RHINELANDER, WISCONSIN

RICHARD M. JEFFERS

RESEARCH at the Institute of Forest Genetics

RTH CENTRAL FOREST EXPERIMENT STATION
OREST SERVICE · U.S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication May 7, 1971

FOREWORD

Forest genetics research was begun in the late 1920's in the Lake States. Farsighted men, such as Carlos G. Bates, Paul O. Rudolf, and Joseph H. Stoeckeler, established major studies with both pine and spruce — studies we use in large measure in our research even today, 40 years later.

The second phase began in the early 1950's with the installation of the first major cooperative genetics study in the United States. Paul Rudolf saw clearly that large scale cooperative efforts are essential if we are to harvest the full benefits of our studies. With State conservation departments and universities he began the Lake States Jack Pine Study, which became the pattern for similar efforts across the nation. This has culminated in the NC-51 Cooperative Regional Research Project involving 12 States and two USDA Forest Service Experiment Stations. Without doubt, the NC-51 is the largest cooperative forest genetics project in the world.

The genetics research at the Lake States Forest Experiment Station (now North Central) obtained project status in 1955 and moved to Rhinelander, Wisconsin, in 1957, where a period of program development and establishment of experimental plant material got underway. We are now at a turning point in our program; before us are more penetrating studies of this plant material, and the actual breeding of new strains in close cooperation with the National Forests in the Lake States. This is an appropriate time to review our work and results over the past years.

The entire staff at the Institute contributed material for this report. It was assembled by Richard M. Jeffers, who subsequently has had sole responsibility for revision, updating, and reviews. It is fitting, therefore, that his name appear on the title page.

This summary is intended as a source of information for forest managers and scientists. We have attempted to present the pertinent facts without going into detail. For those interested in details, a list of Institute publications is included at the end of the report. Beyond that, the staff at Rhinelander is available to answer inquiries.

HANS NIENSTAEDT
Chief of Laboratory

CONTENTS

RESEARCH AT THE INSTITUTE OF FOREST GENETICS, RHINELANDER, WISCONSIN

Richard M. Jeffers

The Institute of Forest Genetics was formally opened June 6, 1957, by the North Central (then Lake States) Forest Experiment Station. The main facility of the Institute is a 10,000-square-foot building containing laboratories, offices, controlled-environment growth rooms, and a library. Facilities are available for pollen extraction, microscopy, photography, tissue culture, and chemical analyses. The laboratory-office building is supplemented by a 2,400-square-foot greenhouse, with an attached headhouse. Two combination coldframe-shade houses provide for care of plants in an environment somewhat less severe than outdoors.

The Institute is ideally located for experimental work. It is immediately adjacent to the Hugo Sauer Nursery, which is operated by the Wisconsin Department of Natural Resources. Nursery facilities, therefore, are readily available to staff members for nursery tests and growing seedlings for field plantings. Several test plantations and three National Forests are within 2 hours driving time of Rhinelander. Planting sites for long-range evaluation of test trees throughout the Lake and Central States are necessary. These sites are provided by the National Forests, State agencies, universities, and private organizations.

The Institute was established to centralize the Station's research effort in forest genetics and tree improvement. Studies carried on by the Station since as early as 1928 have showed that genetic improvement is a promising means of increasing the quality and quantity of timber products. However, it was also obvious from the early work that a more intense and fundamental research program was necessary to meet the production goals of the northern forest section of the United States.

The need for increasing the productivity of the forest lands in the north central United States is great. The projected increase in demand for timber products (80 percent by the year 2000) will necessitate full production from all of our forest land. Yet, nearly 60 percent of the forest sites in this region are presently unsuited for the species growing on them.

Planting or seeding of productive sites with genetically improved tree seed, seedlings, or cuttings offers opportunities for increasing future yields of forest raw materials. The Institute of Forest Genetics is dedicated to research that will make possible the production of improved trees for reforesting all feasible areas.

Originally only one project, the Forest Genetics Project, was located at the Institute; today there are four: Forest Genetics, Pioneering Research, Radiobiological Studies of Northern Forest Communities, and Maximum Fiber Yield. This publication will present only the work of the Forest Genetics Project during its first 12 years.

OBJECTIVES OF FOREST GENETICS RESEARCH

Two ways of increasing wood production have long been recognized by foresters: (1) improving the stocking of merchantable tree species, and (2) managing the stands so the most desirable species and most valuable trees make up the harvest. A third related, but less widely demonstrated, way of increasing wood production is to develop and grow genetically better trees than those we now have.

Genetics is the study of similarities and differences between related individuals—the magnitude of the differences, the frequency of variants, and their control. It includes studies of the cells and cellular processes and factors of the environment causing the similarities and differences. Tree improvement is the practical extension of forest genetics. It includes selection of superior trees and races of trees, sexual or vegetative mass production of these selections, and further improvement through actual tree breeding.

The purposes of the research program at the Institute of Forest Genetics are to:

1. Increase knowledge of the genetic constitution and variation in the populations of several forest tree species.

2. Develop guidelines that will enable tree breeders to plan realistic and efficient tree-breeding programs.

3. Breed trees for local use in pilot operations.

WORK PROGRAM

In the 12-year period since the Institute was founded, the work program has steadily grown. It has been directed to include the following areas of research:

1. Seed-source testing
2. Species hybridization
3. Heritability testing
4. Radiation research
5. Genetics of disease and pest resistance
6. Tree improvement
7. Plant introduction
8. Vegetative propagation, including basic studies of root initiation and differentiation in cuttings
9. Cell biology

Most work has been concentrated on white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), and yellow birch (*Betula alleghaniensis*). In addition a large number of other native and exotic genera and species are being studied less intensively. The Institute cooperates on many of its studies with universities and experiment stations throughout the world.

Studies set up in the past 12 years by the Institute have produced some results already, but data will accumulate much more rapidly from now on. Since 1957 approximately 130 technical and nontechnical articles have been published on work conducted at the Institute. The following pages summarize studies in progress and results obtained to date.

SEED SOURCE STUDIES

To determine the improvement that can be expected in a breeding program, the amount and nature of adaptive genetic variation existing in a species must be known. There is no way of examining a natural stand of trees and determining how much of the observed variation is genetic. Some of the variation is undoubtedly due to environmental factors.

Only in seed source studies can genetic and environmental factors be distinguished. Such studies involve collecting seed from stands in more than one area, usually from many sources throughout the species range, planting all of this seed in separate plots in one nursery, and field planting in different environments. The study will usually include evaluation of the seed, nursery investigations of the seedlings, field establishment, and evaluation and measurement of the planted trees for many years.

Seed source studies have been underway at the North Central Forest Experiment Station for over 30 years and have yielded much valuable information.

Red Pine

More red pine has been planted in the Lake States than any other species. Its easy establishment, few diseases and insects, and high utility as a lumber and pulping species have made it valuable. Hence, red pine was one of the first species to be subjected to seed source and progeny tests in the Lake States.

RED PINE SEED SOURCE STUDY—SUPERIOR NATIONAL FOREST

One of the Station's oldest studies is a red pine seed source and individual tree progeny test. One set of plantations was established in 1931 with 37 seed sources and individual tree progenies, and a second in 1933 with 140 seed sources and individual tree progenies. Originally plantations were established in at least three localities in the Lake States, but fire, drought and other causes reduced the number of plantings to one, located near Ely, Minnesota, on the Superior National Forest.

Evaluation of the 1931 planting at age 18 showed significant differences among seed sources and progenies in survival, average height, average diameter, basal area per acre, and cubic volume per acre. In general, trees from northern Minnesota, northeastern Wisconsin, and adjacent southern Upper Michigan sources performed better than those from central and northwestern Wisconsin, Lower Michigan, and New England sources.

Evaluation of the 1933 planting gave similar results at age 23, with the best 20 percent of the sources and progenies (cubic-foot volume) coming from Minnesota, northern Wisconsin, and Upper Michigan. The average total height was 19.6 feet, and the unpeeled volume per acre was 341 cubic feet (the range was from 8 cubic feet to 910 cubic feet).

A plantation of red pine containing 50 of the same sources that were used in the Superior National Forest planting was established in northwestern Pennsylvania in 1937. At the end of the tenth growing season, significant differences in tree height growth among sources were noted. Trees from Upper Michigan, northern Wisconsin, and Minnesota sources had significantly poorer height growth than those from central Wisconsin and Lower Michigan sources. The similar results from these two widely separated plantings show that red pine from Minnesota, northern Wisconsin, and Upper Michigan do differ from central Wisconsin and Lower Michigan red pine. And, in general, trees from sources nearest the planting sites did better than those from more distant sources. However, trees from distant sources occasionally may out-perform the local source, indicating that some genetic variation exists in red pine, although it is a comparatively homogeneous species (Rudolf 1965a).

In 1964 a more intensive evaluation of 69 individual tree (open-pollinated) progenies was made. For the preliminary analysis, the progenies were arranged by region according to the seed collection zones suggested by Rudolf (1959a). Analyses showed significant differences among individual progenies in height, d.b.h., and survival. Height growth rates of the different progenies were relatively uniform; trees from the poorest source grew at a rate of 1.14 feet per year, while those from the best source grew at 1.36 feet per year. Regional differences, however, were significant for survival only.

Progenies from climatic zones differing greatly from that of the planting site appear to be more variable than progenies from climatic zones similar to the planting site, suggesting that some genotypes interact with the environment more strongly than others.

Marked differences in tree form were noted. Some progenies were tall with small diameters, while others were intermediate in height with large diameters.

On the basis of the data analyzed we can expect genetic gains of 3 to 4 percent in rate of height growth. This would mean an increase in board-foot yield of approximately 9 percent at rotation age (Nienstaedt 1965a). This increase is more than enough to provide 4 to 6 percent interest on all development costs, particularly if improved seedlings are planted on the best sites (Lundgren and King 1966).

Jack Pine

Jack pine occupies large acreages in the Lake States, and it is an economically important species. In 1967, 569,000 cords of jack pine pulpwood were consumed in the Lake States, second only to aspen. It fills an important ecological niche because of its rapid juvenile growth on relatively infertile soils.

Jack pine presents some problems for the foresters: growth rate varies widely among seed sources, its form is often poor, and it is susceptible to a number of disease and insect enemies. However, it appears to be extremely variable and flowers early; therefore, it should have a great potential for genetic improvement. For these reasons, several studies were begun to determine the type and magnitude of variation present in the species and the possibility of breeding better strains.

LAKE STATES SEED SOURCE STUDY

The first jack pine seed source study was initiated by the Station and the University of Minnesota in 1951. Seed was collected from 29 jack pine stands in Minnesota, Wisconsin, and Michigan. Each collection was made from dominant and codominant trees in a stand considered good for the area. Seedlings from all 29 stands were grown in State nurseries in Wisconsin and Minnesota, and in 1954 the 2-year-old seedlings were field-planted in 17 locations in the Lake States. In each planting the test seed sources were compared with a local source.

After 10 years of growth, trees in 11 of the plantations were measured; the mean tree height of the plantations varied from 9.6 feet on the

Chippewa National Forest in northern Minnesota to 15.2 feet on the Marinette County Forest in northeastern Wisconsin. Trees in the six plantings in northern Wisconsin were the tallest, and trees in two plantings in northern Minnesota and two in Lower Michigan were the shortest. The greatest range in total tree height among sources was present in a Washburn County, Wisconsin, planting; trees from the shortest source (Minnesota) were 25 percent shorter than the plantation mean, while trees from the tallest source (Lower Michigan) exceeded the mean by 17 percent. In general, trees from Lower Michigan seed sources performed best throughout Michigan and Wisconsin, and trees from north-central Minnesota sources did best in the northern Minnesota plantings.

In nine of the 11 plantings trees from the commercial nursery sources were shorter than those from the test sources by 12 to 28 percent. In almost all of the plantings, trees from the test source closest to the planting site outgrew the commercial nursery stock (King 1966).

Jack pine often exhibits "late-growth" or second flushing during a single growing season. This second flushing may occur only on the terminal (lammas growth) or the laterals (prolepsis), or a combination of both, causing the tree to develop a crooked stem and other undesirable characteristics. A study of the nature and extent of these abnormalities in jack pine, utilizing the 29 seed sources in six of the field plantings, was conducted over three successive growing seasons.

The frequency of occurrence of lammas growth, prolepsis, and their combinations varied significantly among seed sources in all the plantations studied. It is clear that both lammas growth and prolepsis are under strong genetic control. Because of the undesirable results of this type of growth, seed collection from trees exhibiting lammas growth and prolepsis or in stands with a high frequency of these growth types should be avoided (Rudolph 1964).

RANGEWIDE SEED SOURCE STUDY

A study including seed sources representing the entire range of jack pine was initiated in 1962 at the Institute of Forest Genetics. This study was designed to determine the patterns of variation in jack pine over its entire natural distribution in Canada and northern United States, and to increase knowledge and understanding of jack pine evolution and migration.

Ninety-two seed collections, the majority of which were supplied by the Petawawa Forest Experiment Station, Ontario, Canada, were included in the nursery phase of the study. Ninety of these collections were subsequently field-planted in northern Wisconsin in 1965 for further evaluation. Measurements taken during a 5-year period in the nursery showed much variation among sources in tree height growth, fall needle coloration, stem color, female strobili abundance, insect incidence, and wood quality.

Some of the most significant findings to date relate to wood quality. At the end of the fifth growing season in the nursery, 34 of the original 92 sources were selected for measurements of tracheid length and specific gravity. Stem samples were taken from the center of the lowest 1964 internode (jack pine is multinodal). The entire cross-section (1964, 1965, and 1966 wood) was used for specific gravity determination, but only the outermost portion of the 1966 summerwood for tracheid length determination.

The results were as follows:

1. Tracheid length and specific gravity of 3-year-old wood differed significantly among seed sources.

2. There were strong *positive correlations* between mean seed source tracheid length, diameter inside bark, and annual height growth in jack pine at this age. There were strong *negative correlations* between mean seed source specific gravity and tracheid length, diameter inside bark, and annual height growth.

3. Because the seed sources were diverse, the genetic variation among stands was much greater than the variation within stands.

4. Trees from Michigan, Minnesota and Wisconsin seed sources had the highest growth rate, longest tracheids, and lowest specific gravity, while those from northern Canada and eastern Nova Scotia sources had the lowest growth rate, shortest tracheids, and highest specific gravity.

5. Tracheid length estimated from young jack pine may be a good indication of mature-tree tracheid length when the sources have great genetic diversity. Specific gravity of 3-year-old

Figure 1. — Jack pine variation in a plantation in northern Wisconsin containing trees from seed sources throughout the species range. After 8 years from seed the mean tree height from the New Brunswick source being evaluated exceeded the mean tree height from the Nova Scotia source in the foreground by nearly 200 percent.

ood, on the other hand, probably will not be seful in predicting the specific gravity of mature ees (King 1968).

In future experiments, these results will be mpared with results from older trees. If the rrelations are high, the time required for an fective program to improve these characters n be greatly reduced.

EED COLLECTION RECOMMENDATIONS

The following seed collection recommendations r the Lake States can be made:

1. Collect seed only from better-than-average stands.

2. In Lower Michigan plantings, use only seed collected in Lower Michigan.

3. In Wisconsin and Upper Michigan, collect seed from Lower Michigan and mix the Lower Michigan seedlings with seedlings from local stands.

4. In Minnesota, collect seed from selected stands near the planting site (King 1966).

Racial Variation in White Spruce

White spruce seed was collected in 1955, 1956, and 1957 from 29 locations throughout the natural range of the species. Seed from each lot was sown at Rhinelander, Wisconsin, in the spring of 1958 and the seedlings transplanted in 1960. In 1962, trees from 28 of the seed sources were field-planted in 17 locations from North Dakota to New Brunswick, representing a range in latitude of 42° to 48° N. All sources were evaluated during the first, second and fourth year in the nursery and after five growing seasons in the field. Over 30 measurements of vigor and taxonomic characters were made on the nursery material. The field measurements included survival, total height, annual height growth, and number of branches.

Survival in nearly all plantings exceeded 80 percent. With the exception of three sources from Alaska and one from the Yukon Territory, the different seed sources varied little in tree survival. Tree height growth, however, differed significantly among sources after 5 years in the field. The tallest planting at Grand Rapids, Minnesota, had a mean tree height of 36.3 inches. Trees from a Montana source were the shortest in this plantation, with an average height of 15.7 inches, and those from an Ontario source were the tallest (55.2 inches). The average height of trees from two local seed sources (those nearest the planting site) was 48.2 inches.

Analysis suggested that seed sources from the southeastern portion of the species range – the Lake States, southern Ontario, a portion of Quebec, and New England – produced trees relatively well adapted to all of the test sites, and some

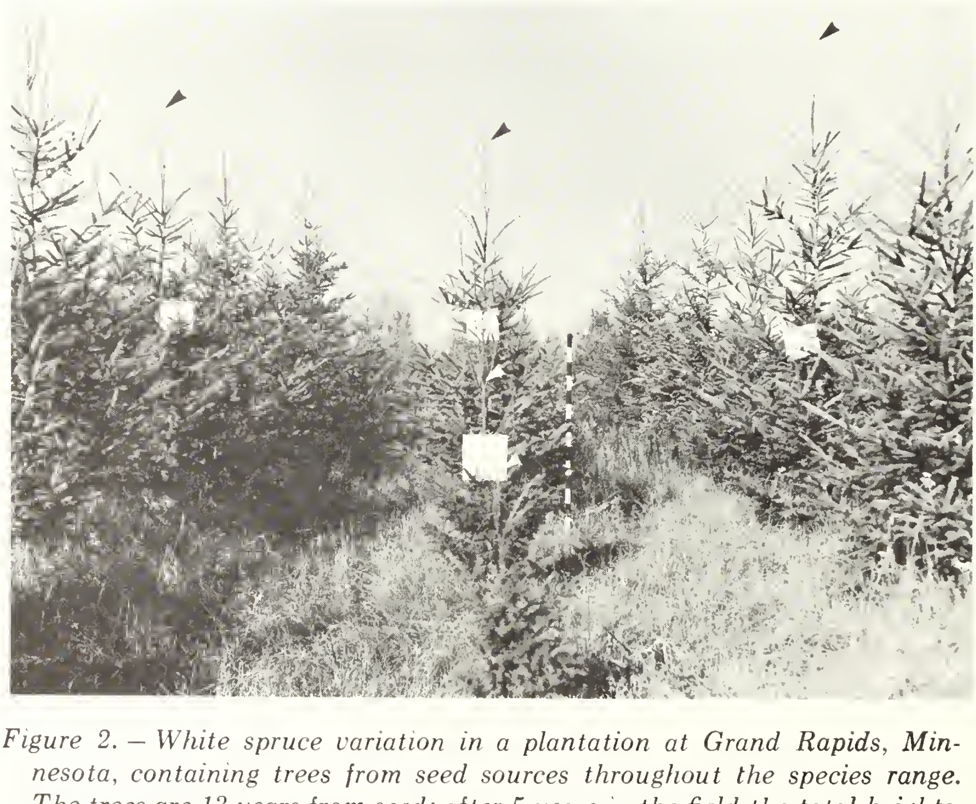

Figure 2. – White spruce variation in a plantation at Grand Rapids, Minnesota, containing trees from seed sources throughout the species range. The trees are 13 years from seed; after 5 years in the field the total heights, in percent of the plantation mean, of the sources shown here were: New Hampshire (right) 119; Alaska (last 2 trees in 4-tree plot, lower center) 45; Minnesota (upper center) 128; Minnesota (left) 137. The best source in this planting was from Beachburg, Ontario. Its height was 153 percent of the plantation mean, and exceeded the average of the two Minnesota sources in the photo by 14 percent.

were growing better than the average for the plantation. Trees from the more northern sources were poorly adapted to the planting sites and had slow overall growth. The one outstanding seed source in this study was from Beachburg, Ontario. Without exception, seedlings from this source were above average on all sites and superior on the best sites. At Grand Rapids, Minnesota, their growth exceeded the plantation average by 52 percent and the average of seedlings from two local sources by 14 percent. It is interesting to note here that a Douglas, Ontario, seed source, in another older study, still maintains a 22 percent superiority in tree height growth over seven other sources after 29 years in a plantation in northern Wisconsin, and an approximate advantage of 16 percent over the local white spruce seed source (King and Rudolf 1969).

The data suggest that white spruce from the entire southeastern region of the species, and southeastern Ontario and southwestern Quebec in particular, may provide excellent breeding stock for the area encompassing the test plantings. Simply introducing the Beachburg-Douglas, Ontario provenance in some of the areas in which tests were conducted would result in direct improvement (Nienstaedt 1969a).

Natural Variation in Yellow Birch

A study of natural variation in yellow birch was initiated at the Institute in 1963. Seed lots collected from 55 sources throughout the species range were sown in the spring of 1965 and the resulting seedlings were transplanted to the Rhinelander nursery in the summer of 1965. The average height of trees from the 55 sources at the end of the third growing season was 47.8 cm., ranging from a low of 29.3 cm. for a Tennessee source to a high of 63.6 cm. for a Lower Michigan source. Height was not correlated with latitude, longtitude, length of growing season, annual precipitation, average January temperature, or average July temperature of the seed sources. Although seedlings from the northern sources showed some tendency to be thicker than those from the southern ones, diameter was only weakly correlated with latitude and length of growing season. Thus, the variation in height and diameter of yellow birch appears to be random, at least in the seedling stage.

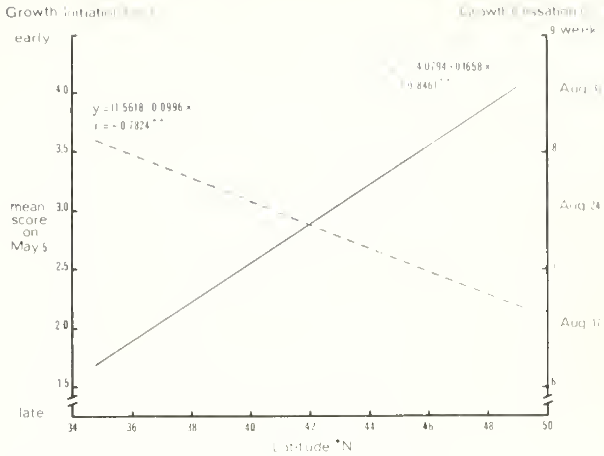

Figure 3. — Yellow birch exhibits a gradual north-south trend, or clinal variation, in growth initiation and cessation at the Rhinelander, Wisconsin nursery. The regression lines show the relationship between growth initiation and cessation and latitude of seed origin. In general, trees from northern sources start flushing and stop growing earlier than those from southern origins. Data are based on 2-year-old trees measured in the fall of 1966 and spring of 1967.

These early results suggest that much potential growth may be lost if the wrong seed source is used in a yellow birch planting. The importance of seed origin was apparent in the great differences in the performance of seedlings from different sources within the same State or Province. For example, the height differences between seedlings from the best and the poorest seed sources amounted to 32 percent for Wisconsin, 55 percent for Michigan, 28 percent for Quebec, and 44 percent for Nova Scotia. Growth rate of seedlings originating from areas relatively close to each other often differed greatly. Thus, one New Hampshire source produced seedlings 19 percent taller than those from a source 40 miles north. Similarly seedlings from one Lower Michigan source were 29 percent taller than those from a source 70 miles away in the Upper Peninsula (Clausen and Garrett 1969).

The apparent random variation in height and diameter growth of yellow birch may, in part, be due to individual tree variation. Catkin and fruit characteristics have already been shown to vary greatly among individual trees within a stand (Clausen 1968a), and similar growth differences may exist. To determine whether the great height variability observed in this study might be due to the fact that the seed lots used were a mixture from about 10 trees per stand, a study of 199 individual tree progenies representing 21 stands located throughout the natural range of yellow birch is now in progress.

Yellow birch, in contrast to its random variation in height and diameter, exhibits a gradual north-south trend, or clinal variation, in growth initiation and cessation at the Rhinelander, Wisconsin, nursery. In general, trees from the northern sources start flushing and also stop growing earlier than those from southern ones (Clausen 1968b). Times of flushing and growth cessation, however, do not appear to be related to total height.

Trees from early-flushing sources are likely to be damaged by late spring frosts, while those that continue growth until fall are susceptible to injury from early fall frosts. Trees from all 55 seed sources showed some degree of winter injury after their second winter in the nursery. Although the percentage of injured trees was often high, the damage was normally light in most of the northern and eastern sources. Most severely damaged were seedlings from the Ohio, Indiana, Virginia, Kentucky, and Tennessee sources. Of the southern group, only the North Carolina and Georgia seedlings from high elevations were relatively frost resistant (Clausen and Garrett 1969). This again illustrates the importance of selecting the right seed source for a particular climate.

On the basis of these early tests, the local yellow birch seed source may not be best. The local source was among the five poorest after 2 years in the Rhinelander nursery. It improved somewhat at the end of the third year, but was still poorer than the other four Wisconsin sources. Current indications are that the largest improvement in this species will come from progeny-tested individual trees selected in provenances within fairly large regions.

Interregional Provenance Study of Eastern White Pine

Eastern white pine seed collected from 17 sources representing the species range was sown in the Toumey Nursery, Watersmeet, Michigan, in 1958. In the spring of 1960 the 2-0 stock was transplanted to the Hugo Sauer State Nursery near Rhinelander, Wisconsin. Subsequently 2-2 stock was field-planted in Minnesota, northern Wisconsin, Upper Michigan and Lower Michigan. These four plantations were evaluated after 5 years in the field. No seed source or group of sources was consistently better than the others in the nursery or in all field plantings. Trees from the Appalachian sources started out well in the nursery and were among the best in the Lower Michigan planting. These sources showed the greatest susceptibility to winter injury and therefore did not do well in the more severe climate of northern Wisconsin and Minnesota. On the other hand, trees from an Ontario source were tallest in Minnesota but below average in Lower Michigan. The ranking by height of the seed sources growing in Lower Michigan was similar to the ranking of the same seed sources growing in southern Illinois, Indiana, Ohio, and North Carolina. However, there is little resemblence to the ranking of the same seed sources being grown in Wisconsin and Minnesota. The results show that trees from white pine seed sources react strongly to the environment, suggesting that many stands must be tested to locate enough superior sources of seed for reforestation in the Lake States.

For the more severe climates of northern Minnesota, northern Wisconsin and Upper Michigan, seed should be obtained from stands in areas where the mean January temperature is less than 20° F. This includes white pine stands in all of Minnesota, Wisconsin, Upper Michigan, and the northern parts of Lower Michigan and Ontario. For planting in southern and western Lower Michigan, southern Appalachian seed sources offer enough promise to warrant further investigation. In the meantime, foresters in the Lake States should use seed from stands no more than 100 miles from the planting site (King and Nienstaedt 1968, 1969).

Other Seed Source Studies

Other seed source studies underway at the Institute include Scotch pine, tamarack, balsam fir, northern white-cedar, Engelmann spruce, and Norway spruce.

INHERITANCE STUDIES OF WHITE SPRUCE

Seed source studies provide information on the total variation within the species. Heritability studies involve individual tree progenies and provide specific information on the inheritance of desirable tree characteristics. Together, seed source and heritability studies guide tree breeders in the choice of an efficient breeding program. Like the seed source studies, these studies involve testing under a variety of environmental conditions. The test plants are derived from open-pollinations or from controlled pollinations in which both the male and female parents are known.

The objectives of the white spruce heritability studies are:

1. To determine the magnitude and nature of genetic variation among individual white spruce trees.
2. To determine genetic correlations between desirable characteristics such as vigor, height growth, form, branchiness, and wood quality.
3. To determine juvenile-mature tree correlations. These are especially important to the tree breeder as they can materially shorten the period between breeding generations.
4. To provide breeding arboreta for crossing tests between trees of known parentage.

Heritability studies in white spruce were started at the Institute in 1962. Twenty-eight mature white spruce trees growing in northeastern Wisconsin, northern Minnesota, and the Upper Peninsula of Michigan were selected and measured. Open-pollinated seed from these parents was sown in the Hugo Sauer State Nursery at Rhinelander, Wisconsin, in the fall of 1963. After four growing seasons in the nursery total and current height growth of the 2-2 seedlings were measured.

The average annual height growth of the parents was strongly correlated with the growth of their respective progenies ($r = 0.80$), indicating that trees making the greatest average annual growth produce the fastest growing seedlings (Jeffers 1969). All of the parents used in this study have been grafted and are established in breeding arboreta and clonal tests at the Institute.

Another study has shown that superior growth of selected individuals in the nursery at 4 years can be maintained for at least 7 years in the field (King *et al.* 1965). If the superior growth of progenies from selected fast-growing parents is maintained to rotation age, considerable increases in yield can be achieved and these increases will more than offset the added costs of seed collection.

Figure 4. — One-year-old white spruce planting in northern Wisconsin containing 90 open-pollinated, half-sib families from selected white spruce trees growing in the Lake States and Ontario, Canada.

Figure 5. — Field evaluation of 8-year-old grafted clones of selected early-and late-flushing white spruce. Late-flushing clones have been damaged less by late spring frosts and also have grown faster than early-flushing clones. The taller grafts are from a late-flushing clone and the shorter grafts are from an early-flushing clone.

Controlled pollinations were made in 1964 utilizing four female parents and six different pollen parents for a total of 24 full-sib (both parents known) families. In 1965, eight pollen parents were crossed with three additional females and seed was collected from 20 of these combinations. Therefore, the Institute has seed or seedlings of 44 full-sib families. By 1972, it is anticipated that this number will be increased to nearly 100 full-sib families. These families will then be used as breeding material in the further development of faster growing white spruce varieties.

A white spruce study was also initiated in 1962 to develop a variety that would be less susceptible to damage from late spring frosts. In a white spruce plantation near Rhinelander, it was noted that date of spring growth flush varied among individual trees by as much as 3 weeks. Nine early-flushing and 16 late-flushing individuals were selected, grafted, and established in a clonal planting near Lake Tomahawk, Wisconsin. Subsequent observation of these clones indicated that the late-flushing clones avoided damage from late spring frost, grew at a faster rate during a shorter growing season, and often ended up producing greater annual height growth than the early-flushing clones.

In 1967 pollen from early-flushing, late-flushing, and randomly selected individuals was crossed on 10 of the original and three additional selections (nine late-flushing and four early-flushing). The seedling progenies were grown for 1 year in the greenhouse and then moved into controlled environment rooms at the Institute. Flushing date and growth rate have been observed in the progeny, and flushing has been shown to be under strong genetic control (heritability estimates have reached $h^2 = 0.705$). It has been estimated that the risk of late spring frost under northern Wisconsin conditions might be reduced 40 to 50 percent (Nienstaedt and King 1969).

Heritability studies are also underway in Jack pine. These studies are discussed in detail in the next section.

DISEASE AND INSECT RESISTANCE BREEDING

The destructive effect of forest pests on timber production is well known. In 1962 it was estimated that 42 percent of the annual sawtimber mortality in the United States – about 2.4 billion cubic feet – was caused by insects and disease. The breeding of pest-resistant varieties of forest trees is one promising method of reducing losses from insects and disease.

Individual jack pine trees vary in susceptibility to a variety of insect and disease organisms, such as the white-pine weevil (*Pissodes strobi* (Peck)), red-headed pine sawfly (*Neodiprion lecontei* (Fitch)), needle rust (probably *Coleosporium asterum* (Diet.) Syd.), jack pine needle cast (*Hypodermella ampla* (Davis) Dearn.), bark beetles (*Pityophthorus* spp.), eastern pine-shoot borer (*Eucosma gloriola* Heinrich) and eastern gall rust (*Cronartium quercuum* (Berk.) Miyabe ex. Shirai) (King 1971, King and Nienstaedt 1965).

Jack pine needle cast, caused by the fungus *Hypodermella ampla* Dearn., causes defoliation of jack pine. Twenty-nine seed sources of jack pine in three plantings in Michigan's Upper Peninsula and northeastern and south-central Wisconsin were found to differ in susceptibility to the fungus. The differences remained constant from year to year and from environment to environment, indicating they have a direct genetic basis (King and Nienstaedt 1965).

The general approach in the study of pest resistance at the Institute is as follows: first, parents are selected from seed sources that have shown variation in pest incidence. This should insure genetic variation in the progenies. Occasionally, parents are selected from natural stands, but only where pest incidence has been severe enough to suggest that undamaged trees did not escape pest infestation by accident. Selection

Figure 6. – Destruction of current-year shoots in jack pine resulting from attack by the eastern pine shoot-borer, Eucosma gloriola. *Variation in jack pine susceptibility to this insect and several other pests appears to be related to seed source. Individual trees have been selected in seed source tests on the basis of white pine weevil and shoot-borer incidence, clonally propagated, and used in controlled pollinations to study inheritance of pest resistance in jack pine.*

Figure 7. – Controlled pollination in jack pine utilizing parents selected on the basis of susceptibility or resistance to the white pine weevil. Progenies produced from the pollinations will be used to study the inheritance of white pine weevil resistance.

of parents is followed by grafting to establish breeding arboreta. The parents are crossed with several pollen-tester parents to produce full-sib families. These families of progeny will then be tested for pest resistance, providing the basis for a new cycle of selections. As an example, controlled pollinations were made in 1968 and 1969 using 24 clones as female parents and six other trees as male parents. All were selected for their relative resistance or susceptibility to the white pine weevil. The crosses will yield 144 full-sib families with which to study the inheritance of variation in white-pine weevil resistance.

This approach has the following advantages: (1) it indicates the degree to which genetic pest resistance is transmitted through the seed parent and pollen parent (narrow-sense heritability), (2) it provides material for studying the underlying causes of resistance, and (3) it provides inheritance data on other economically important characteristics of jack pine.

Thus far 45 trees have been selected within nine seed sources on the basis of white-pine weevil and eastern pine-shoot borer incidence. In 1965 and 1966 the selected parents were grafted. The grafts are now located in a breeding arboretum near Lake Tomahawk, Wisconsin. Six additional trees have been selected for use as pollen parents and grafted in 1970.

Trees that were selected in the Institute's seed source studies for eastern pine-shoot borer inci-

Figure 8. — Exotic spruces in the Institute's spruce arboretum. The species being observed is Picea asperata *from China. At the left is* P. omorika *from Serbia in Yugoslavia, and in the right foreground is* P. glehnii *from Japan. Twenty-nine species of spruce are being tested at Rhinelander.*

dence were grafted in 1966, and the grafts were field-planted in 1968. These grafts will also be used in controlled pollinations as soon as they begin to bear female strobili.

As indicated previously, not all selections are made in seed source test plantations. In 1961 a severe outbreak of jack-pine budworm (*Choristoneura pinus* Freeman) occurred in Douglas County, Wisconsin. In some of the infested stands a few undamaged survivors remained. In the fall of 1961 open-pollinated seed was collected from 10 undamaged trees and one severely defoliated tree. In February 1966 the 10 selected trees were grafted and the successful grafts were field-planted in 1968 at our breeding arboretum near Lake Tomahawk, Wisconsin.

Similarly, 13 trees were selected for studies of pine tortoise scale (*Toumeyella numismaticum* (Pettit and McD.) in a Polk County, Wisconsin, jack pine plantation severely attacked between 1959 and 1961. The selections were grafted in 1966 and the grafts field-planted in 1968.

THE INSTITUTE ARBORETUM

The introduction of exotic tree species is usually a part of any complete forest genetics program. Introduced species will sometimes grow faster and straighter or produce more wood than the species native to the area. Some of these adapted species serve a purpose in forest economics not readily served by a native species.

The Institute not only tests exotic species for their adaptability to this area, but studies hybridization between exotic and native species. The role of interspecific hybridization in tree improvement is discussed in the next section. To facilitate hybridization and other phases of the Institute program, substantial collections of exotic *Betula* and *Picea* species have been assembled at or near the Institute (tables 1 and 2). The

Table 1.—Exotic Betula *species and varieties in tests at or near the Institute of Forest Genetics*

Species and variety	Seedlings	Grafts
Subsection Acuminatae:		
Betula maximowicziana Reg.		X
Subsection Costatae:		
B. albo-sinensis var. septentrionalis Schneid.		X
B. delavayi Franch.		X
B. ermani Cham.	X	X
B. ermani var. subcordata (Reg.) Koidz.		X
B. forrestii (W. W. Sim.) Hand.-Mazz.		X
B. grossa Sieb. & Zucc.	X	
B. lenta L.	X	X
B. nigra L.	X	X
B. raddeana Trautv.		X
Subsection Albae:		
B. cordifolia Reg.	X	
B. davurica Pall.		X
B. minor (Tuckerm.) Fern.	X	
B. obscura Kot.	X	
B. occidentalis Hook.	X	
B. pendula Roth	X	X
B. pendula var. dalecarlia (L.) Schneid.		X
B. pendula var. fastigiata (Clemenceau) K. Koch		X
B. pendula var. gracilis Rehd.		X
B. pendula var. purpurea (Andre) Schneid.		X
B. pendula var. tristis (Beiss.) Schneid.		X
B. pendula var. youngii (Th. Moore) Schneid.		X
B. platyphylla var. japonica (Miq.) Hara	X	
B. populifolia Marsh.	X	X
B..pubescens Ehrh.	X	X
B. pubescens var. urticifolia (Loud.) Schelle		X
B. pubescens forma aurea		X
B. tortuosa (Ledeb.) Schneid.	X	
B. turkestanica Litvin.		X
Subsection Nanae:		
B. glandulosa Michx.	X	X
B. humilis Schrank		X
B. nana L.	X	X
B. ovalifolia Rupr.	X	
B. pumila var. glandulifera Reg.	X	X
B. tatewakiana Ohki & Watanabe	X	
Natural hybrids:		
B. x jackii Schneid.		X
B. x purpusii Schneid.		X
B. x sandbergii Britt.		X

Table 2. — Exotic Picea *species and varieties in tests at or near the Institute of Forest Genetics*

Species and variety	Seedlings	Grafts
Subsection Eupicea:		
Picea abies (L.) Karst	X	X
P. abies cv. acrocona (Fries) Krü.		X
P. abies var. viminalis (Alstroem) Fries		X
P. asperata Mast.	X	X
P. bicolor (Maxim.) Mayr.	X	X
P. bicolor var. acicularis Shiras. and Koyama	X	
P. glauca var. albertiana (densata) (S. Brown) Sarg.	X	
P. glehnii (Fr. Schmidt) Mast.	X	X
P. koyamai (koraiensis) Shiras.	X	X
P. maximowiczii Reg.	X	
P. obovata Ledeb.	X	
P. orientalis (L.) Link	X	X
P. polita (Sieb. and Zucc.) Carr.	X	X
P. retroflexa Mast.		X
P. rubens Sarg.	X	
P. schrenkiana Fisch. and Mey.	X	X
P. smithiana Boiss.	X	
P. wilsonii Mast.	X	
Subsection Casicta:		
P. engelmannii Parry	X	
P. jezoensis (Sieb. and Zucc.) Carr.	X	X
P. jezoensis var. hondoensis (Mayr.) Rehd.	X	
P. likiangensis var. balfouriana (Rehd. and Wils.) Cheng		X
P. montigena Mast.		X
P. pungens Engelm.	X	
P. purpurea Mast.		X
P. sitchensis (Bong.) Carr.	X	
Subsection Omorika:		
P. breweriana S. Wats.	X	
P. omorika (Pancic) Purkyne	X	X
P. spinulosa (Griff.) Henry	X	
Taxonomic status not known:		
P. chihuahuana Martinez	X	
P. mexicana Martinez	X	X
P. morrisonicola Hayata	X	

birch collections represent 26 species from four subsections of the genus, nine named varieties of these species, and three natural hybrids. European, Asian, and North American species are represented. Also included are the four species native to northern Wisconsin. Twenty-seven species of spruce and five named varieties have been assembled. Two species native to northern Wisconsin are included in the collection.

To develop successful hybrids both parents much be at least reasonably well-adapted to the climate where the hybrids are to be grown. Hybrids between California lodgepole pine and Wisconsin jack pine, for instance, are a total failure in the Lake States (Rudolph and Nienstaedt 1962). Hybrids between *Pinus monticola* and *P. strobus* have also shown poor adaptation.

To find exotic species able to survive and grow at least moderately well in the severe climate of northern Wisconsin, small-scale seed source studies have been initiated, particularly in spruce. The species involved are *Picea engelmannii, P. rubens, P. omorika, P. orientalis,* and *P. jezoensis.* Large scale tests of *P. abies* have been started more recently. Grafted trees established with scions from mature trees cannot be used to evaluate climatic adaptation. For example, young *Picea omorika* seedlings at Rhinelander suffer severely from winter drying, while grafts with the needle structure of mature trees suffer little or no injury. The time of flushing becomes later with age. Grafts of scions from mature trees will, therefore, show less spring frost injury than seedlings.

INTERSPECIFIC HYBRIDIZATION

Species hybridization has played a major role in tree improvement. Hybrid poplar and larch have been widely used and are favored by forest managers in many parts of the world. The efforts to produce new hybrids involving species in many genera continue. In the following pages, our studies of species crossability in the genera *Picea* and *Betula* will be discussed.

The objectives have been (1) to determine if (or how well) the species within each genus cross with one another and (2) to determine the evolutionary relations among the species. This objective is based on the theory that closely related species generally will cross more readily than those more distantly related.

Spruce Hybridization

Fifty-two combinations of spruce species have been attempated (table 3). Eight species, of which three are North American, were used as female parents, and 15 were used as male parents. Two of the taxonomic subsections – *Eupicea* and *Omorika* – were represented by the species used as females. The third subsection – *Casicta* – was represented among the males.

Twenty-seven crosses produced seedlings. Of these, 12 were crosses between species in the subsection *Eupicea*, six involved species in *Eupicea* and *Omorika*, and nine were crosses between subsections *Eupicea* and *Casicta*. One attempted cross between *P. omorika* subsection *Omorika*) and *P. likiangensis* (subsection *Casictoa*) failed.

Ten of the successful crosses, as far as we know, have not been reported in the literature. Many of these have yielded only a few seedlings and we have not been able to design adequate tests that would enable us to verify hybridity. Of the six crosses for which replicated tests could be made, the following four appear to be verified hybrids: *P. glauca* x *P. maximowiczii*, *P. omorika* x *P. glauca*, *P. mariana* x *P. abies*, and *P. mariana* x *P. pungens*. Two crosses – *P. glauca* x *P. abies* and *P. mariana* x *P. montigena* – are doubtful hybrids; they show significant differences in a few characteristics, but cannot be established as hybrids with certainty.

Table 3. – Crossing patterns in the genus Picea, *IFG crosses 1956-1966*

Female parent	Male parent															Total	No. of combinations	Comb.-seedlings
	Eupicea									Casicta					Omorika			
	abies	asperata	glauca	koyamai	mariana	maximowiczii	orientalis	retroflexa	schrenkiana	jezoensis	likiangensis	montigena	pungens	sitchensis	omorika			
Eupicea abies		5 3 ?	2 0				1 0				2 1 ?				2 0	12 4	5	2
asperata	3 2		1 0								1 0				1 0	6 2	4	1
glauca	15 5 ?	12 3 +		3 0		6 1 N +	9 2	2 1 N	5 1	6 2 +	1 1 N +	12 7 N	6 4	4 4 +	14 3 N +	95 34	13	12
koyamai		3 2	9 0		1 0		1 0				1 1 N				1 0	16 3	6	2
mariana	4 2 N +	4 0	4 0				4 0					3 1 N ?	2 1 N +		2 2 +	23 6	7	4
orientalis	1 1	2 0	1 0		1 0						1 0					6 1	5	1
rubens		4 0	1 0		6 0		2 1		6 0						2 1	21 2	6	2
Omorika omorika	1 1 N	2 0	8 4 +		3 1 +				1 0		2 0					17 6	6	3
Total	24 11	32 8	26 4	3 0	11 1	6 1	17 3	2 1	12 1	6 2	8 3	15 8	8 5	4 4	22 6	196 58		
No. of combinations	5	7	7	1	4	1	5	1	3	1	6	2	2	1	6		52	
Comb.-Seedlings	5	3	1	0	1	1	2	1	1	1	3	2	2	1	3			27

Number of attempts. → 3 ← Attempts resulting in seedlings. (1)
N ← Combination not previously reported.
Hybridity of seedlings substantiated. → + ? ← Hybridity of seedlings not fully substantiated.

Figure 9. – One of two promising spruce hybrids produced at the Institute, a cross between black spruce and Serbian spruce from Yugoslavia, is indicated by the arrows on the right. At 8 years of age from seed the total height growth of the hybrid exceeded that of the native parent species (arrows on the left) by 20 percent.

Two crosses are particularly interesting from a tree improvement standpoint. In 1959 we crossed *P. mariana* growing near the Institute with *P. omorika* of unknown origin growing at the Morton Arboretum, Lisle, Illinois. In 1968 when the resulting trees were 8 years old from seed, their average heights were:

P. mariana x *P. omorika*	2.50 m.
P. omorika x *P. mariana*	2.21 m.
P. mariana control	1.99 m.

P. mariana x *P. omorika* exceeded the native parent species by 20 percent and is a well-formed, promising tree. The reciprocal cross, *P. omorika* x *P. mariana*, is taller than the native black spruce, but is variable and some trees have poor form.

The *P. omorika* x *P. glauca* cross was made in 1964. Seedlings were forced in the greenhouse in 1966 and planted in the nursery in 1967. In the fall of 1968 they measured:

P. glauca	204 mm.
P. omorika x *P. glauca*	286 mm.
P. omorika x *P. glauca*	228 mm.
P. omorika x *P. glauca*	278 mm.
P. omorika x *P. omorika*	237 mm.

Thus, the best hybrid was 40 percent taller than the native parent; furthermore, while *P. omorika* was susceptible to frost injury in the fall, the hybrid showed little injury. The injury percentages were as follows:

	P. glauca	*P. omorika* x *P. glauca*	*P. omorika* x *P. omorika*
Normal top development	71.2	61.8	8.3
Dead terminal	.0	4.4	85.0
Lateral shoot in dominant position	28.8	33.8	6.7

Additional crosses and studies of the hybrids are necessary before results can begin to shed any light on the evolutionary history of the genus *Picea*. In the meantime, two promising hybrids have been developed. They will be repeated using selected *P. glauca*, *P. mariana*, and *P. omorika* parent trees.

Birch Hybridization

To study compatibility in *Betula*, crosses have been made among 12 birch species belonging to three subsections of the genus (table 4). Seven species are North American and five are exotic. In all, 110 interspecific combinations were attempted between 1962 and 1968. Each combination has been repeated several times, bringing the total number of attempts to 423 and individual crosses to about 900.

Crossability has been verified for 20 of the 28 combinations reported in the literature; only six attempted combinations were unsuccessful. An additional 84 new combinations were attempted and some degree of success was reached in 50 of these. Because many of the crosses produced only a few seedlings, we have not been able to verify hybridity of these. Most crosses are now being studied to determine which have yielded true hybrids.

B. nigra, *B. ermani*, and *B. papyrifera* were generally more successful as female parents than they were as male parents. On the other hand, *B. lenta*, *B. pendula*, *B. pubescens* and *B. pumila* performed better as male parents. Three species, *B. alleghaniensis*, *B. populifolia*, and *B. glandulosa*, were equally successful as female or male parents.

Table 4. — Crossing patterns in the genus Betula, *IFG crosses 1962-1968*

Female parent species and ploidy	Male parent* Costatae nig 2X	len 2X	erm 4X	all 6X	Albae pen 2X	pop 2X	pub 4X	pap 4-6X	Nanae gla 2X	hum 2X	nan 2X	pum 4X	Number of attempts Total	Succ.	Number of combinations Total	Succ.
Costatae																
nigra 2X		6 2 N	7 5 N	11 1 N	15 9 N	9 2 N	7 3 N	15 1 N	5 1 N	1 0		5 1 N	81	25	10	9
lenta 2X	3 0			1 1	4 0	2 0	1 0	2 0					13	1	6	1
ermani 4X	10 2 N	8 2 N		5 0	9 4 N	2 1 N	5 4 N	3 1 N	3 0	2 2 N	1 0	6 5 N	54	21	11	8
alleghaniensis 6X	12 1 N	4 1	2 1 N		6 0	4 1 N	1 1 N	9 4	3 1 N			2 1	43	11	9	8
Albae																
pendula 2X	9 1 N	3 0		3 1		6 1 N	6 0	10 4	1 0			2 1	40	8	8	5
populifolia 2X	3 1 N	3 1	3 1 N	1 1 N	3 2 N		3 1 N	2 1	1 1 N			2 2 N	21	11	9	9
pubescens 4X	2 1 N	1 0		1 1	2 1	5 1 N		2 1	2 1 N	1 0		1 1 N	17	7	9	7
papyrifera 4-6X	7 5	5 2	3 1 N	7 5	4 3	4 1	3 2		3 0			3 1	39	20	9	8
Nanae																
glandulosa 2X	8 0		1 0	3 0	7 0	7 0	4 2 N	7 0			1 0	2 0	40	2	9	1
humilis 2X	2 0	1 0	1 1 N	2 1 N	2 0	2 0	2 1 N	2 1 N	2 0			1 0	17	4	10	4
nana 2X	3 1 N	1 0	2 0	1 0	2 0	3 1 N	2 1 N	3 0	3 1 N			2 0	22	4	10	4
pumila 4X	7 0	3 0	2 1 N	5 0	3 1 N	4 1 N	5 1 N	3 1	3 0	1 1 N			36	6	10	6
Attempts																
Total	66	35	21	40	57	48	39	58	26	5	2	26	423			
Successful	12	8	10	11	20	9	16	14	5	3	0	12		120		
Combinations																
Total	11	10	8	11	11	11	11	11	10	4	2	10			110	
Successful	7	5	6	7	6	8	9	8	5	2	0	7				70

*Names of species used as male parents are abbreviated but listed in the same order as under female species.

Key to cells: Number of attempts → 3 1 ← Number of successful attempts. N ← Combination not previously reported.

Species belonging to the same subsection presumably are more closely related to each other than to members of other subsections, so one might expect greater crossability within than between subsections. So far, this does not appear to be the case in *Betula*. Crosses with *Costatae* as female parents and *Albae* as male parents were generally more successful than crosses within either *Costatae* or *Albae*. Similarly, crosses within *Nanae* were less successful than crosses between female *Nanae* and male *Albae*.

The birches represent a polyploid series with chromosome numbers ranging from $2n = 28$ (diploid) to $2n = 84$ (hexaploid). Results indicate that in interspecific crosses between parents of similar ploidy, crossability appears to increase with increasing ploidy, as it does in certain other plant genera; e.g., *Solanum*.

Early evidence indicated that crosses between low ploidy females and high ploidy males were most successful (Clausen 1966). Although there are exceptions, this appears to be a general pattern in *Betula*.

Differences between reciprocal crosses are common. Seed from the cross *B. ermani* x *B. pumila* had 75 percent germination, while the riciprocal cross produced few germinable seed; both species have the same sumber of chromosomes. In most cases, the difference in success of reciprocal crosses appears to be due to differences in ploidy levels of the parents. The success of crosses has also been shown to vary with the individual trees used as parents (Clausen 1966). Apparently interspecific compatibilities depend not only on the species themselves, but also on the compatibility of the individuals involved in the cross.

RADIATION GENETICS AND RADIOBIOLOGY

Radiation resulting from fallout and natural background sources is of particular concern to the forester. Because of their longevity, trees may be continuously exposed to low-level radiation over many decades. It has been estimated that in forest trees, the natural background radiation may be responsible for 40 to 50 percent of all genetic changes that occur. Also, the threat of whole forests being exposed to high dosages of ionizing radiation from nuclear disasters makes knowledge of the biological effects of radiation on forest trees important. From a more practical viewpoint, radiation can be used to induce genetic changes. As such, it is potentially a valuable tool (1) in producing marker genes for basic tree genetic studies and (2) in producing additional variability for tree improvement programs of species with limited natural variation.

It is within this frame of reference that the Institute of Forest Genetics at Rhinelander was assigned responsibility for radiation research within the Forest Service. The broad, long-term objectives of the project are as follows:

1. The fundamental study of acute and chronic gamma irradiation effects on forest trees.
2. The development of radiation as a possible tool in genetic studies of forest trees.
3. A comparison of the responses of trees to gamma radiation with responses to other types of radiation and chemical mutagens.
4. The induction of mutations useful in a tree improvement program.

Figure 10. — Gamma field radiation source support and operating mechanism. The radioactive source capsule, containing 1,500 curies of Cesium ^{137}, is elevated in the tube to a position just below the sky shield to irradiate tree seedlings planted in the area around the source.

Figure 11. — Plots of various tree species are arranged in arcs around the gamma source.

For this research, two major sources of gamma radiation were installed in 1965. The first is a 6.5-acre gamma radiation field in which a 1,500 curie source of Cesium 137 (^{137}Cs) is exposed in the center for 20 hours each day from about April 15 to October 15 each year. The other is a self-contained gamma irradiator containing 260 curies of ^{137}Cs used for irradiation of seeds, pollen, small seedlings, and cuttings.

Some radiation research was conducted by the North Central Forest Experiment Station as early as 1951, when jack pine seed was irradiated with 1,000 and 4,000 Roentgens (R) of X-rays.[1] The response to the X-rays was tested under nursery conditions and in the field. At 4,000 R no seedlings survived beyond 1 year of age. At 1,000 R seedling survival was approximately 30 percent of control survival after 2 years. The LD_{50} (the exposure resulting in 50-percent mortality) decreased as the seedlings aged – 2,025 R at 40 days, 1,710 R at 130 days, and 700 R at 14 months. Irradiated jack pine also showed a low reproductive capacity – about 10 percent after cross-pollination, and less than 5 percent after self-pollination. Thus, the effects of seed irradiation in jack pine, and probably other conifers, cannot be fully evaluated in the first generation – at least two generations are required (Rudolph 1967).

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[1] *This work was done in cooperation with Dr. Scott S. Pauley (now deceased), who then was on the staff of the Maria Moors Cabot Foundation for Botanical Research at Harvard University.*

The jack pine seed X-irradiation studies have resulted in some additional important findings. More than 30 trees carrying genes for chlorophyll deficiencies and other genetic markers were discovered. Genetic segregation ratios were determined for these easily identifiable characteristics (Rudolph 1966a), and the parent trees are now being studied further to more fully assess their usefulness in modes of inheritance and other basic genetic studies.

Much of the radiation research thus far has been devoted to studying the relative radiosensitivity of gymnosperm seeds and seedlings. Soaked seeds of eastern larch, Norway spruce, white spruce, black spruce, red pine, jack pine, lodgepole pine, Scotch pine, and northern white-cedar were irradiated with ^{137}Cs gamma rays in two experiments at exposures ranging from 150 to 38,400 R. Seed radiosensitivity varied among species by a factor of more than four. Norway spruce, white spruce, and Scotch pine were the most sensitive species, and jack pine the most resistant. The average LD_{50} exposure for all endpoints studied varied between 2,300 R for the most sensitive species to 10,500 R for the most resistant. The more than fourfold differences in seed radiosensitivity were found to be unrelated to differences in nuclear volume, chromosome volume, and DNA (deoxyribonucleic acid) content of these species. The seed sensitivity pattern showed no relation to predicted seedling and mature plant sensitivities for the same species (Rudolph and Miksche 1970).

Relative radiosensitivity of gymnosperm seedlings was studied in seven species: eastern larch, white spruce, black spruce, jack pine, lodgepole pine, red pine, and northern white-cedar. The seedlings were irradiated when the seedcoats were shed on half of the seedlings. Gamma ray exposures ranged from 150 to 3,600 R. Shoot dry weight 50 days after treatment showed the greatest radiosensitivity, with a D_{50} (50 inhibition exposure) ranging from 195 to 380 R for the seven species. The number of leaves at 50 days and survival and shoot dry weight at 130 days had consistently higher D_{50} exposures, ranging from 400 to 750 R. Seedling and seed radiosensitivity in the same populations were not closely correlated, nor was seedling sensitivity related to predicted mature plant sensitivity. Seedling sensitivity was, however, related to

DNA content but not to other nuclear variables. These results further point out the variation in radiosensitivity among stages of the gymnosperm life cycle (Rudolph 1971).

A preliminary study showed that white spruce pollen irradiated with gamma ray exposures up to 800 R and applied to nonirradiated female strobili stimulated seed yield (Rudolph 1965). A followup study that included pollen exposed to 16 levels of gamma radiation showed that viable seed yield apparently was stimulated at pollen exposures below 1,500 R. However, a significant decrease in yield of filled seed was noted at pollen exposures above 3,000 R. The yield of filled seed and seed viability indicated an LD_{50} ranging between 4,500 and 9,500 R for the three pollen lots studied. This contrasts with an average LD_{50} of 400 R for white spruce seedlings and about 2,500 R for seed. Less than 1 percent of the seed produced was filled and viable at the 19,200 R exposure, and none was filled or viable with pollen exposed to 28,800 R (Rudolph 1969). Thus, a total lethal dose for white spruce pollen appears to be about 20,000 R.

The radiation research at the Institute is currently being expanded to include a comprehensive study of the response of natural northern forest communities to gamma radiation. The new research will include studies ranging from cell biology to general forest ecology. The program will include several seasonal exposures of northern forest communities as well as one long period of chronic irradiation. Support will be provided by the Atomic Energy Commission and the USDA Forest Service. In addition, a wide variety of research in the project will be undertaken by university cooperators.

VEGETATIVE PROPAGATION RESEARCH

Vegetative propagation (propagation of a plant by asexual means) provides a way to maintain the genetic identity of an individual. It has, therefore, found wide use in forest tree improvement work. The techniques are used for preserving and multiplying valuable tree germ plasm, in analyzing inheritance, establishing breeding arboreta and seed orchards, and in various research projects where it is desirable to use clonal material.

Research at the Institute includes (1) basic studies of the physiology of root initiation and differentiation, (2) production of plantlets through rooting of cuttings, and (3) improvement of grafting techniques.

Rooting Research

Vegetive reproduction of forest trees from cuttings would simplify production of clones for tree breeding and forest genetics research. However, this is still impractical because cuttings of many desired species (particularly older trees) do not root easily enough. To gain an understanding of the physiology of adventitious root initiation, basic studies of root formation on cuttings were initiated. Hormonal control of root initiation, the action of indole-3-acetic acid, benzyladenine, and gibberellic acid in particular, is under study. A dual approach is being used in studying the regulation of nucleic acid and protein metabolism at the cellular level in adventitious root initials: (1) semiquantitative histochemical and cytochemical techniques, such as microautoradiography, and (2) quantitative biochemical analyses of tissues from cuttings in various stages of root initiation. This approach will be continued until a clearer understanding of the hormonal control of adventitious root initiation has been obtained. With this new knowledge we hope to be able to develop economic and efficient rooting techniques.

Production of Plantlets by Rooting of Needle Fascicles

In 1960 a study was initiated to develop jack pine plants by rooting needle fascicles. The terminal buds were removed on 2- and 5-year-old jack pine seedlings in early July at about the time elongation had ceased. By September, buds had developed in many of the needle fascicles. The needle bundles were treated with 0.1 percent and 0.8 percent indole butyric acid (IBA), and placed in a sand medium. Best rooting — 70 percent — was on fascicles from 2-year-old plants when propagated under 20-hour photoperiods in a heated rooting medium, and treated with 0.1 percent IBA. Fascicles from the older plants and those receiving other treatments gave poorer results. Fascicles without large preformed buds fail to form shoots although they may form roots (Rudolph and Nienstaedt 1964).

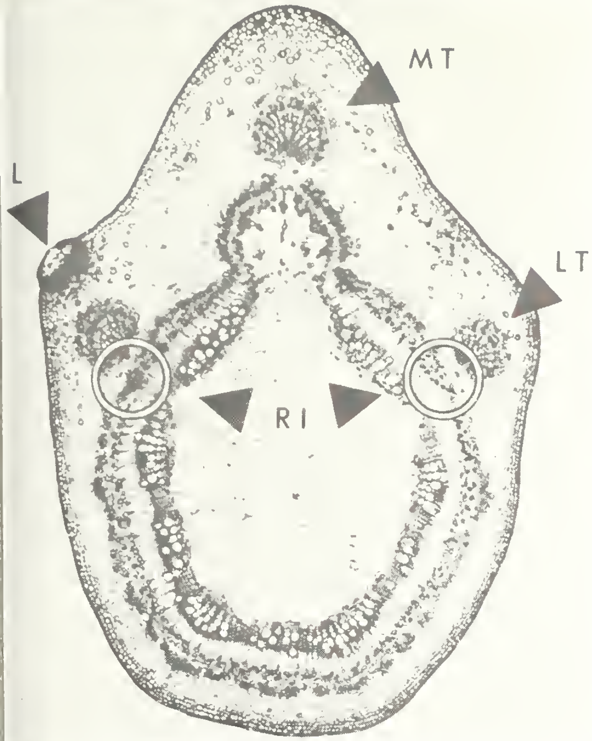

Figure 12. — Transverse section through a node of brittle willow showing the proximity of developing lenticel (L), lateral leaf trace (LT), medium leaf trace (MT), and root initials (RI). Brittle willow has been used to study adventitious root initiation because root primordia always develop at specified locations.

The results of this study showed that jack pine plants can be propagated successfully from rooted needle fascicles provided the fascicles are taken from young plants and possess well-developed buds before they are placed in the rooting medium. The ability to propagate individual trees by rooting needle fascicles provides a useful technique for isolating somatic mutations in studies concerned with induced mutations.

Grafting Research

Standard grafting techniques (Nienstaedt *et al.* 1958) work well with spruce, pine, fir, and birch. Side grafting on potted root stock, forced in the greenhouse in late winter and early spring, will give excellent results for most species. Research at the Institute has, therefore, been concentrated on developing methods for extending the grafting season.

Greenhouse grafting can be performed successfully in September on potted stock using standard grafting techniques; the grafts are maintained on long-day photoperiods for 4 to 6 weeks after grafting, then transferred to short-day conditions for a few weeks, and finally to cold storage for 6 to 8 weeks of chilling (Nienstaedt (1959c). Exposure to 40° F. during this period fulfills chilling requirements. The plants can then be returned to the greenhouse where they will start growing in 3 to 5 weeks.

In the field, best results have been obtained from the middle of May to the first week in June, with grafting near the base of the previous year's leader. The best time is just when the bud scales break, before any substantial elongation of the new shoots has taken place. Small tests in the nursery on 6- to 7-year-old plants have demonstrated that earlier grafting is possible. We grafted as early as the last week of March and until the first week of May with good results. The survival ranged from 90 to 100 percent, and subsequent growth was excellent.

Grafting on potted root stock in an open lathhouse has been successful as early as the last week of March. Success was 80 to 90 percent about the middle of April. Grafting did not become unsatisfactory until the scions began to show activity.

Another field study has shown that scion material from 30- and 60-year-old trees can be grafted successfully from the middle to the end of July. The grafts were made at the base of the leader on 8-year-old plantation-grown trees. Near the end of the third summer after grafting, survival for the 30- and 60-year-old scion material was 63 and 50 percent for grafts made on July 17, 33 and 30 percent for grafts made on July 31, and 13 and 27 percent for those made on August 14. All grafts done after August 14 failed completely (Nienstaedt 1965b).

CELL BIOLOGY

The cell biology program is relatively new at the Institute of Forest Genetics. As a field of study, it is essentially an extension of cytology that developed from the convergence of cytology with other fields of biological research, particularly genetics, physiology, and biochemistry. The investigation of the cell as the primary unit of biological organization is the objective of cell biology, as it is with cytology, but the problems of the cell are approached at all levels of organization from molecular structure to cellular differentiation.

Examples of research that fall within the general objectives are: physical and chemical aspects of cellular and intercellular structure, biosynthesis with reference to cell growth, reproduction and differentiation, mechanism of meiosis and mitosis, cell cycles, membrane function, interactions between cells in tissues or in culture, environmental relations and adaptations, interactions between genome and cytoplasmic factors, functional role of subcellular particles, and regulation of cellular processes.

Some results of the cell biology program are described in the following pages.

Cycle Time

Cycle time is defined as the time necessary for a cell to begin and terminate nuclear division. The cycle time of a forest tree species is important to the researcher because the time required for a cell to divide has a direct bearing upon growth rate. The cycle time is also an important factor in determining the plant radiosensitivity.

There are several stages during a cycle of cell division: G_1 (resting), S (DNA synthesis), G_2 (resting), and mitosis. The quantity of DNA (deoxyribonucleic acid) doubles during the course of division and the levels are notated by 2C, intermediate, and 4C amounts, corresponding to G_1, S, and G_2, respectively.

Using seeds of a northeastern Wisconsin seed source, the miotic cycle time of jack pine (*Pinus banksiana*) was determined with the use of tritiated thymidine as a labeled DNA precursor. The extent of the labeling was determined using liquid emulsion autoradiography. Beta particles emitted from the tritiated thymidine reduce the silver grains of the photographic emulsion. The number of labeled cells (prophase stage) scored, when plotted over a time course, yields the cycle time. The estimated duration of the mitotic cycle of *Pinus banksiana* was 25.7 hours. The time intervals of interphase were found to be: G_1, 15.3; S, 7.6; and G_2, 1.4 hours (Miksche 1967b).

The most important finding was the long G_1 period of 15.3 hours. This may be an important factor related to the high radiosensitivity of gymnosperms. Cells in G_1 (interphase) yield chromosome type aberrations that ultimately result in a greater loss of genetic material than losses due to chromatid aberrations originating in late S or G_2 phases.

Figure 13. — Jack pine chromosomes observed during the prenuclear stage in ovule development. Twelve chromosomes are visable on each side of the anaphase figure shown here. Apparent bands on some chromosomes are artifacts produced during slide preparation.

Physical and Chemical Aspects of Cellular and Intercellular Structure

Experiments were conducted to determine the variation in nuclear volume and DNA per cell among 13 coniferous species. We also determined the correlation between nuclear volume and DNA, and tried to establish a relationship between these factors and the distribution of the species.

Feulgen microspectrophotometry and biochemical analysis were used to estimate the amount of DNA per cell. Prepared slides were also used to measure the nuclear volumes of root meristems. Nuclear volume among the 13 species varied by a factor of 11.3, while DNA per cell varied by a factor of 3.2. The correlation between absolute amounts and cytophotometric estimation of DNA and nuclear volume was high, with a correlation coefficient of 0.81. The large amounts of DNA per cell compared with most dicotyledons suggests that conifers contain an excess of DNA because it is highly unlikely that conifers contain more genetic information than other plants

Nuclear size (and DNA per cell) may have an adaptive value in the ecological sense. In the species studied, those with small nuclear volumes tended to have a wider distribution (Miksche 1967a).

The response of white spruce shoot apices to chronic gamma irradiation has been investigated (Cecich and Miksche 1970). It was found that the volume of the apical initial and central mother cell zones changed during the growing season. Apices were extremely radiosensitive when these zones were the largest in size.

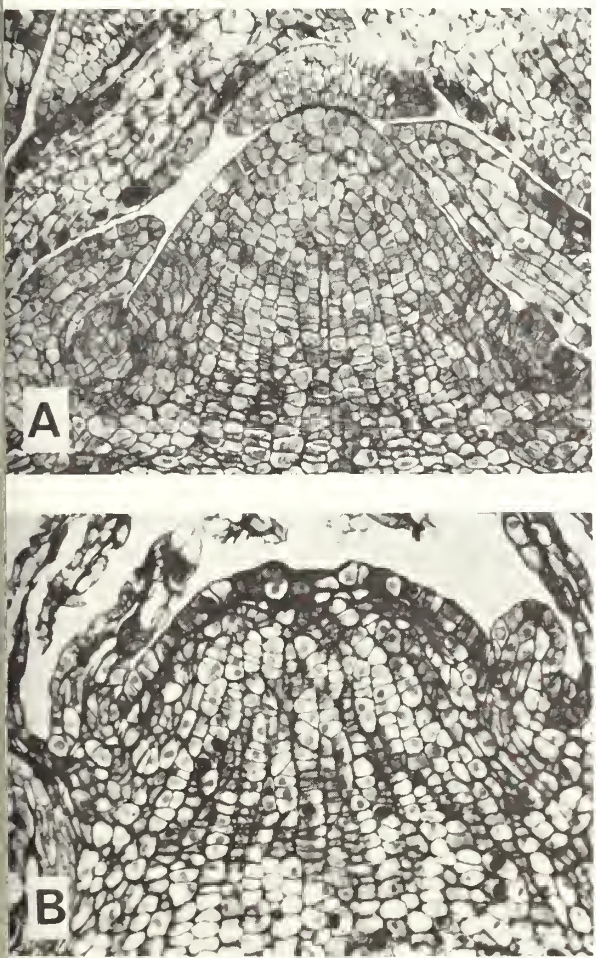

Figure 14. — Response of white spruce shoot apices to chronic gamma irradiation: (A) cone-shaped apex of nonirradiated white spruce during early July; (B) indented apex — a typical response after exposure to 15 and 30 Roentgens of Cesium ^{137}/20-hour date during late June and early July.

Environmental Relations and Adaptation

A study was conducted to determine the amount of intraspecific variation in DNA per cell among different seed sources of jack pine (*Pinus banksiana*) and white spruce (*Picea glauca*). The amount of DNA per cell was established chemically and cytophotometrically for 17 seed sources of *P. glauca* and cytophotometrically for 11 sources of *P. banksiana*. The DNA Feulgen absorption per cell varied from the lowest to the highest amount by factors of 1.6 and 1.5 for *P. glauca* and *P. banksiana*, respectively. Intraspecific variation of histone was similar to the observed DNA variation. There was also a significant positive correlation between the amount of DNA and the nuclear volume within species.

A regression analysis between DNA per cell and latitude showed that *Picea glauca* has eastern and western populations series.

Another objective of the study was to determine the relationship between DNA per cell and the growth rate in white spruce. Measurements of taxonomic characteristics have suggested that eastern sources are different from western sources. The study of the relationship between DNA and height growth gave similar results. Seedling height in the western provenances varied inversely with DNA content; that is, seedlings from seed sources with low DNA per cell displayed greater growth. The eastern sources did not display the inverse relationship between DNA amount and 2-year growth (Miksche 1968a).

Differentiation and Metabolic Activity in the Apical Meristem of Sugar Pine

Germinating seeds and seedlings were used to determine the relative metabolic activities of the different regions in the vegetative shoot of sugar pine (*Pinus lambertiana*) (Fosket and Miksche 1966a).[2] Seedlings were selected for morphological examination and histochemical study at 5, 8, 10, 13, and 16 days after planting. At 5 days the shoot apical meristem consisted of a relatively

[2] *Research carried out at Brookhaven National Laboratory under the direction of the U.S. Atomic Energy Commission. Paper published after Miksche was employed by the North Central Forest Experiment Station.*

homogeneous population of cells. After 8 days, four distinct cytohistological zones could be recognized: (1) the apical initial zone, (2) the central mother cell zone, (3) the peripheral zone, and (4) the rib meristem. Needle primordia were also evident at this time.

The pattern of histochemical staining for acid phosphatase (AP) activity was closely correlated with the development of the cytohistological zones in the apex. By the fifth day after planting, AP activity was relatively more intense in the potential apical initial and central mother cell zones than in the other two potential zones. After 8 days, when cytohistological zonation was evident, the pattern of AP activity was reversed; the most intense activity was noted in the peripheral zone, but almost no activity was observed in the apical initial zone and the central mother cell zone. The apical meristem of the 16-day-old seedlings exhibited high AP activity in the peripheral zone only during the early stages of needle primordia initiation.

The distribution of cytoplasmic and nuclear protein-bound sulfhydryl (SH) groups and succinic dehydrogenase (SD) activity were also closely correlated with cytohistological zonation. At 5 days protein-bound SH was distributed rather uniformly and SD activity was observed throughout the apex. By the eighth day, the four zones contained differential quantities of protein-bound SH, and the apical initial and central mother cell zones exhibited differentially greater levels of SD activity.

TREE IMPROVEMENT STUDIES

Purpose of Tree Improvement Research

The application of forest genetics in practical forestry is accomplished by planting genetically improved nursery stock in the forest. Trees in future forests will be faster growing, of better quality for specific end products, and will utilize the sites on which they are planted much more effectively than do most trees in present stands.

The results of many studies reported here, such as seed source studies, can be applied immediately by the managing forester, nurseryman or tree-improvement forester. The studies of heritability, compatibility, and vegetative propagation, however, need to be interpreted and enlarged in order to become usable. The Institute's tree improvement program is oriented toward this objective.

Seed Collection Zones

The use of the proper seed source was interpreted by P. O. Rudolf in 1959. He proposed seed collection zones based on: (1) a summation of normal average daily temperature per year above 50° F. ("growth degrees"), and (2) mean January temperatures (Rudolf 1959a). Twenty-year growth of 119 red pine seed sources and individual tree progenies substantiated his proposed seed collection zones.

Individual Tree Selection

In any forest stand individual trees vary considerably as to growth rate, crown size, branch angle, and resistance to insects and diseases. Until the progenies of a tree are evaluated for these traits, it cannot be ascertained whether the traits can be transmitted. However, as shown by the white spruce and jack pine studies described previously, many traits are under strong genetic control and the nurseryman should collect seed from superior individuals.

In addition to securing seed from selected trees, scions can be collected from them and grafted to rootstock of the same species, and the graftings set out in seed orchards. The trees in the seed orchard that are contributing favorable characteristics to the next generation can be determined by making crosses, and the poorest trees can be rogued out.

Several selection guides have been produced at the Institute describing traits that are probably under strong genetic control in economically important species. A guide for 11 Lake States species was developed first (Rudolf 1956b), followed by a guide for 17 shelterbelt species (Dawson and Read 1964), and later by a guide for the selection of superior phenotypes of yellow birch (Clausen and Godman 1967).

Selection can also take place in nursery beds. Clausen (1963c) found that the size of plants of *Betula pubescens* and *B. pendula*, after 9 years in the field, was directly related to the initial size of nursery stock. Height and diameter of the trees still reflected the original classification into large, medium, and small seedlings. Similarly, King *et al.* (1965) found that white spruce eedlings selected for superior nursery performnce maintained their height growth advantage ›ver average 2-2 nursery stock after seven growng seasons in the field.

Seed Production Areas

Seed production areas consist of the *best trees* n the *best stands* of a species within the *best eographic* area. In other words, superior stands ›f a species are upgraded by removing undesirble trees and are treated for early and abundant eed production. Rudolf (1959d, 1961, 1962b) tudied the possibilities of seed production areas or red pine, jack pine, eastern white pine, white pruce, and black spruce, and set standards for heir development, estimated yield, spacing beween trees, optimum age for seed production, naintenance measures, and cost of seed. Seed ›roduction areas are intended to serve until seed ›rchards become established.

Stimulation of Jack Pine Seed Production

It was found that flowering and seed producion of jack pine seedlings under greenhouse and iursery conditions could be stimulated to occur ooner and more often than under natural condiions. Female strobili developed on as many as wo-thirds of 23-month-old seedlings and oneourth of 17-month-old seedlings when good rowing conditions were provided. These freuences contrast sharply with the 0.3 percent lowering on 3-year-old seedlings grown under iormal commercial nursery conditions (Rudolph 966b). The ability to reduce the time between exual generations in jack pine to less than 3 ears (including the period required for seed naturation) gives the forest geneticist a chance o make research progress akin to that of the eneticist working on annual plant species.

Economics of Tree Improvement

Tree improvement as a forest practice must be considered, along with other forest practices such as timber stand improvement and fertilizaion, as a means of raising forest productivity. Lundgren and King (1966) described a method for evaluating the potential benefits of tree improvement programs. They showed that under "long-term" and "short-term" programs, both red pine and jack pine management could be improved economically.

Forest Seed Quality Control

One of the urgent needs of nurserymen the world over is the assurance of the quality of seed they are purchasing. The place of origin (including latitude, longtitude, and altitude), the year of seed collection, and the germination and purity of the seed are of vital importance. The need for standardizing State and Federal laws and international policies in relation to seed quality has been of primary concern to researchers at the Institute. In all, there have been 17 publications dealing exclusively with the work being done on upgrading seed quality, standardizing seed testing, and providing adequate labeling (Nienstaedt 1968; Rudolf 1962a,b, 1964a,c,d, 1965b,c,d, 1966e,f, 1967a; SAF Seed Certification Subcommittee 1961, 1963a,b; SAF Tree Seed Committee 1964a,b). Much of the work described has been done by the Society of American Foresters, the Organization for Economic Cooperation and Development of the United Nations, and the International Crop Development Association.

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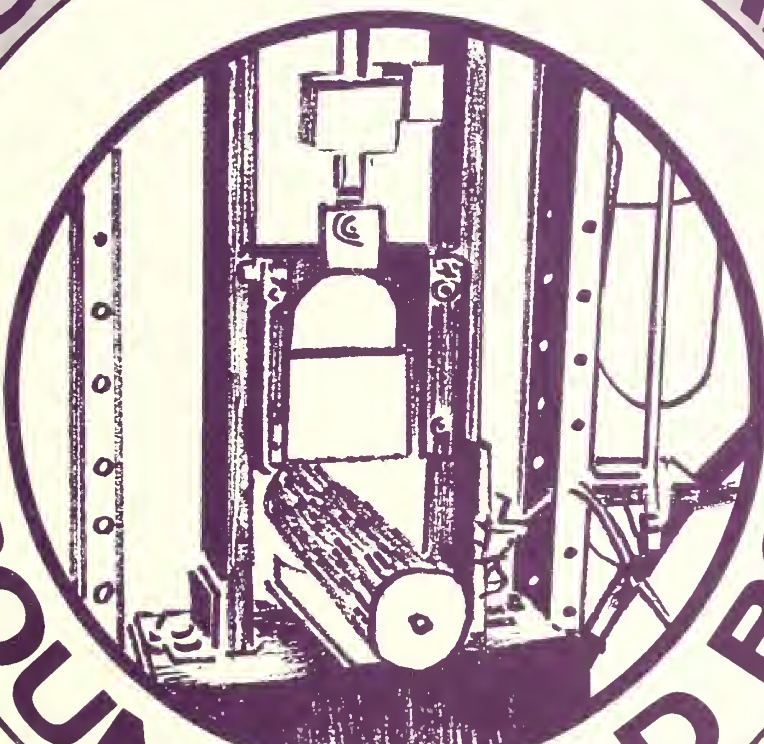
1971

RODGER A. AROLA

CROSSCUT SHEARING OF ROUNDWOOD BOLTS



ORTH CENTRAL FOREST EXPERIMENT STATION
OREST SERVICE·U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

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Manuscript approved for publication May 7, 1971.

CROSSCUT SHEARING OF ROUNDWOOD BOLTS

RODGER A. AROLA

SUMMARY

The objective of the study was to evaluate the iation in force requirements and splitting damage en shearing roundwood bolts up to approximately inches in diameter. The species investigated were swood, aspen, white spruce, yellow birch, and hard ple. Using a single-acting, ½-inch thick shear de, three basic anvil designs were tested: (1) a ormable pad providing sample support immedi- ly opposite the shear blade and permitting blade etration, (2) the same deformable pad with addi- nal exterior supports that restrained bending of the nple, and (3) a rigid anvil that conformed closely the shape of the roundwood bolts, with an adjust- e gap permitting blade side clearance. Twelve in shear blades of varying thickness and bevel gle were tested in addition to tapered, guillotine, ted, very thin, and dull blades. The effects of od temperature, specific gravity, and cutting speed e also investigated.

Anvil Design. — No discernible trends were noted force required to shear unfrozen aspen or spruce h a single-acting shear blade against either a de- mable anvil or contoured anvil with adjustable . However, with frozen wood (particularly aspen), contoured anvil appeared to require less shearing ce. Maximum splitting penetration in unfrozen en was approximately the same (slightly less than nches) with both deformable anvils tested; there- e, restraining sample bending apparently was not neficial. The rigid anvil resulted in slightly greater tting damage in unfrozen aspen for all gaps tested ereas the least splitting penetration in frozen aspen s observed with the contoured anvil adjusted to a -inch blade side clearance. Splitting penetration in rozen spruce did not vary appreciably with the erent anvils, and was erratic in frozen spruce. The ormable, flat, padded anvil frequently resulted in nplete tearout of the spruce samples near the last -quarter of the shear cut, as did the larger gap ings tested with the contoured anvil. When bend- of the spruce samples was restrained by using erior pads, more crushing of the fibers on the cut e, or "mushrooming," resulted. This was attributed to a greater normal pressure on the sides of the shear blade (also causing a slight increase in shearing force).

Blade Bevel (Plain Shear Blade Design). — Significant differences in shear force requirements were observed among individual blade bevels within the range of 20° to 50°, but consistent trends were not apparent. In the dense species (yellow birch and hard maple), the smaller blade bevel angles (20° and 30°) *appeared* to produce more gross splitting damage than the greater bevel angles (40° and 50°), but no trends defining the magnitude of maximum splitting penetration with bevel angle could be established. Predicted maximum splitting penetration occurred at a depth of cut to diameter ratio of approximately 0.75 for a single shear blade acting against an anvil.

Blade Thickness (Plain Shear Blade Design). — Blade thickness had a nonlinear effect on shear force requirements for the five species tested. The force required to shear hard maple increased 57 percent when blade thickness increased from ⅛ inch to ¼ inch, and 46 percent when blade thickness increased from ¼ inch to ½ inch. With basswood, the same increases in blade thickness increased shearing force 73 and 41 percent respectively. Percentage increases for species having densities intermediate to hard maple and basswood can be predicted. Splitting damage generally increased with increasing blade thickness; hard maple was the most sensitive. Maximum split length in hard maple was estimated at 2.5 inches per ⅛ inch of blade thickness. Spruce showed the least change in splitting damage with varying blade thickness.

Guillotine Shear Blades. — Guillotine shear blades, with the cutting edge obliquely inclined to the direction of cut, required less force to shear unfrozen aspen, spruce, and hard maple than a plain, straight-edged shear blade of equal thickness and bevel angle with the cutting edge orthogonal to the direction of cut. However, splitting damage in spruce and aspen increased with increasing guillotine angle.

Tapered Shear Blades. — Tapering the shear blade (—1° to +3° taper angles) did not greatly affect the force required to shear unfrozen aspen, spruce, or hard maple. (Shear blades were of equal thickness

across the bevel and bevel angle.) The shear blade that tapered positively at 3° from ½ inch across the bevel to ¾ inch in thickness resulted in greater splitting damage in aspen and spruce than the ½-inch untapered shear blade. The negatively tapered blade did not reduce splitting damage. Splitting penetration in hard maple sheared with either the negatively or positively tapered blade was severe, but comparable to that in maple sheared with the blade of constant thickness.

Coated Shear Blades. — Low-friction coatings applied to the shear blade surface resulted in significant reductions in shear force requirements for the five species tested, but did not reduce splitting damage. Force reductions in excess of 40 percent were recorded with some species. For all species and the two blade coatings investigated, the average force reduction was approximately 30 percent. Coating durability was a problem in the area of the blade bevel.

Thin Shear Blades. — The advantages of thin shear blades (⅛ and 3/16 inch) for reducing cutting force and splitting damage have already been summarized under blade thickness; however, the following items are also pertinent: very thin shear blades are extremely sensitive to lateral buckling due to the presence of compressive stresses within the plane of the blade. Attempts to improve the elastic stability of the blade by prestressing were only partially successful, due to the presence of compressive stresses in the chosen methods of prestressing and slight misalignment in the assembly containing the thin blades. A uniform tensioning prestress distribution would appear to be more desirable to avoid compressive stresses. With dense species, the cutting edge of very thin shear blades has a tendency to follow the path of least resistance (along the fiber lines), once the cutting edge deviates even slightly from orthogonal cutting of the fibers.

Physical Properties. — For a given blade thickness, specific gravity was found by an analysis of covariance to be the best single physical-property indicator of shear force requirements when the maximum shear force is put on a normalized pounds per maximum width of cut basis. Variations in shear force requirements within a species can also be expected due to natural variation in specific gravity. From linear regressions provided, the 95-percent upper confidence limits on a single estimate are recommended for estimating maximum shear force requirements for a given blade thickness. Specific gravity, moisture content, and bolt diameter, either treated singly or combined in an analysis of covariance, were generally not good predictors of splitting damage, except in case of hard maple.

Dulling. — With unfrozen aspen, spruce, and low birch, dulling of plain and guillotine blades flats up to 1/32 inch did not greatly increase shea force. The largest increases in force, 20 and 30 cent, were observed when shearing aspen with plain and guillotine blades, respectively. Split damage in aspen and birch was generally gre with dull blades, and in spruce, extreme fractu to the sheared face resulted.

Temperature. — Shearing force increased sig cantly with decreasing temperature. Compared unfrozen wood (60° to 70° F.), wood frozen at a 0° F. required the following increases in shea force with five different shear blades: aspen, 5 80 percent; spruce, 56 to 72 percent; and maple to 37 percent. As an approximate pooled estimat the increase in force required to shear wood any base value due to decreasing temperature, a value of 20 pounds per inch width of cut per drop in temperature is recommended. Splitting increased considerably with decreasing tempera

Cutting Speed. — Cutting speeds varying betw 2 inches per second and 12 inches per second not affect shear force requirements with either co or uncoated shear blades; however, power is a f tion of cutting speed. No relationships could be es lished between splitting damage and cutting spee

INTRODUCTION

Numerous pulpwood harvesters employing s blades were designed in the 1960's to fell, delimb, buck trees. Many of the early prototypes were signed despite a lack of basic engineering infor tion relating force and power requirements to s blade design and other parameters. The "seat-of- pants" approach in prototype design adds to the equipment cost necessary to recover total developr costs, including second and third generation pr types. Equipment manufacturers are still in nee reliable engineering data on crosscut shearing. In dition to force and energy, shear blade-induced d age is of vital concern. Pulpmills complain of cru fibers on the sheared face (hindering penetratio pulping liquors) and excessive penetration of s into the bole (causing too many oversize pulp chi Shear blades are seldom used for felling sawtin due to splitting damage.

To learn more about crosscut shearing of woo preliminary study was conducted by Erickson (1

968a,b) in 1965. The study reported here was de- gned to extend and corroborate the results of this reliminary investigation. The primary objective was evaluate and provide basic engineering data on the ariation in force requirements and resultant splitting amage to roundwood bolts when sheared under dif- rent prescribed cutting conditions. The test species lected and their specific gravities are summarized low (table 1).

Table 1. — *Specific gravities*[1] *of the test species*

Species	Number of: samples	Specific gravity: Low	Mean	High	Standard deviation
Basswood (Tilia americana)	108	0.27	0.32	0.42	0.06
Aspen (Populus tremuloides)	312	.27	.38	.50	.04
White spruce (Picea mariana)	282	.27	.35	.43	.04
Yellow birch (Betula alleghaniensis)	156	.48	.55	.67	.03
Hard maple (Acer saccharum)	240	.53	.61	.68	.03

1/ Based on oven-dry weight, green volume.

The following basic anvil and shear blade designs ere tested:

- Anvil design (fig. 1).
  - Deformable — flat pad support permitting shear blade penetration (anvils A and B).
  - Rigid — contoured support with adjustable gap permitting shear blade side-clearance (anvil C).
- Shear blade design (fig. 2).
  - Plain — constant thickness with double bevel and cutting edge at right angles to direction of cut (three thicknesses x four bevel angles).
  - Guillotine — constant thickness with double bevel and cutting edge obliquely inclined to direction of cut.
  - Tapered — variable thickness (increasing and decreasing) with double bevel and cutting edge at right angles to direction of cut.
  - Thin — same basic design as plain shear blade but very thin and sensitive to structural buckling (⅛- and 3/16-inch thickness.)
  - Coated — same basic design as plain shear blade but coated with low-friction material.

Various conditions and physical properties of the undwood samples were also evaluated. These in- uded specific gravity, moisture content, internal mple temperature at the time of shearing, cutting eed, and blade dulling. Except in tests designed to aluate the effects of cutting speed and anvil design, no-load cutting speed of 4.7 inches per second and rigid anvil (fig. 1) with a 1.5-inch gap were used.

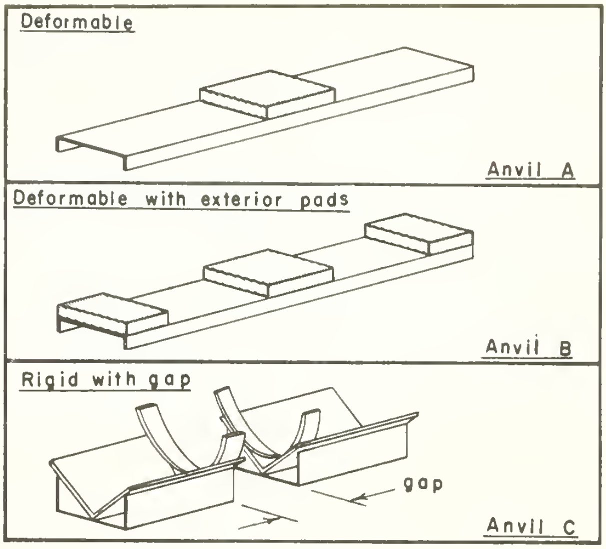

Figure 1. — *Anvil designs.*

EQUIPMENT

Shear Assembly. — The structural frame from a 25-ton hydraulic press was modified to suit the needs of this study (fig. 3). The original power package was replaced with a heavy-duty hydraulic cylinder having a 4-inch bore and 12-inch stroke. The shear blades were rigidly mounted in a U-shaped, roller-guided carriage. A load transducer was placed between the carriage and cylinder rod to measure shearing force. Axial loads were insured by providing a pin and spherical alignment bearing connection between the transducer and blade carriage.

Power Package. — A 45 g.p.m. hydraulic pump (@ 1,800 r.p.m.) driven by a 25 horsepower electric motor supplied power for cutting speeds between 2 and 12 inches per second (fig. 4). The system was designed to operate at a maximum pressure of 3,000 p.s.i.; thus, with the 4-inch bore on the hydraulic cylinder the maximum available cutting force was approximately 38,000 pounds.

Instrumentation. — The system designed was capable of continuously monitoring and graphically displaying the crosscut shearing force along with a measure of the area under the force-time curve (fig. 5a). The ring transducer, made from high-strength aluminum, was designed to measure shearing forces up to 40,000 pounds. Four 120-ohm, ¼-inch foil strain gages were mounted on the inside surface of the ring and arranged in a Wheatstone bridge (fig. 5b) to maximize the output. The maximum shearing force was extracted directly from one channel of a

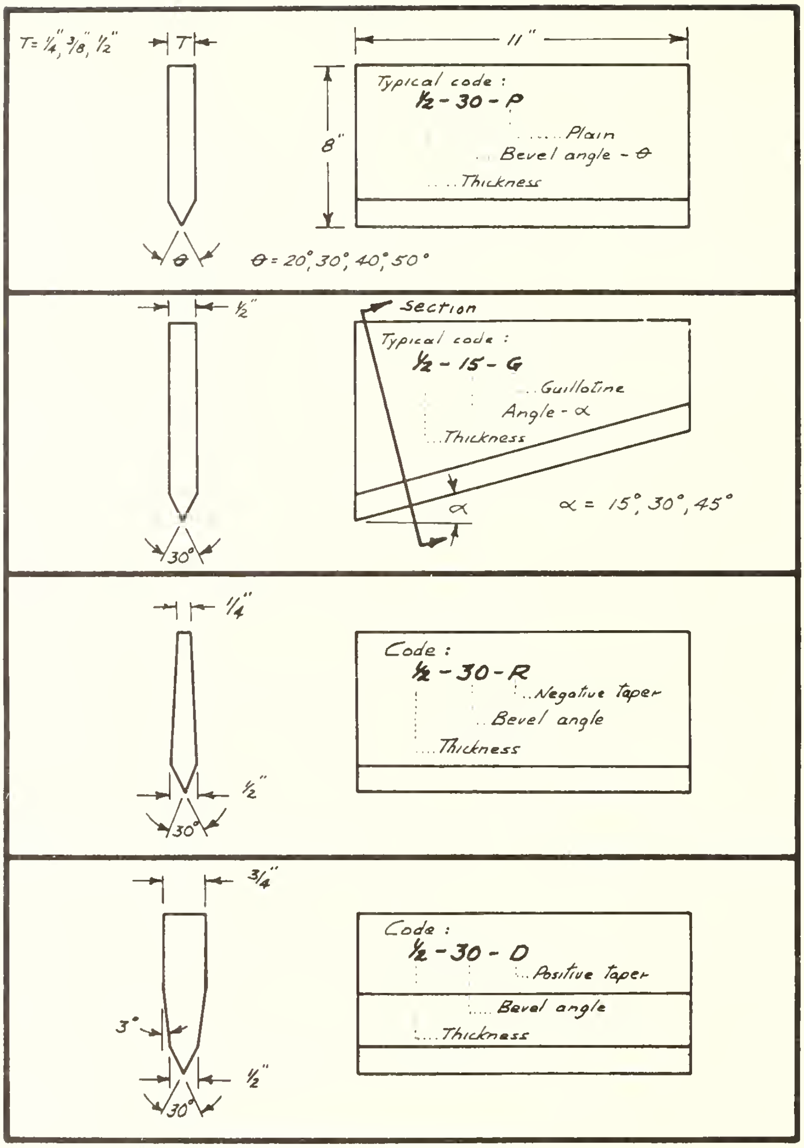

Figure 2. — *Shear blades and coding.*

dual channel strip chart oscillograph recorder. An analog computer circuit automatically determined the area under the force-time curve and this measure was displayed on the second channel of the recorder (fig. 5c). This area measure of the average power expended during the entire cut and was used to calculate the average force.

DATA COLLECTION

Data for this study included initial test conditions, sample measurements made before and after cutting, moisture content, specific gravity, wood temperature, and measurements extracted from the strip-chart recordings. All moisture content and specific gravity determinations were made on disks taken from nea the sheared face and were in accordance with TAPP Standard T18m-53. Data-reduction formulas wer derived to coincide with the data extracted from th strip-chart recordings (fig. 6). Because of the cross sectional irregularity of "roundwood" samples, thre outside bark measurements were made: diamete (with diameter tape), maximum width of cut, an depth of cut. The internal sample temperature wa determined immediately after cutting with a ther mistor probe. Six shear cuts were made at each tes level.

Maximum shearing force is reported in pounds pe inch width of cut. This normalized value was de

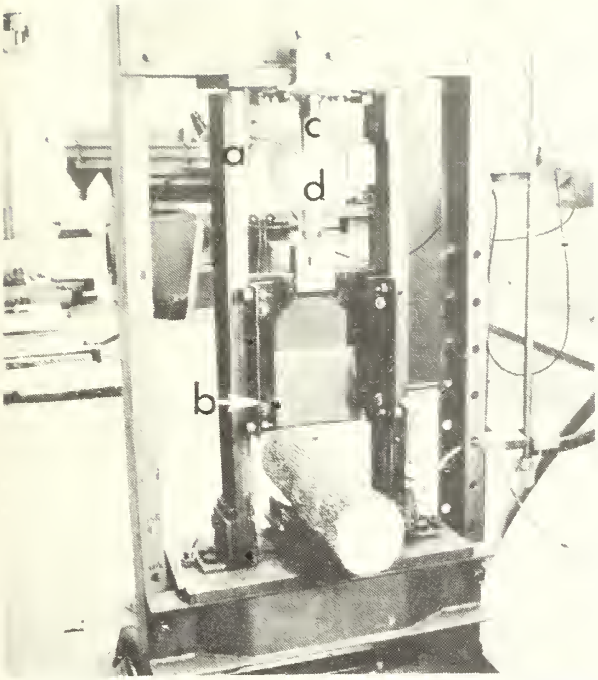

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Figure 3. — *Crosscut shearing assembly; (a) carriage guides, (b) knife carriage, (c) hydraulic cylinder, (d) ring transducer.*

rived by dividing the actual maximum shearing force, as calculated from the strip-chart recording, by the maximum width of cut in inches (outside bark) (fig. 6). For estimating or applied design purposes, the total force requirements for a given log size can be determined by multiplying the appropriate normalized value by the maximum width of cut (or sample diameter).

All sheared bolts were analyzed for splitting damage. This consisted of a measurement of the maximum split length and an "observed" average. The maximum split length is the longest crack penetrating into the bolt from the sheared face. The average split length is the measurement from the cut face to the point where the majority of splitting damage appeared to be concentrated.

Also, for several random samples of yellow birch and hard maple, the length and location of each split were recorded. The objective was to find out if characteristic splitting patterns could be detected due to variations in shear blade thickness and blade bevel. Each roundwood sample was sawed longitudinally through the center and at right angles to the laminar splits, sanded, stained, and the splits were measured.

The roundwood bolts were not all from clear logs. Because of cost and large sample requirements, it was

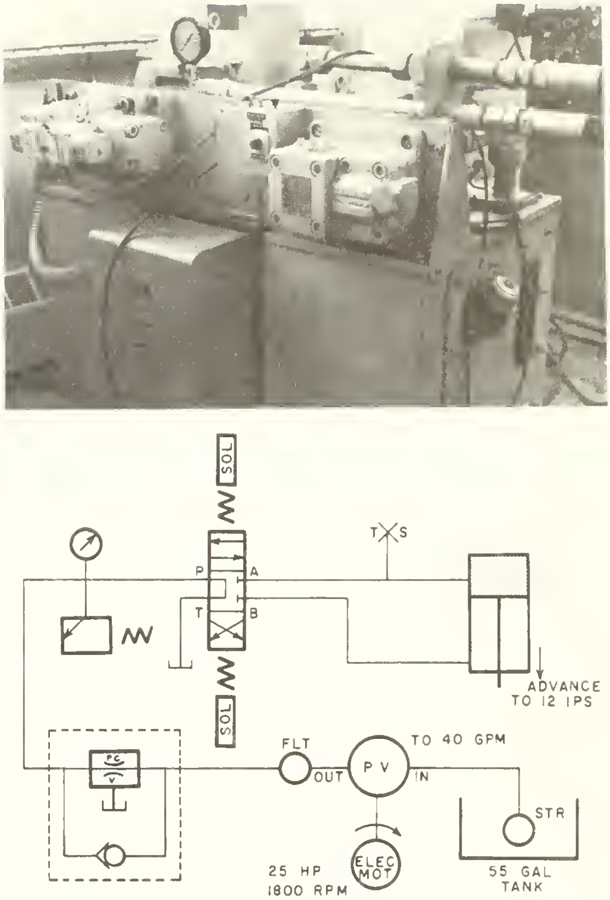

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Figure 4. — *Hydraulic power package and hydraulic circuit schematic.*

necessary to utilize as much of the merchantable bole as possible. Subsequently, bolts having limbs removed could not be avoided. To lessen the effect of knots on splitting damage, the clearest section within the middle third of each sample was sheared, and the clearest half of the sheared bolt then analyzed for splitting damage. The effect of knots on shear force was not evaluated in this study. For most species, other than those characterized by large limbs, such as dense hardwoods, a power-package design for a felling shear based on the diameter at the root collar should generally be sufficient to effect bucking cuts at limb junctures.

RESULTS

Anvil Design

The effects of three different anvil designs on the maximum crosscut shearing force and splitting damage for both unfrozen and frozen (23° to 32° F. internal wood temperature) aspen and spruce were

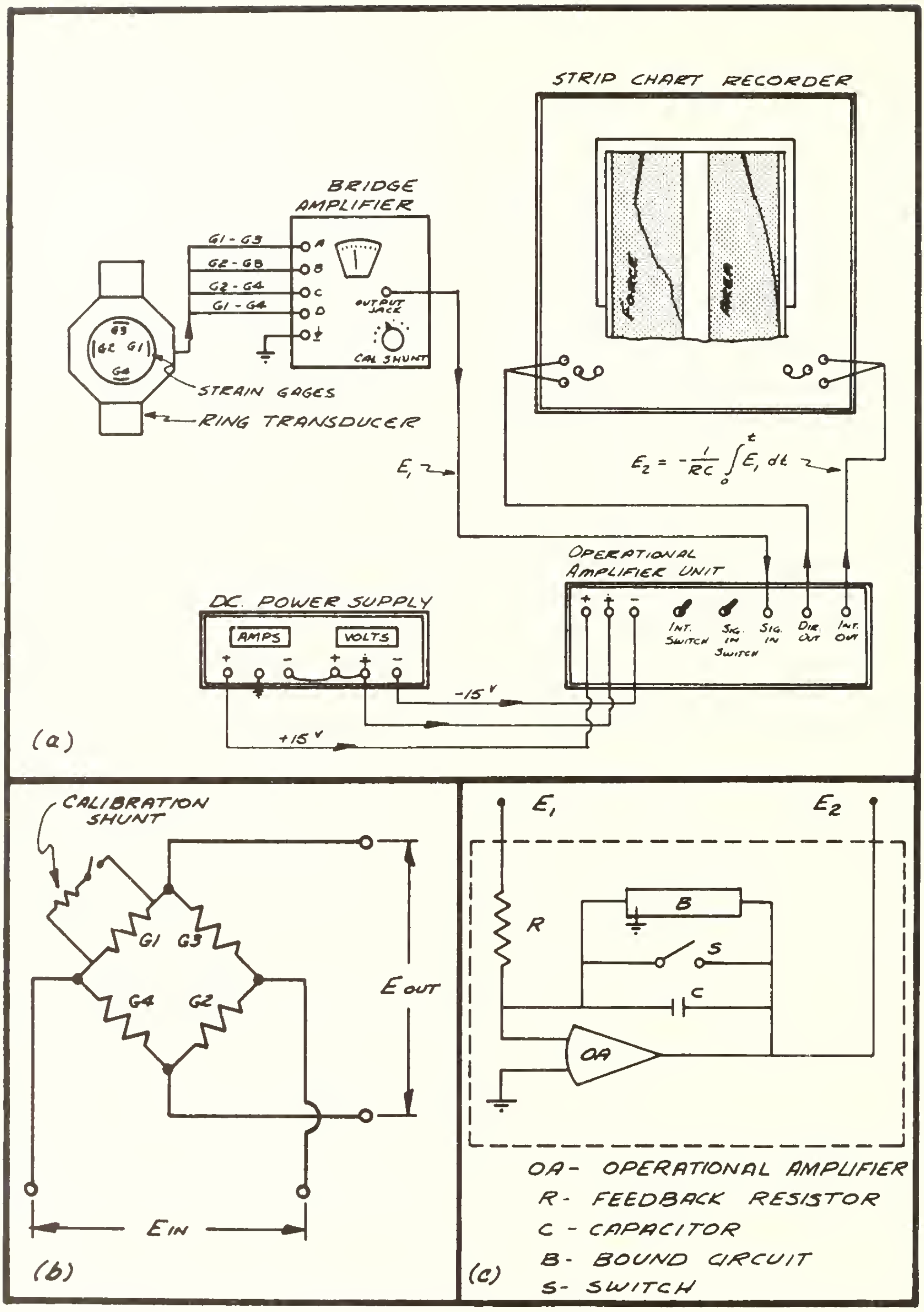
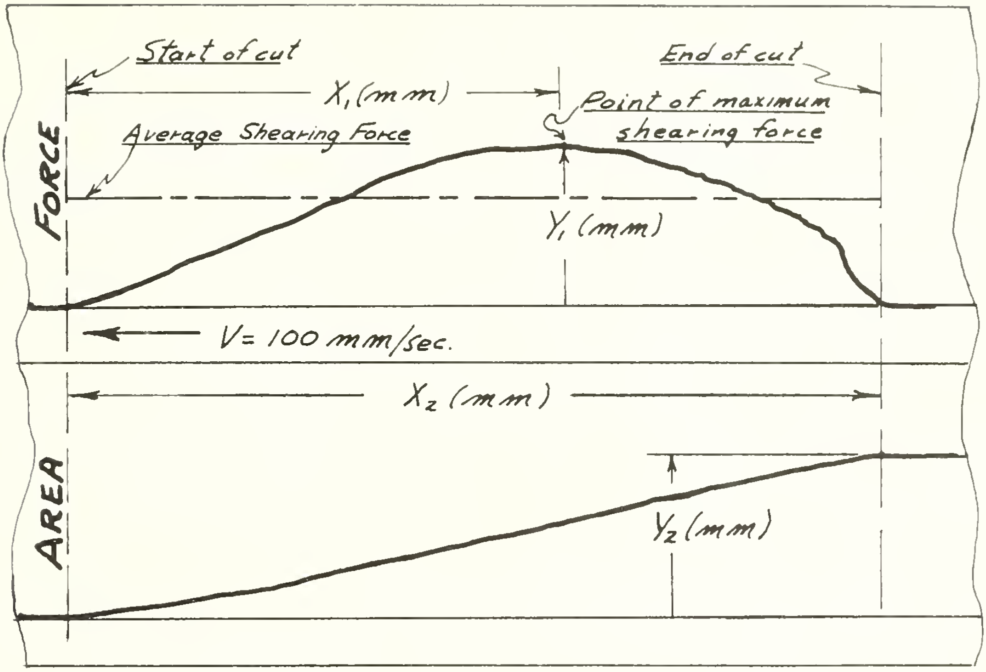


Figure 5.—*Instrumentation schematic (a), Wheatstone bridge arrangement of strain gages (b), and signal integrating circuit (c).*

evaluated when shearing with a single-acting, ½-inch thick shear blade at a no-load cutting speed of 4.7 inches per second (fig. 7). Anvil A had a deformable pad that provided sample support immediately opposite the shear blade and permitted penetration of the blade after completion of the cut. Anvil B had the same deformable pad used with anvil A, in addition to exterior deformable pads that provided restraint against bending of the sample due to the wedging action of the shear blade. The third basic anvil design consisted of a rigid, contoured sample support permitting passage of the shear blade between the



Maximum shearing force (pounds):

$$F_{max} = CY_1$$

Maximum shearing force per inch width cut:

$$Fpiwc = \frac{F_{max}}{\text{Max. Width Cut}}$$

Average shearing force (pounds):

$$Favg = \frac{CY_2V}{X_2}$$

Average speed of cut (inches per second):

$$Savg = \frac{(\text{Max. Depth Cut})\ V}{X_2}$$

where:

C = Calibration constant for ring transducer

X_2 = Length of trace on force channel from start of cut to end of cut

Y_1 = Maximum vertical deflection on force channel

Y_2 = Maximum vertical deflection on area channel at end of cut

V = Strip chart recording speed

Figure 6. — *Typical strip-chart recordings with pertinent data-reduction formulas.*

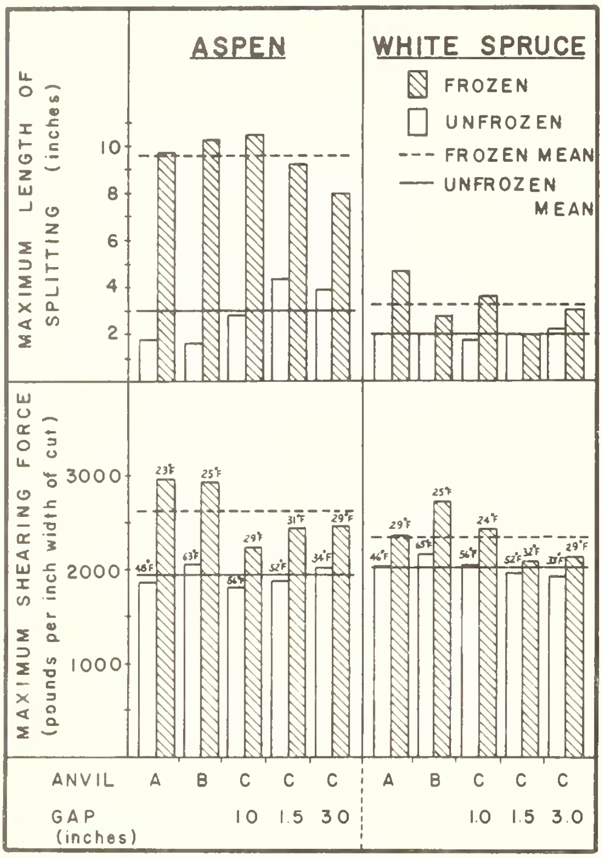


Figure 7. — *Effect of anvil design on shearing force and splitting damage for spruce and aspen (shear blade: ½ inch, 30°, plain).*

two halves of anvil C; thus, this anvil did not provide sample support immediately opposite the shear blade. This contoured, rigid anvil was tested at three nominal gap settings of 1 inch, 1½ inch, and 3 inches. Since a ½-inch thick shear blade was used, the respective side clearances between the blade and anvil were ¼ inch, ½ inch, and 1¼ inches.

In comparing the shear force requirements for unfrozen aspen and spruce, gross differences with the five possible anvil designs were not recorded (fig. 7). For frozen aspen the two deformable padded anvils required larger shear forces than the rigid, contoured anvils. This difference in shear force requirement was not as apparent with frozen spruce. An uncontrolled variability in wood temperatures (noted above each test level in fig. 7) may have had an influential effect on force.

Restraint against bending of the sample caused by the wedging action of the shear blade did not appear to reduce splitting damage. In unfrozen aspen both deformable anvils resulted in mean maximum splitting penetration of less than 2 inches, and with frozen aspen approximately 10-inch splits were recorded. Shearing unfrozen aspen against the contoured anvil yielded maximum splits of 3 to 4 inches, appearing to increase with increasing blade side clearance. With frozen aspen, 8- to 10-inch splits were recorded, with the least penetration being at a 1¼-inch blade side clearance. Splitting penetration in unfrozen spruce was approximately the same for all anvils tested, and was erratic in frozen spruce. However, the sheared face of most frozen spruce samples had "macro-tearouts" of the fibers and some "complete tearout" of wood chunks near the end of the shear cut — particularly when the contoured anvil was set with the two larger blade side clearances. (See figure 8 for descriptions and photographs of typical sheared faces.) In addition, the sheared faces of several frozen spruce samples were severely crushed or "mushroomed" when anvil B was used. This was attributed to a greater pressure normal to the sides of the shear caused by restraining the bending of the sheared bolt. This greater pressure also caused a slight increase in shearing force due to an increased frictional force.

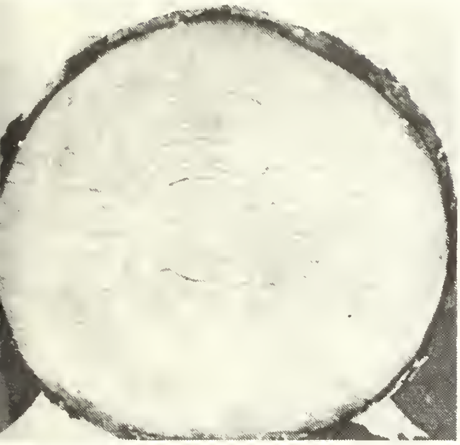
The characteristic splitting damage to aspen can generally be described as laminar splitting occurring at right angles to the direction of cut. The splitting damage to spruce was characterized by the presence of numerous concentric ring separations and very little laminar splitting.

Although the test results do not conclusively show which anvil design is best for use with a single-acting shear blade, my personal preference would be a rigid, contoured anvil with adjustable gap to permit a close shear blade side clearance. If the gap were fixed, a blade side clearance of approximately ½ inch would appear to be a reasonable compromise.

Plain Shear Blade Designs

Unfrozen samples of all five test species were cut with all combinations of three nominal shear blade thicknesses (¼, ⅜, and ½ inch) and four blade bevels (20°, 30° 40°, and 50°). However, to extend the test range of shear blade thicknesses, the experiment was supplemented with crosscut shearing tests on basswood and hard maple with blades having nominal thicknesses of ⅛ and 3/16 inches, and a 30° bevel. The rigid, conformative anvil design was used at a 1½-inch gap setting and a no-load cutting speed of 4.7 inches per second.

Concentric ring-type failures and minor splitting



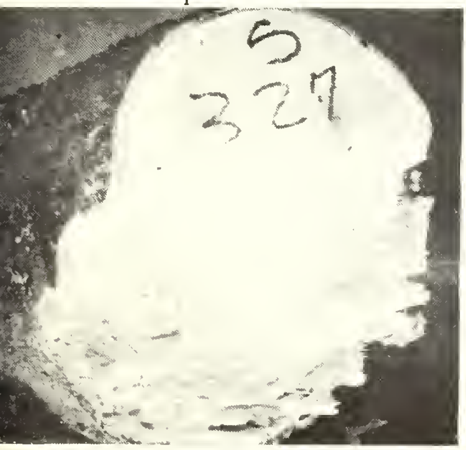
Material condition unfrozen; shear blade ½ inch, 30°, plain; anvil C; gap 1½ inches; temperature 52° F.

White Spruce

Concentric ring-type failures and macro-tearout

Material condition frozen; shear blade ½ inch, 30°, plain; anvil C; gap 3 inches; temperature 29° F.

Complete tearout



Material condition frozen; shear blade ½ inch, 30°; plain; anvil C; gap 1½ inches; temperature 5° F.

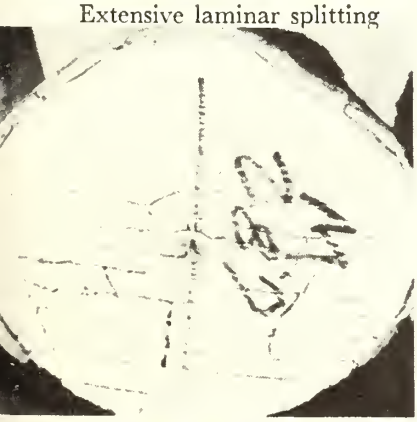
White Spruce

Minor laminar splitting

Material condition unfrozen; shear blade ½ inch, 50°, plain; anvil C; gap 1½ inches; temperature 51° F.

Hard Maple

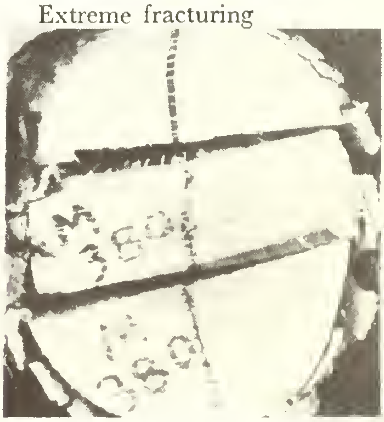
Extensive laminar splitting



Material condition unfrozen; shear blade ½ inch, 30°, plain; anvil C; gap 1 inch; temperature 60° F.

Hard Maple

Extreme fracturing



Material condition frozen; shear blade ½ inch, 30°, + 3° taper; anvil C; gap 1½ inches; temperature 6° F.

Figure 8. — *Typical sheared faces.*

SHEAR BLADE BEVEL

Past investigators have reported that blade bevel has little or no influence on shear force requirements (Johnston 1968d, Wiklund 1967). Exceptions noted were white spruce and eastern hemlock, where Erickson (1967) reported a 15- to 20-percent reduction in maximum shearing force when going from a 20° to a 40° bevel angle with a ½-inch-thick blade. In this study significant differences were recorded between individual bevel angles; however, it is concluded that bevel angle has *no consistent effect* on the magnitude of shearing force (fig. 9). An analysis of covariance to adjust for uncontrolled natural variations in specific gravity, moisture content, and bolt diameter did not yield adjusted treatment means that would change the above conclusions.

In a detailed analysis of all splits produced in individual bolts from yellow birch and hard maple, it appeared that the smaller blade bevel angles (20° and 30°) produced thicker laminar beam failures and more gross splitting damage than the greater bevel angles (40° and 50°); however, no consistent trend could be established in terms of the actual maximum depth of splitting penetration. Or, to put it in other terms, the larger bevel angles appeared to produce a greater number of laminar splits throughout the depth of cut, but they were more concentrated about the average length of split. This is best illustrated in the computer plots of the scatter diagrams of split length versus depth of cut along with a least-squares best-fit curve based on a fourth-order polynomial for each combination of blade thickness and bevel angle (fig. 10). The maximum predicted split lengths generally "peaked out" at a depth of cut to diameter ratio of approximately 0.75. The regression equations were used mainly to illustrate what appeared to be characteristic splitting patterns due to changes in blade bevel; they are not recommended for quantitative use. Thus, the equations have not been included in figure 10.

BLADE THICKNESS

Because blade bevel had no consistent effect on shearing force, the data for all bevel angles were pooled and averaged for each blade thickness. This gave a mean value of maximum cutting force for each blade thickness (excluding the ⅛- and 3/16-inch) based on 24 shear cuts instead of six.

The results revealed that as blade thickness increased, the shearing force increased nonlinearly (fig. 11). For hard maple, doubling the blade thickness from ⅛ to ¼ inch resulted in a 57-percent increase in shearing force. When blade thickness was increased from ¼ inch to ½ inch the shearing force increased 46 percent. For basswood, the same order

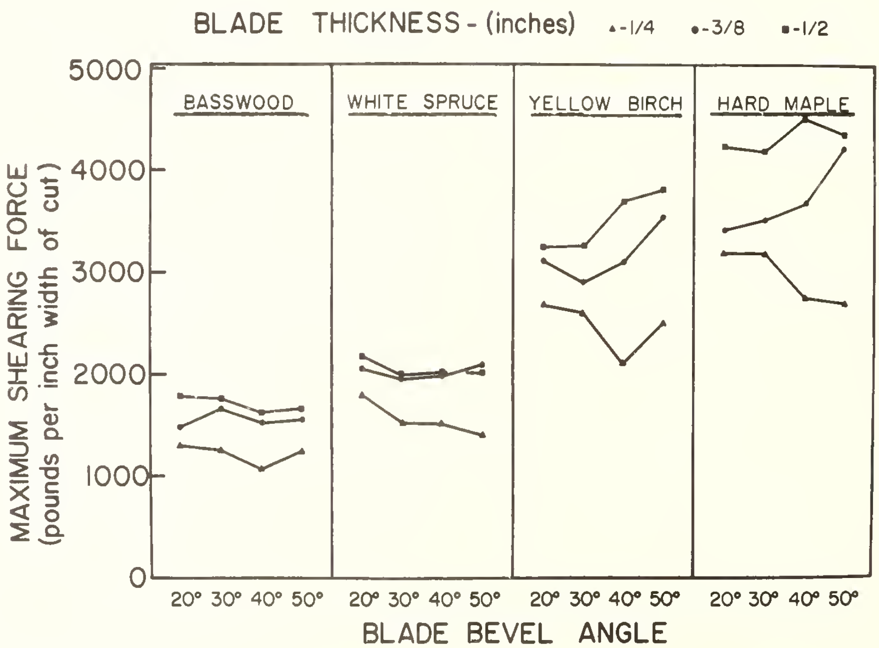


Figure 9.—*Effect of blade bevel on shearing force (anvil C, 1.5-inch gap).*

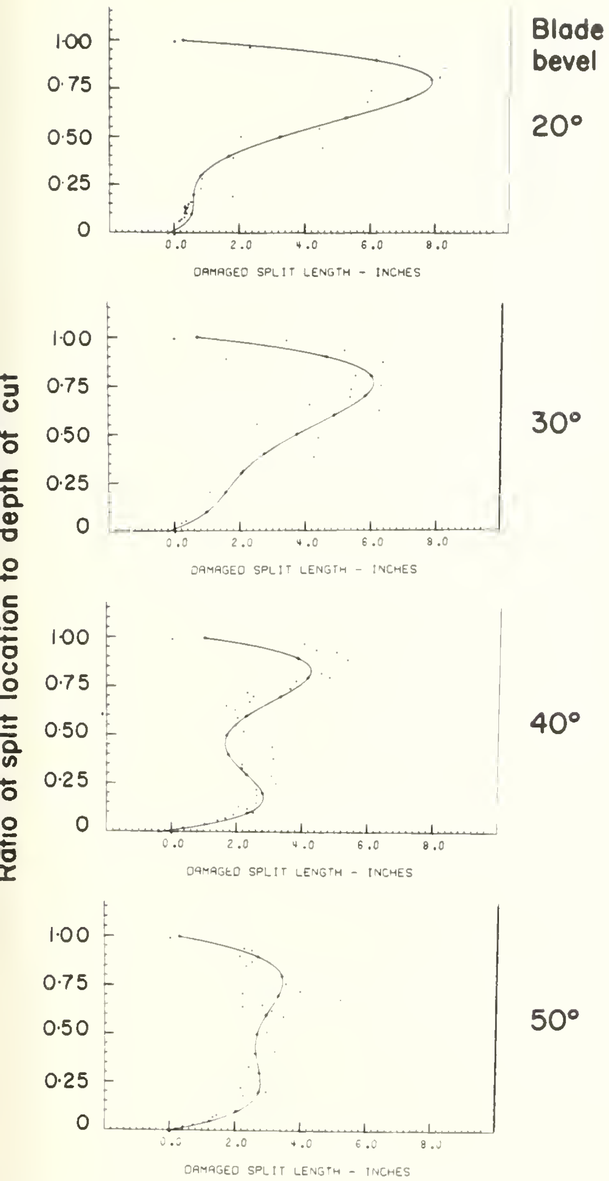


Figure 10. — *Splitting damage in yellow birch roundwood bolts sheared with 3/8-inch shear blades with varying blade bevel (anvil C, 1.5-inch gap, 4.7 inches/second cutting speed).*

of increases in blade thickness increased the shearing force 73 and 41 percent. By extrapolating the upper and lower bounds through the origin (fig. 11), a smooth envelope results for the given test conditions. It is expected that all species with densities between basswood and hard maple would be included within this envelope under similar cutting conditions. If this curve is used for estimating purposes, the user should remember that the plotted values are treatment level means, and the 95-percent upper confidence limits are recommended for design (see discussion concerning physical properties).

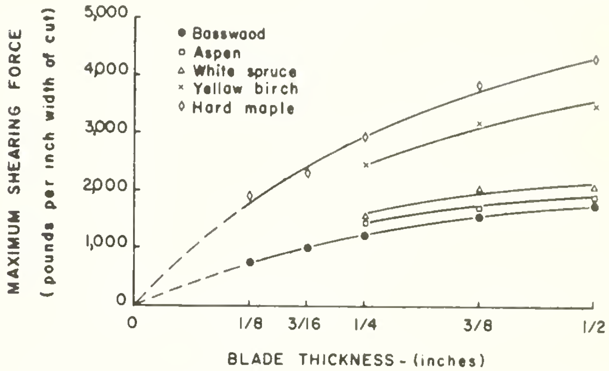


Figure 11. — *Effect of blade thickness on shearing force.*

My impression of the sheared roundwood bolts was that shear blades having 40° or 50° bevel angle generally produced a higher quality cut — the laminar splitting was not as distinct. Perhaps this is analagous to the carpenter's trick of minimizing splitting by blunting the point of a nail before driving near the end of a board, thus causing the nail to act more as a punch than a wedge.

The conclusions on the effect of blade thickness agree closely with those of other investigators. Johnston (1968d) and Kempe (1964) reported a 50-percent increase in shear force when doubling blade thickness between the range of 0.2 to 0.5 inches. Erickson (1967) reported a range of 35 to 64 percent increase in force, depending on species.

Splitting damage in unfrozen hard maple bolts was found to be the most sensitive to changes in blade thickness (fig. 12). Assuming an approximate linear relationship for mean values of maximum split length in hard maple within the range of blade thicknesses tested, an average slope of 2.5 inches of split per 1/8 inch of blade thickness is recommended for estimating purposes. The splitting damage in unfrozen spruce appeared to be the least sensitive to changes in blade thickness, with maximum splits concentrating around a depth of penetration of approximately 2 inches.

Physical Properties

Based on an analysis of covariance for each species sheared with the plain shear blades, specific gravity and shear force were found to be highly correlated, accounting for most of the variation among bolts within a treatment. Because specific gravity was the

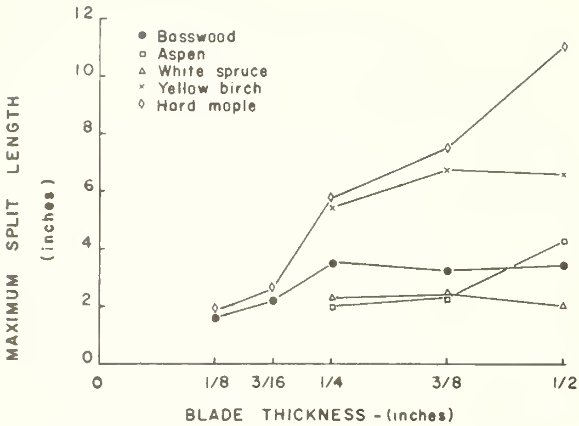


Figure 12. — *Effect of blade thickness on splitting damage.*

best single physical property indicator of crosscut shear force requirements, three separate linear regression analyses relating force to specific gravity were run for the ¼-, ⅜-, and ½-inch blade thicknesses and all blade bevel angles tested. For estimating purposes, the resulting linear regression lines, 95-percent upper and lower confidence limits on both the mean and a single estimate, and the scatter diagrams were computer-plotted for each of the three blade thicknesses (fig. 13). The 95-percent upper confidence limits on a single estimate are recommended for establishing design limits (do not include effects of dulling or shearing frozen wood). In an analysis of covariance, moisture content, specific gravity, and diameter, either treated singly or combined, were not highly correlated with splitting damage in aspen, spruce, basswood, or yellow birch. The coefficients of determination for these species ranged from 0.07 for yellow birch to 0.40 for spruce. However, with hard maple the combined coefficient was approximately 0.78, with diameter accounting for most of the variation.

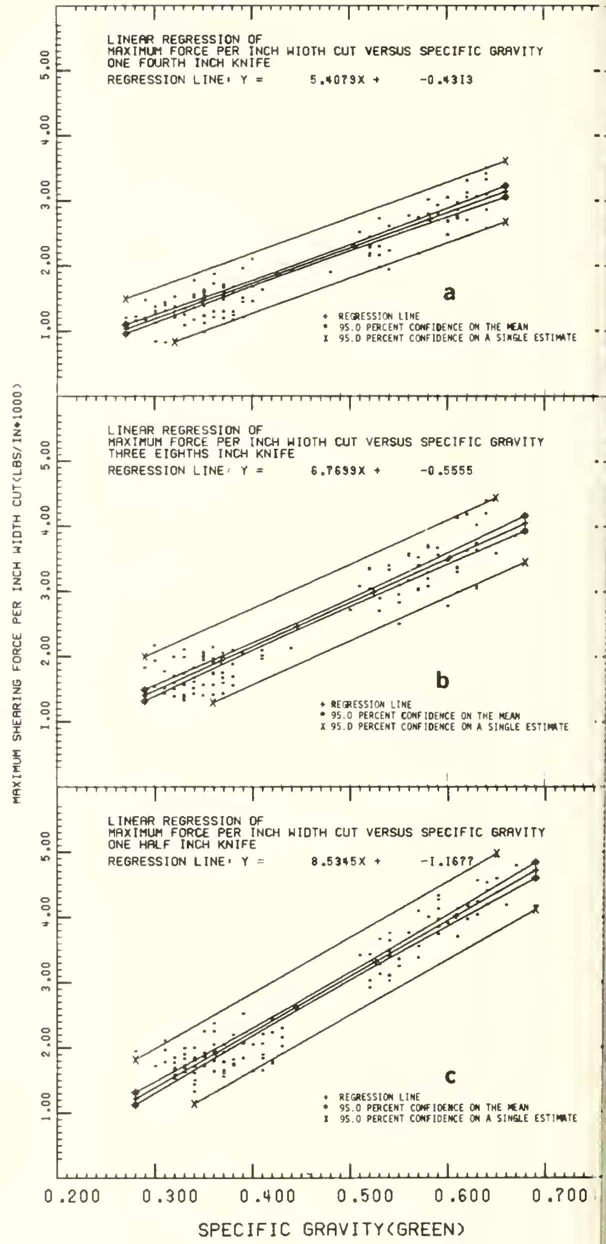


Figure 13. — *Effect of specific gravity on shearing force: (a) ¼-inch blade thickness, (b) ⅜-inch blade thickness, (c) ½-inch blade thickness.*

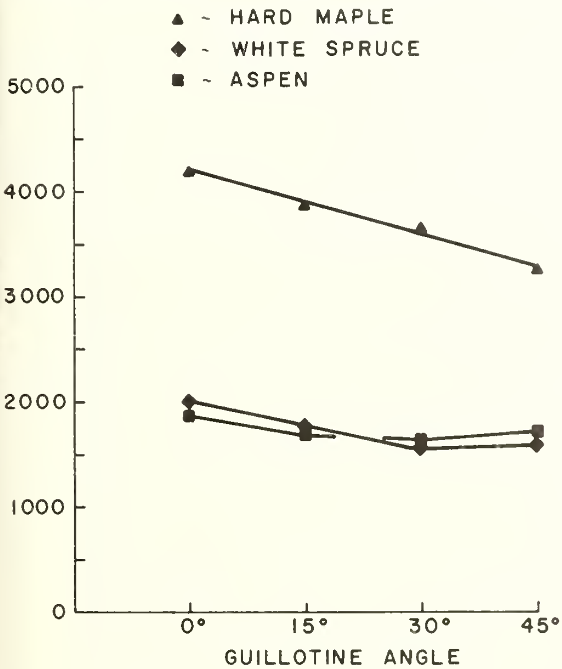
Guillotine Shear Blades

The purpose of testing the guillotine shear blades was to determine if a cutting edge inclined at an oblique angle to the direction of cut would induce a slicing action, thereby reducing the force requirements and splitting damage.

It has been hypothesized by previous investigators that during orthogonal cutting of the fibers (where the cutting edge is at right angles to the direction of cut), the failure is not by fiber severance but rather by tensile failures slightly ahead of the cutting edge.

n other words, beam failures (laminar splits) would ccur, but at the same time, tensile failures of the bers would result on the tension side of the beams s they are formed. If this hypothesis is true, the aximum benefit of a keen cutting edge is not being ecognized. Therefore, an induced slicing action cre-ing fiber severance appeared to be worthy of in-estigation.

The mean values of maximum shearing force for l guillotine blade angles (15°, 30°, and 45°) were ss than for a plain shear blade of equal thickness ig. 14). The shearing force requirements for hard aple decreased linearly with increasing guillotine ngle. With maple, the 45° guillotine blade reduced earing force about 25 percent compared with the ain shear blade (0° guillotine angle). For spruce



gure 14. — *Effect of guillotine angle on shearing force (½-inch blade thickness).*

nd aspen, shearing force requirements also decreased ith increasing guillotine angle, with the exception the 45° guillotine angle. However, this is attributed the above-average specific gravities for each species this 45° treatment level.

Surprisingly, splitting damage appeared to in-ease with guillotine angle for aspen and spruce, but o trend was observed for maple (table 2). Frozen ood was not tested in this phase of the study.

Table 2. — *Mean[1] splitting damage by guillotine blade angle[2] and species*

Guillotine angle and species	Splitting damage (inches)			
	Maximum		Average	
	Mean	Range	Mean	Range
0:				
Aspen	4.3	1.4- 5.6	1.7	1.1- 2.5
Spruce	2.0	1.1- 2.5	1.0	.6- 1.3
Maple	11.0	7.0-15.6	--	--
15°:				
Aspen	4.7	2.8- 7.9	1.8	.8- 2.7
Spruce	--	--	--	--
Maple	14.0	11.4-18.5	8.8	6.4-10.2
30:				
Aspen	6.1	4.0- 8.4	2.7	1.1- 5.0
Spruce	4.3	2.5- 7.3	3/1.5	.5- 3.2
Maple	10.8	6.8-14.3	3/8.8	5.5-11.2
45°:				
Aspen	7.5	4.3-10.6	3.1	1.5- 4.9
Spruce	4.7	3.2- 7.0	1.1	.6- 1.8
Maple	9.9	3.3-12.7	5.8	1.2- 9.2

1/ Average of six bolts sheared at each treatment level.

2/ The four shear blades listed were 1/2 inch in thickness.

3/ Average based on only four bolts.

Tapered Shear Blades

Two basic shear blades of variable thickness were tested to evaluate the effect of blade taper on shear force and splitting damage. Both of these shear blades were fabricated with a 30° bevel angle to a ½-inch thickness, at which point they tapered either positively to a thickness of ¾ inch, or negatively to ¼ inch. The respective taper angles were approximately +3° and —1°.

Within this limited range of shear blade taper angles there was little difference in shear force requirements (fig. 15). The mean values and ranges of maximum split length in spruce and aspen for the positively tapered shear blade were distinctly greater than for the untapered shear blade (table 3). It was anticipated that splitting damage would be less with the negatively tapered shear blade than with the untapered blade; however, slight increases in the mean value of maximum split length were recorded. Splitting damage in hard maple for all three shear blades was extensive, with the mean values of maximum splits about 10 inches. For a ½-inch-thick shear blade, this maximum split length agrees with the previously given estimate of 2.5 inches of split per ⅛ inch of blade thickness.

Thin Shear Blades

Two experiments were conducted with thin shear blades. The first was to conduct an experimental photoelastic analysis of a thin shear blade by bonding a photoelastic coating to the blade surface and then subjecting the blade to compressive edge loadings (approximating crosscut shear loads), to pretensioning loads as investigated under the first phase, and

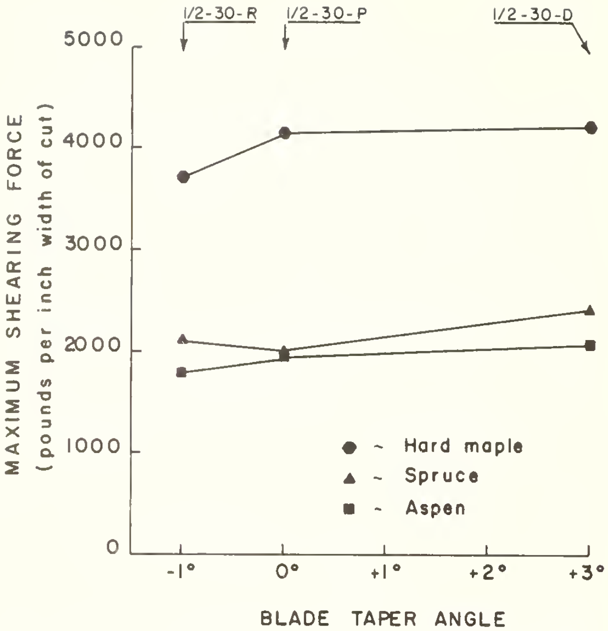


Figure 15. — *Effect of blade taper on shear-force requirements (anvil C, 1.5-inch gap).*

Table 3. — *Mean[1] splitting damage by shear blade taper and species*

Shear blade taper and species	Splitting damage (inches)			
	Maximum		Average	
	Mean	Range	Mean	Range
No taper:				
Aspen	4.3	1.4- 5.6	1.7	1.1- 2.5
Spruce	2.0	1.1- 2.5	1.0	.6- 1.3
Maple	11.0	7.0-15.6	--	--
Positive taper = 3°:				
Aspen	6.6	2.6-14.9	2.1	.8- 3.2
Spruce	4.6	2.1-10.0	1.0	.6- 2.4
Maple	9.7	3.6-13.8	6.0	1.2- 8.0
Negative taper = 1°:				
Aspen	4.7	2.7- 7.9	1.8	1.3- 2.6
Spruce	2.3	1.7- 3.4	1.0	.6- 1.5
Maple	11.7	8.5-13.0	7.8	6.2-10.7

1/ Average of six bolts sheared at each treatment level.

to a combination of approximated shearing and pretensioning loads. The second was to permit an evaluation of the performance of thin blades under actual shearing operations, during which pretensioning methods were employed to increase the elastic stability of the blade.

For both experiments the shear blades were rigidly contained in loading arms and pretensioned by means of a hydraulic cylinder (figs. 16, 17). Both phases also included an investigation of two alternative pretensioning pin connection locations (A and B) on the loading arms. Under prestressing loads, these pin locations were assumed to produce stress distributions similar to those that would be produced in thick, deep beams subjected to the same loadings (fig. 18). It must be emphasized that the thin plates

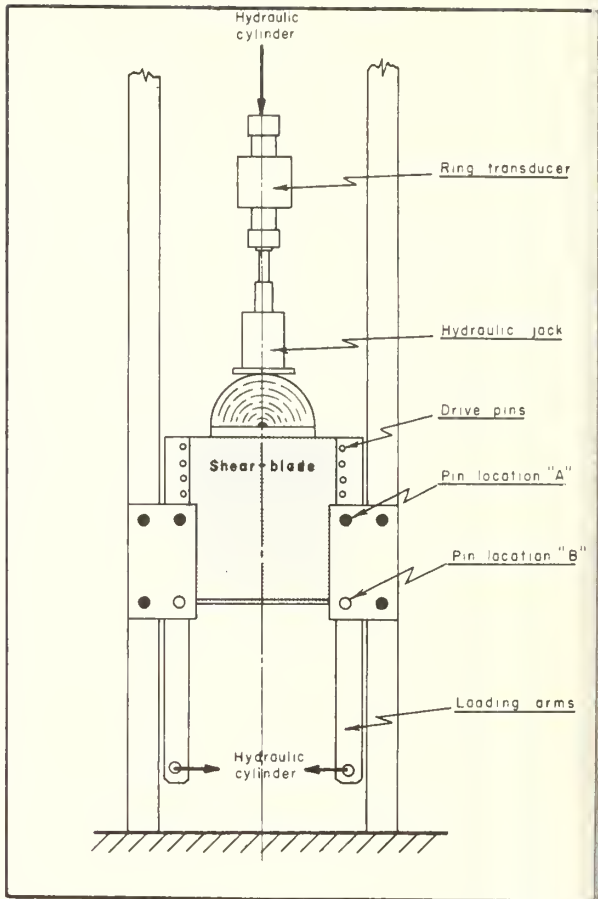


Figure 16. — *Test arrangement for conducting pre-tensioning and photoelastic analysis of thin shear blades.*

(shear blades) used *do not* behave as thick, dee beams. The objective of the photoelastic study was t determine how the shear blades vary from thick, dee beams, and to provide insight into establishing mo exacting theoretical approaches for predicting th performance of thin shear blades. The results of th photoelastic analysis are too extensive for inclusio in this paper; however, several comments are in orde concerning the actual shearing tests that were con ducted with thin shear blades.

Unfrozen basswood bolts with maximum diamete of about 8 and 9 inches were sheared with the ⅛ and 3/16-inch shear blades, respectively. The max mum diameters for unfrozen hard maple were 6 and 7.3 inches for the same two blades. When th thin blades were pretensioned, inelastic stability prob lems were not encountered under the following cond tions: with pin location A and the ⅛-inch blade (pre stress moment applied was approximately 19,000 inch pounds); with the same pin location and the 3/16 inch blade (three prestress moments were applied—

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Figure 17. — *Assembly for conducting crosscut shearing tests with pretensioned, thin shear blades.*

approximately 38,000 inch-pounds, 57,000 inch-pounds, and 76,000 inch-pounds); with pin location B and the 3/16-inch blade pretensioned with a 3,800-pound cylinder force at a 10-inch lever arm from the pin connection. It was not hypothesized that the pretensioning results in less shear force, but rather that the pretensioning permits the use of thinner shear blades because of increased elastic stability. Figures 11 and 12 clearly indicate the benefit of thin blades for reducing shear force requirements and splitting damage.

As a final test with the 3/16-inch pretensioned blade, a *frozen* 7.5-inch diameter hard maple bolt was sheared resulting in complete blade failure (fig. 19a). This blade failure prompted the testing of several basswood samples (low density) with the ⅛-inch blade without pretensioning. Extremely smooth cuts were obtained without blade failure. The same thin shear was then tested without pretensioning on a 6-inch diameter oak bolt (high density) — blade failure resulted (fig. 19b).

In summary, the pretensioning methods appeared to increase the stability of the shear blade to a lim-

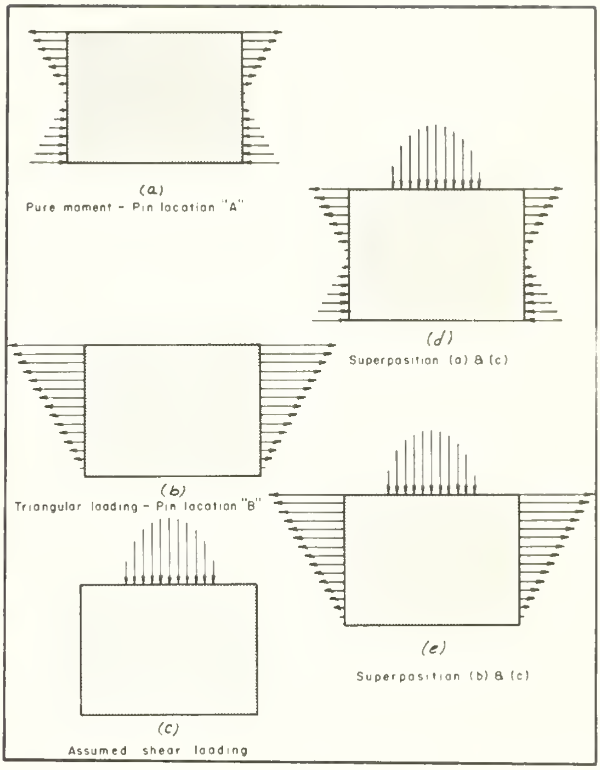

Figure 18. — *Load and prestress configurations studies for pretensioning of thin shear blades.*

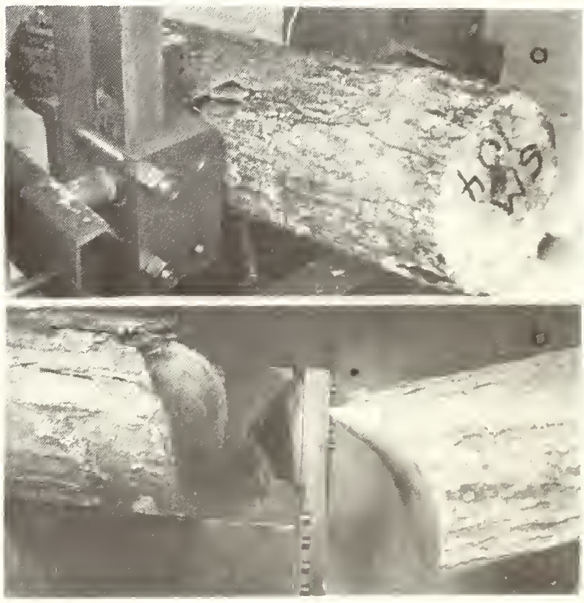

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Figure 19. — *Thin shear blade failures. (a) Pretensioned blade, 3/16-inch, 30° bevel angle; 7.5-inch diameter hard maple (frozen). (b) Shear blade without pretensioning, ⅛-inch, 30° bevel angle; 6.0-inch diameter oak (unfrozen).*

ited extent, but not to complete satisfaction, as is obvious from the pretensioned blade failure with frozen maple. Further work needs to be done in the area of pretensioning. Perhaps a better approach would be to subject the shear blade to a uniform tensile stress throughout its depth.

The mechanical arrangement of the test assembly did not permit investigating pure tensioning without major modifications. Pure tensioning is suggested because of the difficulty encountered in pretensioning the very thin shears by the methods used in this study. Almost as soon as the pretensioning loads were applied, (with either pin arrangement A or B, fig. 15) elastic buckling occurred (opposite of what happens during shearing).

Another problem associated with the performance of thin shear blades, whether pretensioned or not, is preventing the cutting edge from drifting along the direction of the fiber lines in the denser species. In other words, once the thin shear blade starts cutting at even the slightest angular variation to orthogonal cutting (perpendicular to the fibers), the edge of the blade tends to follow the path of least resistance — along the fiber lines. Structural failure of the shear blade may be the final result. Thus the equipment designer contemplating the use of thin shear blades must consider the elastic stability of the shear blade and localized buckling.

Dulling

Unfrozen aspen, spruce, and yellow birch bolts were sheared to evaluate the effect of blade dulling on shear force requirements and splitting damage (fig. 20). Two shear blades, a plain and a guillotine, were machined to two arbitrary levels of dulling — flats of 1/32 and 1/64 inch were ground along the cutting edge and were classified as dull and half-dull, respectively. Blade dulling was not found to influence shear force requirements as much as in the earlier study by Erickson (1968a). Erickson found dulling to a 1/32-inch at to increase shear force for a ⅜-inch blade having a 30° bevel by 34, 44, and 27 percent in spruce, aspen, and birch, respectively. In this study, for the same level of dulling and same species, the percentage increases were only 6, 19, and 5 for a ½-inch shear blade having a 30° bevel. The differences between the results in the two studies may be attributed to variation in the classification "full sharp," and in wood samples (roundwood bolts vs. 2 by 4 sections). Erickson's "full sharp" shear blades were maintained in a honed condition, whereas mine were machine-ground only.

The dull guillotine blade appeared to increase shear force slightly more than the plain shear blade. Full dulling of the guillotine blade increased shear force approximatey 31, 13, and 15 percent for spruce, aspen, and birch, respectively.

Both levels of dulling produced greater splitting damage than the sharp condition; however, no consistent trend was apparent (table 4). Visually examining the cut face of spruce sheared with dull blades was found to be misleading, because it appeared that splitting penetration was extensive (fig. 21). However, maximum splits detected for the two dull shear blades were only 4 to 4.5 inches (table 4). This is attributed in part to the characteristic concentric-

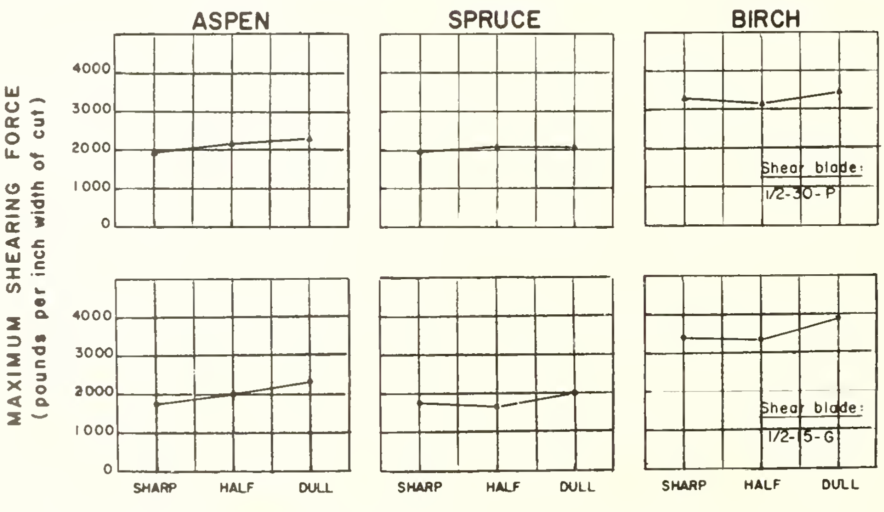

Figure 20. — *Effect of blade dulling on shear force requirements.*

Table 4. — *Mean[1] splitting damage with dull shear blades*

Shear blade type and species	Maximum split length (inches) Sharp	Half-dull (1/64-inch flat)	Dull (1/32-inch flat)
½ inch, 30°, plain			
Aspen	4.3	7.4	5.2
Spruce	2.0	2.3	3.9
Birch	6.5	6.9	8.8
½ inch, 15°, guillotine			
Aspen	4.7	10.3	9.4
Spruce	--	3.1	4.4
Birch	--	9.8	7.8

1/ Average of six shear cuts at each treatment level.

ing type failure in spruce rather than laminar plitting.

Coated Shear Blades

To find out if the effect of friction on the sides of he shear blade could be reduced, two ⅜-inch blades vere completely coated with different low-friction naterials. A blade having a 40° bevel was coated with 'Teflon-S"[1]. The second shear blade having a 20° bevel was coated with a different low-friction maerial.

Consistent reductions in shearing force with both oatings were observed with all species (table 5).

Table 5. — *Crosscut shearing force (pounds per inch width of cut) for coated and uncoated shear blades*

Species	Uncoated blades[1/] Mean force	Teflon-S[2/] Mean force	Teflon-S[2/] Reduction (percent)	New material[3/] Mean force	New material[3/] Reduction (percent)
Basswood	1,548	898	42	882	43
Aspen	1,709	1,218	29	1,299	24
Spruce	2,026	1,141	44	1,203	41
Birch	3,164	2,232	29	2,021	36
Maple	3,812	3,100	19	3,286	14
Average	--	--	33	--	32

1/ Average of six shear cuts at each bevel angle (20°, 30°, 40°, and 50°); i.e., average of 24 bolts.
2/ Applied to blade code 3/8 inch, 40°, plain (six shear cuts).
3/ Applied to blade code 3/8 inch, 20°, plain (six shear cuts).

he most significant force reductions — more than 0 percent — were with basswood and spruce. Hard naple, the densest species tested, resulted in the east force reduction. Pooling all species, both coatngs yielded roughly a 30-percent reduction in shearng force. These results indicate significant benefits of ow-friction coatings and point out the need for further investigations. No consistent differences in splitting damage were noted between the coated shear blades and the uncoated blades tested earlier. After approximately 50 cuts with each shear blade the coating in the bevel area showed signs of excessive wear.

Other researchers have estimated the effect of the friction forces between the blade and wood during the shearing operation. Both Kempe (1964) and Johnston (1968d), using coefficients of friction of 0.20 and 0.23, respectively, estimated the friction force to contribute up to a third of the total energy required to effect the cut in spruce. Grease on the blade surface was unsuccessful in reducing the shearing force. Through the use of metal inserts impregnated with a low-friction polytetraflourethylene, Wiklund (1967) reduced the maximum shearing force by approximately 10 percent.

Temperature

The effects of wood temperatures ranging from 0° to 60°F. were evaluated for several blades when shearing aspen, white spruce, and hard maple (the shear blades were not cooled to corresponding temperatures). Although much scatter resulted in mean shear-force values for the random temperature levels (fig. 22), the approximate linear trends shown for the ½-inch, 30°, plain shear blade can be used for discussion. For hard maple a force increase of approximately 17 percent was noted when temperature was decreased from 50° to 5° F. For aspen and spruce, the median force increase was about 55 percent for the same drop in temperature.

Aspen, spruce, and hard maple bolts were also sheared with five different blades at several internal wood temperatures below 32° F. The mean values of shearing force and splitting damage for these tests were summarized along with the data for the corresponding blades at temperatures above freezing (tables 6, 7, and 8). Compared with unfrozen wood, increases in force required to cut frozen wood at the lowest temperatures in each test level fell within the following ranges: aspen, 51 to 80 percent; spruce, 56 to 72 percent; and maple, 13 to 37 percent. Another measure illustrating the effect of decreasing temperature on shear force is an approximate unit increase of 20 (pounds/inch width cut)/°F. for aspen, 23 (pounds/inch width cut)/°F. for spruce and 13 (pounds/inch width cut)/°F. for hard maple. A pooled value for all three species of 20 (pounds/inch width cut)/°F. can be used for estimating purposes.

In general, splitting damage increased with de-

[1] *Dupont, 958-200 Series, Stratified Non-Stick nd Self-Lubricating Finish. The names of manufacurers and models of equipment are mentioned in this aper for identification only, and no endorsement by he USDA Forest Service is implied.*

Shear blade ½ inch, 30° plain
Half-dull (1/64 inch flat) Dull (1/32 inch flat)

Shear blade ½ inch, 30°, guillotine
Half-dull (1/64 inch flat) Dull (1/32 inch flat)

Aspen

Yellow Birch

White Spruce

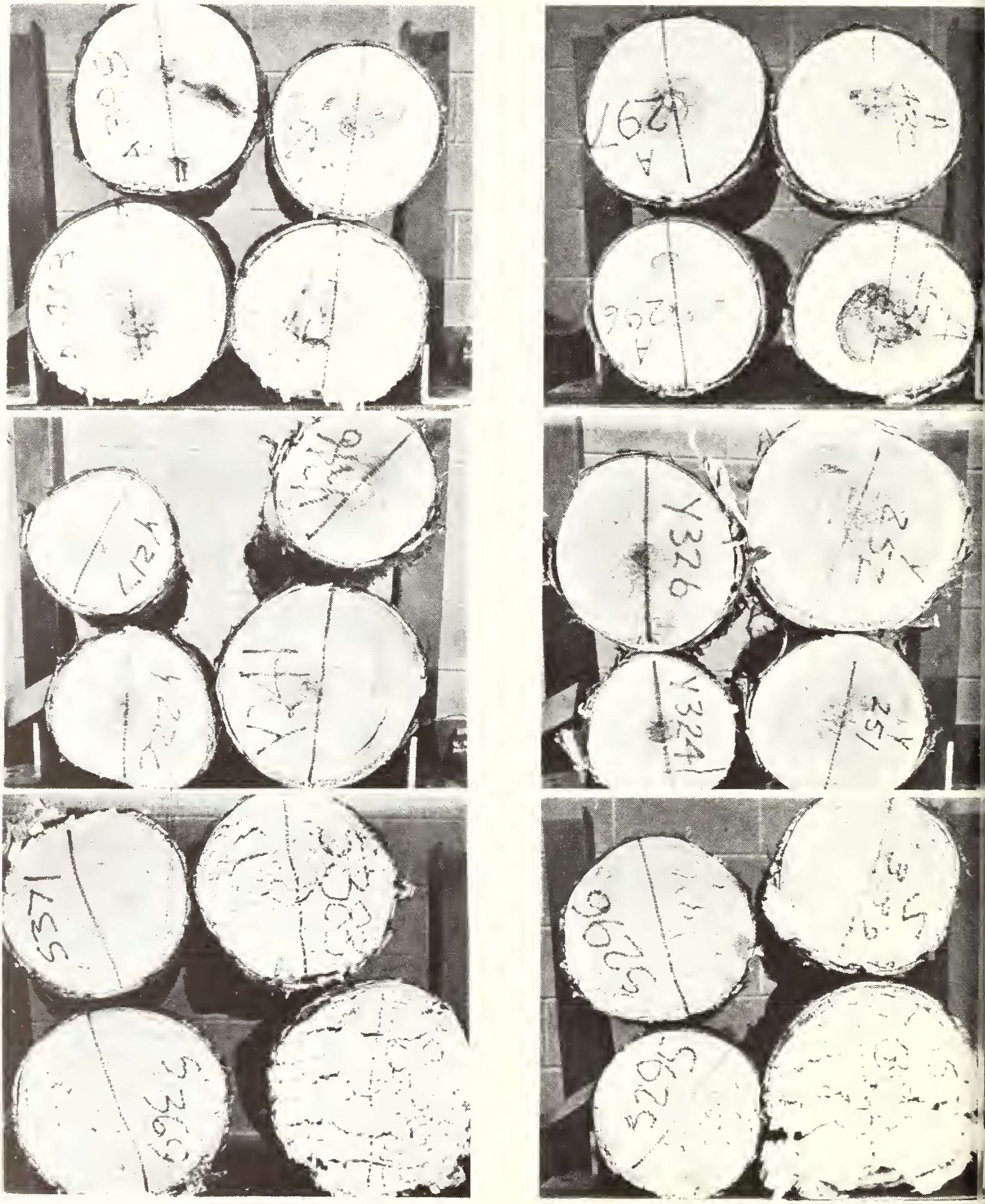

Figure 21. — *Cut faces of unfrozen roundwood bolts sheared with dull shear blades (anvil E, 1.5-inch gap).*

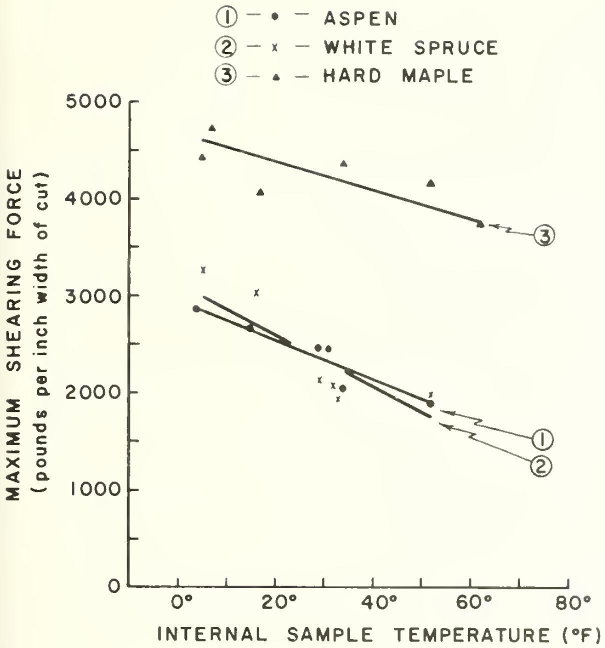

Figure 22. — *Effect of temperature on shearing force (shear blade: ½-inch, 30°, plain).*

creasing temperature. With frozen maple at the lower temperatures, many of the bolts split the entire length, or about 2 feet. These completely split bolts were not included in calculating the mean value of splitting damage because it is not known whether the splits would have been longer or shorter had the bolts been longer to begin with. This is also the case in table 8, where forces are recorded but splitting damage has been omitted. With frozen spruce, extreme fracturing of the cut-face area was frequently noted at the lower temperatures; however, the splits did not extend as far into the bolts as with aspen and maple. In addition, occasional complete tearout of wood chunks was noted in spruce near the last one-quarter of the cut, and the remainder of the cut face was characterized by macro-tearouts of the fibers.

Cutting Speed

Cutting speeds varying between 2 inches per second and 12 inches per second did not affect shear force requirements with either coated or uncoated shear blades. However, power is a function of cutting speed. The instantaneous maximum power which corresponds to the maximum force required to effect the cut is defined as follows:

$$P_{max} = F_{piwc} \times D \times V$$

where

P_{max} = maximum power in inch-pounds per second

F_{piwc} = maximum force required to effect the cut in pounds per maximum inch width of cut

V = cutting speed in inches per second, and

D = log diameter (or maximum width of cut) in inches.

Table 6. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen aspen sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	59	1,584			2.3	1.0
	27	2,299			5.4	1.3
	15	2,374			9.1	3.3
	0	2.608	65	17.4	9.3	1.8
1/2", 30°, Plain	52	1,888			4.3	1.7
	15	2,668			13.7	4.0
	4	2,855	51	20.1	1/ 14.2	1/ 4.0
1/2", 30°, Guillotine	67	1,591			6.1	2.7
	9	2,349			11.7	4.2
	2	2,864	80	19.5	2/ 14.2	2/ 5.1
1/2", 30°, Positive Taper	67	2,074			6.6	2.1
	30	2,960			7.9	1.8
	7	3,041			10.3	4.2
	4	3,463	67	22.1	10.8	3.8
1/2", 30°, Negative Taper	67	1,815			4.7	1.8
	30	2,328			7.0	2.0
	9	3,110			2/ 9.4	2/ 3.1
	0	3,177	75	20.3	2/ 10.9	2/ 3.3
Average				19.5		

1/ Average of four bolts.
2/ Average of three bolts.

A conclusion based on calculations from shear cuts made during the entire study revealed the ratio between average force and the actual maximum required force to effect the cut to be generally 0.65 to 0.75. Thus, the *average* power required to shear a log of a given diameter can be approximated by the following formula using 0.75 for the above ratio:

$$P_{avg} = \tfrac{3}{4}\, P_{max.}$$

To convert either maximum or average power to the standard unit of measurement of horsepower the following conversion is used:

$$1 \text{ HP} = 6600 \text{ in.-lb./sec.}$$

No relationships could be established between splitting damage and cutting speed.

Table 7. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen spruce sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	45	1,962			2.4	1.0
	30	1,902			3.5	1/ 1.2
	16	2,585			3.3	1/ 1.3
	-1	3,347	71	32.3	6.4	1/ 1.4
1/2", 30°, Plain	52	1,978			2.0	1.0
	16	3,016			1/ 6.8	1/ 2.4
	5	3,291	66	27.9	1/ 5.2	2/ 1.4
1/2", 30°, Guillotine	68	1,534			4.3	2/ 1.5
	11	2,631	72	19.2	1/ 6.6	1/ 1.7
1/2", 30°, Positive Taper	65	2,353			4.6	1.0
	32	2,463			1/ 3.6	1/ 1.5
	12	2/ 3,651			3/ 10.0	3/ 1.4
	-3	2/ 3,673	56	19.4	2/ 7.2	2/ 1.1
1/2", 30°, Negative Taper	67	2,158			2.3	1.0
	29	2,123			4.6	1.7
	10	1/ 3,053			1/ 6.3	1/ 0.9
	-2	1/ 3,457	60	18.9	3/ 3.8	3/ 1.0
Average				23.4		

1/ Average of five bolts.
2/ Average of four bolts.
3/ Average of three bolts.

Table 8. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen hard maple sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	64	3,511			7.5	3.3
	16	4,308			1/ 10.6	1/ 7.2
	2	4,296	22	12.7	3/ 6.0	--
1/2", 30°, Plain	52	4.174			11.0	--
	17	4,065			2/ 13.7	1/ 11.2
	7	4,708	13	11.8	--	--
1/2", 30°, Guillotine	69	3,611			10.8	2/ 8.8
	9	4,306			3/ 17.6	3/ 16.2
	0	2/ 4,414	22	11.6	--	--
1/2", 30°, Positive Taper	65	4,187			9.7	6.0
	10	4,743			--	--
	6	4,784	14	10.1	3/ 20.9	3/ 15.1
1/2", 30°, Negative Taper	69	3,673			11.7	7.8
	10	4,823			3/ 16.4	--
	0	5,022	37	19.6	--	--
Average				13.2		

1/ Average of five bolts.
2/ Average of four bolts.
3/ Average of three bolts.

☆ U.S. Government Printing Office 1971-760-19

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PAPER NC-69
1971

STORM FLOW from Dual-Use Watersheds in Southwestern Wisconsin

RICHARD S. SARTZ

NORTH CENTRAL FOREST EXPERIMENT STATION • FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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Approved for publication April 29, 1971

STORM FLOW FROM DUAL-USE WATERSHEDS IN SOUTHWESTERN WISCONSIN

Richard S. Sartz

In southwestern Wisconsin's Driftless Area, known as the "Coulee Region" because of its many narrow, steep-sided valleys, the landscape typically consists of flat or gently rounded ridges, steep slopes, and coulees. Ridgetops and coulees are usually farmed, and the steeper slopes sandwiched between the two are usually forested (fig. 1). This distinctive land-use pattern has an important effect on floods, since runoff from upland fields must pass through the forest zone on its way to valley streams.

The forest zone rarely contributes to floods; and then only insignificant amounts compared with open land (Sartz 1969). Curtis (1966) has shown that the forest zone also absorbs runoff from upland fields, and that only large flows reach valley streams. This paper presents some quantitative comparisons of storm flow from upland fields and outflow at the bottom of the wooded slopes below.

F-510527

Figure 1. — *Looking down a coulee from top of the ridge.*

THE WATERSHEDS

The study watersheds, which are made up of forested slopes rimmed by a segment of open land at the top, are all on the Coulee Experimental Forest. The open uplands rim the watersheds in a rough contour belt that averages about 300 feet wide on a slope of about 15 percent. Gullies carved by overland flow from upland fields slash the forested slopes from top to bottom. The gullies may be 50 feet wide and 25 feet deep on the steeper slopes, and they often form a dendritic pattern, following the natural shape of the watershed (fig. 2). In some places they are washed to bedrock (dolomite in upper reaches, sandstone in lower reaches), and between flows they may become clogged with leaves and debris. The forest is oak-hickory and associated species, typical of high-graded farm woods in the region.

Only four of seven dual-use watersheds studied yielded flow enough times at the lower gage to give a reasonable comparison between upland and total watershed runoff. Total areas ranged from 28 to 83 acres, and upland areas from 6 to 23 acres. The open uplands made up 12 to 31 percent of the study watersheds. Ridgetops are about 350 feet above the lower gaging stations, and slopes range up to about 40 percent.

It was not feasible to gage the entire upland areas because they do not form natural basins. Instead, upland runoff was measured on sample areas. These were simply parts of the upland bounded by natural

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Figure 2. — *Woodland gully on C2 watershed, Coulee Experimental Forest. Note man holding rod (lower left).*

divides on the sides and top and terraced at the field-forest border to channel water through a measuring device. Seven such sample areas that ranged from 1.4 to 2.8 acres were instrumented (fig. 3). The areas chosen approximated natural basins, and thus gave a maximum sample area for a minimum number of measuring stations.

The objective of the study was to determine the effectiveness of the forest zone in disposing of runoff water from fields above. To produce variable amounts of field runoff, the uplands were planted to both high (corn, oats, and field peas) and low (alfalfa meadow) runoff-producing crops during the study period.

Watershed C2 was gaged from 1962 to 1967, and the other three from 1962 to 1969. The upland sample watersheds were gaged concurrently. The upland areas of watersheds C1, C2, and C3, which were treated alike, were planted annually to row crops from 1962 through 1965. In 1965 alfalfa was seeded along with oats. C4 upland was seeded to alfalfa in 1962 and remained in meadow for the duration of the study. Row-crop runoff was, of course, much greater than meadow runoff (Sartz 1970), but the differences are immaterial here except that they provided variable amounts of field runoff for the field versus total watershed runoff comparison. Because the objective of the study was to determine how much of the field runoff passed through the forest zone, lower station runoff is given in terms of inches depth on the upland area.

Runoff was measured by 1.5-foot H flumes at upper stations and by 2-foot San Dimas flumes at lower stations (fig. 4). Suspended sediment was measured as described by Sartz and Curtis (1967). Upland runoff from watersheds C2, C3, and C4 was assumed to equal the mean runoff from their respective sample areas, and upland runoff from C1 was assumed to equal that of adjacent watershed C2 (fig. 3). Most of the water measured at the lower stations was assumed to have come from the upland areas of the water-

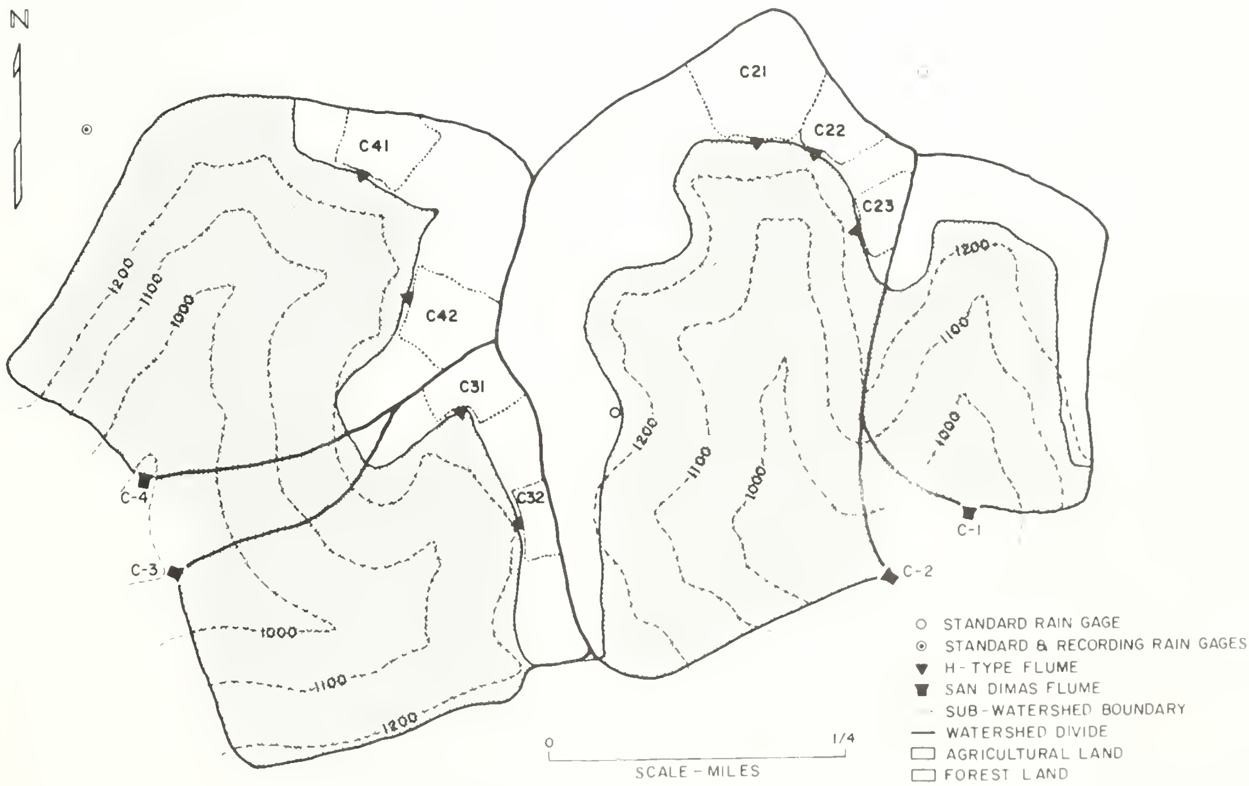

Figure 3. — *Map of study watersheds.*

sheds. Although some may have come from channel or forest areas during major storms, the amounts would have been small compared with the upland component (Sartz 1970).

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Figure 4. — *San Dimas flume used at lower stations.*

RESULTS

As previously reported by Curtis (1966), most of the upland flows never reached the bottom of the forested slopes. The number of flows recorded at upper and lower stations on three watersheds (C1 had no upland gages) in a 6-year period was:

Watershed	*Upper*	*Lower*
C2	118	40
C3	89	13
C4	69	3

Minimum upland flows that produced lower station flows ranged from 0.02 to 0.08 area inches. In general, the larger the upland flow, the larger the lower station flow and the larger the proportion of upland runoff that reached lower stations; but there were many exceptions. For example, the largest flow on watershed C3 (produced by a 3-inch, high-intensity storm) was 1.49 inches from the upland and 1.00 inch at the lower station. Assuming no contribution from the forest zone, only 67 percent of the upland flow reached the bottom of the forested slope. But a much smaller upland flow of only 0.19 inch from another storm produced a lower station flow of 0.16 inch, or 84 percent. Similar examples could be cited for the other three watersheds.

Lower station flow as a percentage of upland flow for individual storms ranged from 0 to 110. Lower station flows exceeded the estimated upland runoff (reflecting some contribution from forest and/or gullied channel areas) once on three of the four catchments. Lower station flows as mean percentage of upland runoff for eight large storms were as follows: C1, 84; C2, 94; C3, 79. C4 was not included because it yielded flow at the lower station from only one of the eight storms. In six other major storms when C4 did have flow at the lower station, the flow was 56 percent of the upland flow, while for the same storms, the value for C3 was 62 percent.

Maximum peak flows at lower stations ranged from 0.21 (C4) to 0.99 (C1) inch per hour, based on total watershed area. Considering only the uplands as the contributing area, the values were 1.71 and 4.96 inches per hour. The corresponding upper station peaks were 2.62 and 2.37 inches per hour. Timing of flow at upper and lower stations is illustrated by the hydrographs for a short, high-intensity rain (fig. 5) and for a longer, but less intense rain (fig. 6). Rainfall for the former was 1.25 inches in 35 minutes, for the latter, 2.50 inches in 150 minutes. Both rains fell on wet soil. Although the larger storm produced more flow on two of the three watersheds, the smaller storm produced considerably higher peak flows at both upper and lower stations.

Some differences between watersheds in the response of lower station flow to upland flow have already been shown. Data from the May 25, 1965, storm, which produced the greatest amount of flow and the highest peaks, offer an additional comparison:

Upper stations	*Total flow Inches*	*Peak-flow Inches per hour*
21	1.40	1.89
22	1.82	2.14
23	1.75	3.08
31	1.36	2.48
32	1.62	3.14
Lower stations		
1	1.61	4.96
2	1.59	1.88
3	1.00	3.27

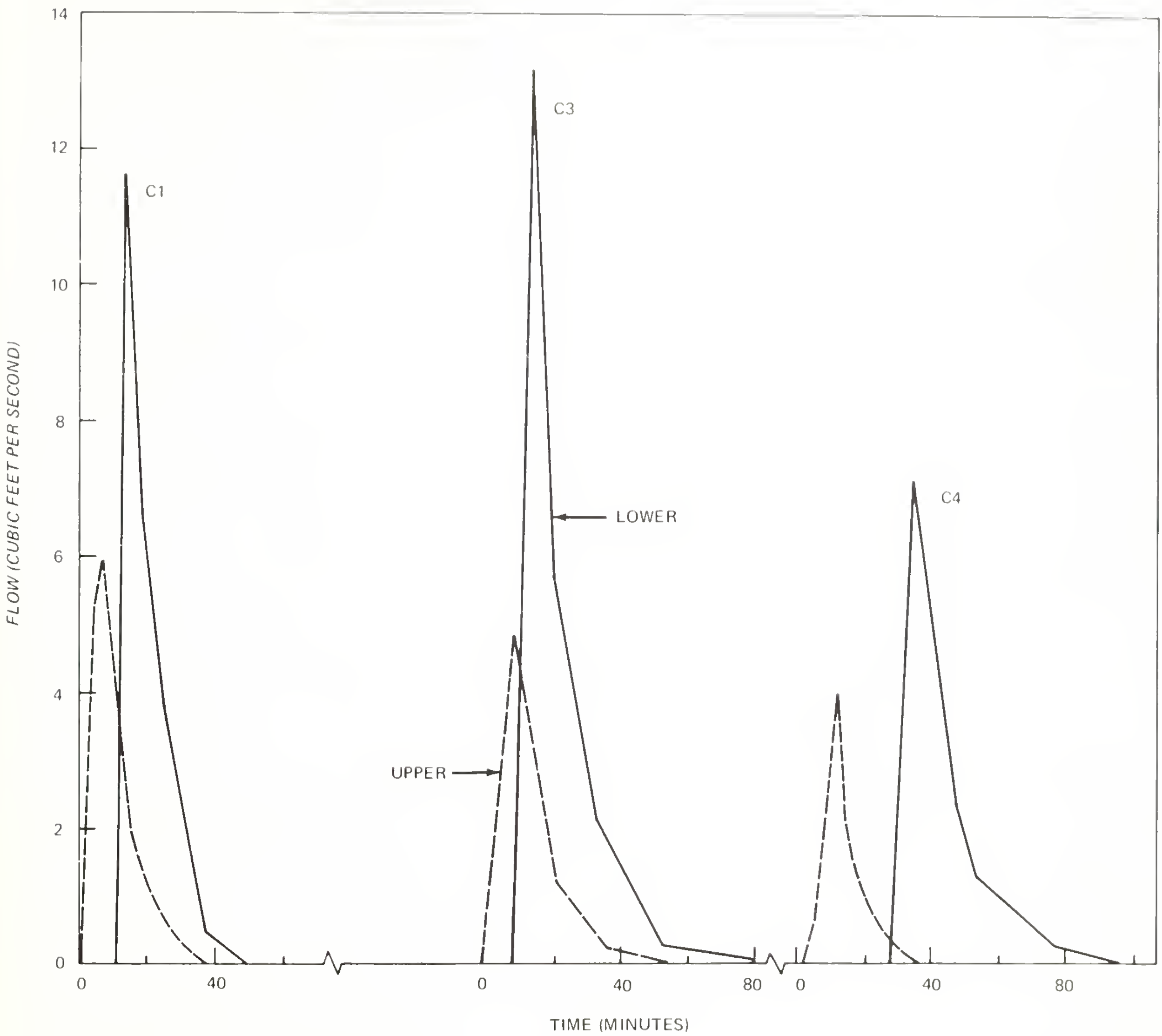

Figure 5. — *Hydrographs for three upper and lower stations, storm of June 8-9, 1967. Flow is in cubic feet per second. Comparative size of the individual watersheds can be seen in figure 3.*

Both total and peak flows for lower as well as upper stations are based on upland watershed areas. The upland areas of all three watersheds were newly seeded to oats and there was little cover at the time of the storm. C4 upland was in third-year meadow, and although it produced an estimated 0.20 inch of runoff, there was no flow at the lower station. Suspended sediment in the runoff water was generally higher at lower stations than at upper stations (table 1).

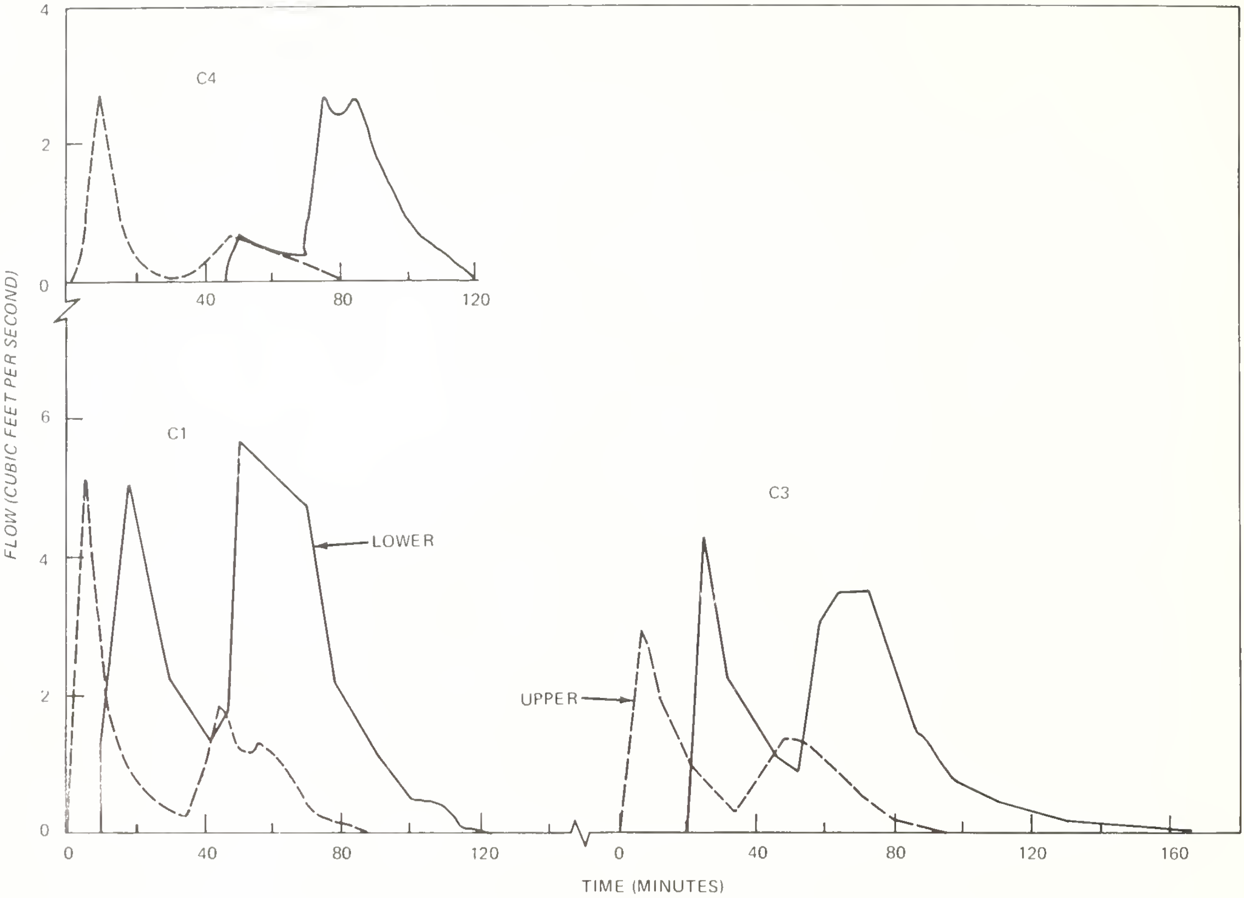

Figure 6. — *Hydrographs for three upper and lower stations, storm of June 26, 1969. Flow is in cubic feet per second. Comparative size of the individual watersheds can be seen in figure 3.*

Table 1. — *Mean suspended sediment content at upper and lower stations on watersheds C2 and C3*
(In parts per million/100)

Date of storm	C2		C3	
	Upper	Lower	Upper	Lower
May 21, 1965	1,667	1,969	716	918
May 25, 1965	1,956	1,392	818	1,406
July 9, 1965	232	431	80	432
August 14, 1965	40	205	36	83
August 17, 1965	58	129	22	86
August 27-28, 1965	24	59	11	97
June 9, 1967	103	375	46	1,800
Average	583	651	247	689

DISCUSSION

Although the forest zone disposed of much of the upland runoff, its effectiveness varied greatly from storm to storm and from watershed to watershed. Storm-to-storm variation resulted from differences in rainfall amount, intensity, interaction of the two, and in the amount of water in the soil when the storm began. The amount of channel debris also may have been a factor. The lower channels of watersheds C3 and C4, which had much less frequent flows than those of watersheds C1 and C2, sometimes had 2- or 3-year accumulations of leaves and branch material, and this would have slowed the flow, allowing more channel infiltration.

Water flow differences among watersheds could result from differences in the size and shape of the watersheds, channel areas, debris, meander patterns, the forest litter cover, storm rainfall, the relative size and shape of the upland, and the reliability of the upland runoff estimate.

Although we did not survey the forest litter cover on each watershed, a comprehensive survey of the experimental forest showed uniform litter and humus depths on similar ungrazed areas (Knighton 1970). Storm rainfall was generally uniform, particularly for the larger storms (Sartz 1966). Of the geomorphic features that we measured (total area, upland and forest areas, and gullied channel area), only the ratio of upland to forest areas appeared related to the response of lower station flow to upland flow. The relationship was most evident for larger storms:

	Watershed			
	C2	*C1*	*C3*	*C4*
Lower station flow as percent of upland runoff	96	80	71	56
Ratio of upland to forest areas	1:3	1:5	1:7	1:8

Some lower station peak flows were higher (based on the upland area) than their corresponding upper station peak flows. This might be expected. Lower station runoff came from the entire upland area of the watershed while upper station runoff came from small sample areas. The larger contributing area could have generated higher peaks because of timing effects. Channel interception of rainfall may also have contributed to the higher peaks. However, as recently pointed out by Hewlett and Helvey (1970), peak flows on small, upstream tributaries have less effect on downstream floods than the total volume of storm flow from the tributaries.

Higher sediment contents in lower station flows was not surprising. We have seen muddy water flowing through lower station flumes when upland runoff (from snowmelt) was clear. Apparently the water picks up sediment deposited by earlier, smaller flows or by bank sloughing as it flows through the steep, eroded channels of the forest zone.

The method of estimating upland runoff by measuring the flow from sample watersheds may have tended to increase both the flow and sediment content measured at lower stations on those watersheds (C2, C3, and C4) that had upland sample areas. The sample watersheds made up 31 to 53 percent of the upland areas. Their runoff was cut off by the artificial terraces and thus concentrated in the channels in larger amounts than would have occurred naturally. Without the terraces the water would have flowed into the forest in a more diffuse pattern, and some of it would have infiltrated before it reached runoff channels.

The study showed that the forest zone in the Driftless Area does reduce the contribution of upland fields to flooding streams. Further reductions can be made by simple practices along the field-forest border (Curtis 1967). Information is now being sought on how the forested slopes might be improved as the disposing ground for field runoff.

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SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Pest Susceptibility Variation in Lake States Jack-Pine Seed Sources, by James P. King, USDA Forest Serv. Res. Pap. NC-53, 10 p., illus. 1971.

Influence of Stand Density on Stem Quality in Pole-size Northern Hardwoods, by Richard M. Godman and David J. Books, USDA Forest Serv. Res. Pap. NC-54, 7 p., illus. 1971.

The Dynamic Forces and Moments Required in Handling Tree-length Logs, by John A. Sturos, USDA Forest Serv. Res. Pap. NC-55, 8 p., illus. 1971.

Growth and Yield of Black Spruce on Organic Soils in Minnesota, by Donald A. Perala. USDA Forest Serv. Res. Pap. NC-56, 16 p., illus. 1971.

Impact of Insects on Multiple-Use Values of North-Central Forests: An Experimental Rating Scheme, by Norton D. Addy, Harold O. Batzer, William J. Mattson, and William E. Miller. USDA Forest Serv. Res. Pap. NC-57, 8 p., illus. 1971.

Growth and Yield of Quaking Aspen in North-Central Minnesota, by Bryce E. Schlaegel. USDA Forest Serv. Res. Pap. NC-58, 11 p., illus. 1971.

Sediment in a Michigan Trout Stream, Its Source, Movement, and Some Effects on Fish Habitat. by Edward A. Hansen, USDA Forest Serv. Res. Pap. NC-59, 14 p., illus. 1971.

Factors Influencing Campground Use in the Superior National Forest of Minnesota, by David W. Lime. USDA Forest Serv. Res. Pap. NC-60, 18 p., illus. 1971.

The Changing Market for Wood Materials Used in Farm Structures, by David C. Baumgartner. USDA Forest Serv. Res. Pap. NC-61, 6 p., illus. 1971.

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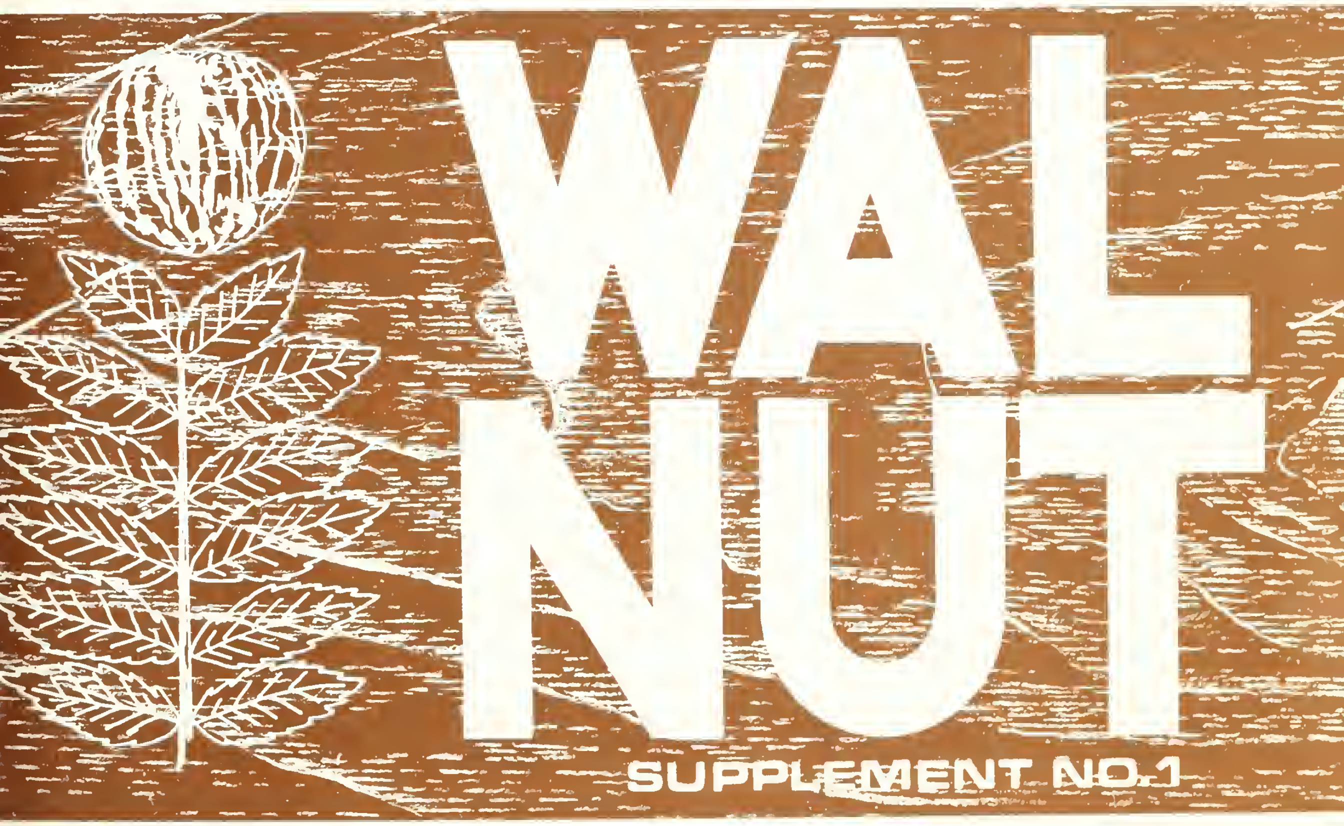

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FOREWORD

Since publication of "An Annotated Bibliography of Walnut and Related Species," USDA Forest Service Research Paper NC-9, by David T. Funk in 1966, we have accumulated an additional 208 literature references dealing with *Juglans* ecology, silviculture, and timber products. This supplement is an attempt to up-date the previous bibliography, by including citations that were unintentially omitted in the original publication and those published since 1966.

The bibliography is arranged in alphabetical order by author. An index at the back provides a list of items by subject matter. More than four-fifths of the items are annotated. Most of the remainder were either not seen by the authors or were in a foreign language, with no English summary or translation available.

We would appreciate being notified of any errors in the list and also would be glad to know of any publications that were omitted and should be included in a future supplement.

THE AUTHORS: Martha K. Dillow, Clerk-Stenographer, and Norman L. Hawker, Forestry Research Technician, are stationed at the Forestry Sciences Laboratory in Carbondale, Illinois. The Laboratory is maintained in cooperation with Southern Illinois University.

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Manuscript approved for publication September 3, 1971

ANNOTATED BIBLIOGRAPHY OF WALNUT — SUPPLEMENT NO. 1

Martha K. Dillow and Norman L. Hawker

1. Althen, F. W., von. 1968. INCOMPATIBILITY OF BLACK WALNUT AND RED PINE. Bimon. Res. Notes 24(2): 19.
In a 16-year-old mixed plantation, red pine interplanted with red oak appeared healthy and grew normally, while red pine mixed with black walnut began to die after 15 years; all pine trees mixed with walnut appeared to be sick or dying.

2. Althen, F. W., von. 1971. BLACK POLYETHYLENE MULCH, BEST FOR GERMINATION AND GROWTH OF SEEDED BLACK WALNUT. Bimon. Res. Notes 27(2): 16-17.
Three walnut seeds were seeded in each seed spot. Weed control treatments consisted of (1) mulching with a 3-foot-wide cover of black polyethylene film, (2) mulching with a layer of hardwood sawdust, (3) manual weeding in June and July of the first year, and (4) a single application of 1.5 pounds of active dalapon per acre. Emergence of germinants was earliest and germination was highest in the polyethylene-covered plots. Seedling survival and 5-year growth were also best in these plots. While weed control was fair to good in all plots during the first year, only polyethylene mulch afforded effective control during the second year.

3. Anonymous. 1969. [SPECIAL NUMBER ON JUGLANS REGIA AND OTHER NUT CROPS.] Lesn. Hoz. 2: 2-59. [In Russian.]
A collection of 20 papers covering various aspects of the fruiting, plantation management, and natural stands of Juglans regia in southern U.S.S.R. The most important papers are: Trial thinnings in mixed Juglans regia stands in the forests of Moldavia *(A. I. Golikov) (recommends, on the basis of trials, a first thinning to 1,200-1,600 trees/ha. at age 5-8, completely removing any associate species and shrubs);* Dichogamy and fruiting of Juglans regia *(A. D. Majackaja) (concludes that selection for high nut yield may be made from both protogynous and protandrous trees, but preference should be given to the protogynous trees);* Selection of plus-trees of Juglans regia in the Ukraine *(V. N. Nenjuhin) (describes procedures in selection for fruit yield, frost- and drought-resistance, etc., and study of fruit quality);* Creating Juglans regia plantations on slopes in the central part of the north Caucasus *(E. M. Hričenko) (discusses growth rate as a function of position on terrace);* Varietal seed production and propagation of Juglans regia in Kirghizia *(Ju. I. Nikitinskij); and* Raising Juglans regia in irrigated nurseries *(T. A. Želtikova) (discusses fertilizer requirements in the production of planting stock in Central Asian nurseries).*

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Describes how to split germinating black walnut seeds to obtain genetically identical paired seedlings for research purposes.

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Quality Nut Tree, Spec. Issue, Part 1, 6(1): 9-12, illus. Ill. Nut Tree Ass., Urbana.
Discusses the two most important characteristics in selecting superior trees for the production of walnut timber: straightness and rapid growth.

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Geographic variation in 480 1-year-old families of black walnut was studied. For most characters, the pattern of variation was clinal. Source variation for most characters was from three to five times greater than family variation.

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A complete black walnut improvement plan should include testing on four cultural intensity-site combinations within each climatic zone. Improved walnut varieties will be bred for rapid growth, strong terminal shoots, straight stems, small branches, insect and disease resistance, and drought hardiness.

10. Bey, Calvin F., and Phares, Robert E. [n.d. Circa 1969]. SEASONAL GROWTH PATTERN FOR FIVE SOURCES OF BLACK WALNUT. Cent. States Forest Tree Improv. Conf. Proc. 6: 44-47, illus.
Height and weight of black walnut seedlings from five sources were measured throughout the growing season. Height growth ceased first, followed by shoot and root dry weight accumulation. Seedlings from southern sources grew taller and accumulated more dry matter than those from northern sources.

11. Bey, Calvin F., Toliver, John R., and Roth, Paul L. 1971. EARLY GROWTH OF BLACK WALNUT TREES FROM TWENTY SEED SOURCES. USDA Forest Serv. Res. Note NC-105, 4 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.
Early results of a black walnut seed source study conducted in southern Illinois suggest that seed should be collected from local or south-of-local areas. Trees from southern sources grew faster and longer than trees from northern sources. Trees from southern sources flushed slightly earlier and held their leaves longer than trees from northern sources. For the 1969 season, height growth rate was best explained by the rainfall pattern. Diameter growth rate was more closely related to air and soil temperatures than to rainfall and soil moisture.

12. Blyth, James E., Kallio, Edwin, and Callahan, John C. 1969. STANDING TIMBER COEFFICIENTS FOR INDIANA WALNUT LOG PRODUCTION. USDA Forest Serv. Res. Pap. NC-33, 9 p., illus. N. Cent. Forest Exp. Sta., St. Paul, Minn.
If the volume of walnut veneer logs and saw logs received at processing plants from Indiana forests is known, conversion factors developed in this paper can be used to determine how much timber was cut to provide these logs and the kinds of timber cut (sawtimber, cull trees, trees on nonforest land, etc.).

13. Boelkins, James N., Everson, Lloyd K., and Auyong, Theodore K. 1968. EFFECTS OF INTRAVENOUS JUGLONE IN THE DOG. Toxicon 6: 99-102, illus.
Juglone was dissolved in an ethanol-glucose mixture and injected intravenously into anesthetized dogs. Histopathologic changes in lungs and liver support the view that juglone is toxic to the cell membrane, increasing capillary permeability.

14. Boesewinkel, F. D., and Bouman, F. 1967. INTEGUMENT INITIATION IN JUGLANS AND PTEROCARYA. Acta bot. neerl. 16(3): 86-101, illus.
A histological study of the initiation and development of the ovule integument in J. regia and P. fraxinifolia.

15. Böhm, H. 1970. [WALNUT PESTS.] ErwObstb. 12: 10-12, illus.
Recommends the following control measures for walnut pests in nurseries: parathion, preferably with a systemic insecticide, for controlling the moth Gracilaria juglandella; sulphur dust, lime-sulphur, or thiodon for the gall mite Eriophyes tristriatus; and phosphoric esters for the damson scale Lecanium corni. Codling moth (Cydia pomonella) infestation of adult trees can only be dealt with by collecting and destroying affected fruits.

16. Bouillot, Jacky. 1968. CONTRIBUTION À L'ÉTUDE DE LA GAMÉTOGENÈSE FEMELLE CHEZ LE JUGLANS REGIA L. (JUGLANDACÉES). Acad. Sci. (Paris) Comptes Rendus 266(D): 1397-1400, illus.
Gamatogenesis of Juglans regia is characterized by its relatively long duration, the occasional presence of excess megosporocytes deep within the nucellus, the customary formation of an embryonic sac from the megaspore micropyle, the delayed fertilization of the polar nucleus, and the production of a male gamete and triploid endosperm.

17. Boyce, S. G., Kaeiser, M., and Bey, C. F. 1970. VARIATIONS OF SOME WOOD FEATURES IN FIVE BLACK WALNUT TREES. Forest Sci. 16(1): 95-100.
Detailed analyses were made of wood samples taken from five black walnut trees grown in southern Illinois. Specific gravity varied with height and distance from the pith. Tangential shrinkage was greater than radial shrinkage and was negatively correlated with the number of vessels. As growth rate increased, specific gravity increased, fiber area increased, vessel lumen size decreased, and number of vessels decreased.

18. Boyer, D. E., et al. 1967. CONTROL OF MISTLETOE, PHORODENDRON FLAVESCENS, ON ENGLISH WALNUTS IN CALIFORNIA. HortScience 2: 10-11.
Clumps of mistletoe 3 to 24 in. in diameter were sprayed with 13 different herbicides all at 10,000 p.p.m. active ingredient together with surfactants at 0.1 percent by volume and oil additions at 6.0 percent to aid penetration of the herbicide into the mistletoe foliage and minimize penetration through the walnut bark. The most satisfactory control 5 years after treatment was obtained with amitrol with X-77 or a dormant emulsive oil, atrazine with dormant emulsive oil, or the isopropyl ester of 2,4-D with Volk oil. Few symptoms of herbicide injury were evident in the host trees.

19. Brauner, A. B., and Loos, W. E. 1968. COLOR CHANGES IN BLACK WALNUT (JUGLANS NIGRA) AS A FUNCTION OF TEMPERATURE, TIME, AND TWO MOISTURE CONDITIONS. Forest Prod. J. 18(5): 29-34.
Saturated sapwood treated at 125° C. closely approached the color of natural heartwood within about 16 hours.

20. Brinkman, Kenneth A. 1966. GROWTH AND YIELD ON PRAIRIE SOILS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 50-52, illus.
In "cornbelt" black walnut plantations, board-foot volume growth rate was correlated with site quality and yields were influenced by degree of grazing and initial spacing of trees; maximum growth occurred between ages 40 and 50 on the better sites.

21. Byrnes, W. R. 1966. SITE PREPARATION AND WEED CONTROL. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 20-27.
Describes methods for site preparation and weed control in black walnut plantings and their possible results.

22. Calo, Luciana. 1966. [ON THE FLORAL BIOLOGY OF THE WALNUT IN PUGLIA.] Bari. Univ. Fac. Agr. Ann. (It.) 20: 323-342.
Describes morphological characters of different types of walnut buds and flowers and reports results of 2 years of observations on flower biology. These studies were carried out on 275 seedlings. In 1965 protandry and protogyny were observed on 29.4 percent and 31.3 percent of the trees respectively, and in 1966 on 4.4 and 4.0 percent of the trees.

23. Carmean, Willard H. 1966. SOIL AND WATER REQUIREMENTS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 32-34, illus.
Walnut grows best on deep, loamy, well-aerated soils. Intensive treatment to improve poor sites may be feasible in the future.

24. Černý, L. 1965. [GRAFTING WALNUT AND OTHER WOODY SPECIES DURING THE PERIOD OF TRUE WINTER DORMANCY.] Biol. Plant., Praha 7(3): 226-237, illus. [In German.]
Under favorable conditions--e.g., in a propagating house--during true winter dormancy, damage to the shoots of woody species results in localized elimination of the inhibition of cell division in meristem near the wound, while the rest of the plant still remains dormant. Grafting can thus be done indoors in winter without buds opening on the stock or scions. Photomicrographs are presented of the graft tissue formed with this grafting technique in J. regia.

25. Černý, L. 1969. [A NEW METHOD OF PRODUCING JUGLANS REGIA GRAFTS.] Rost. Vyroba, Praha 15(5): 521-530. [In Czechoslovakian with English summary.]
A detailed, illustrated description of the procedure and equipment developed for large-scale grafting of scions to 1- or 2-year rootstocks indoors during true winter dormancy, without buds opening. The grafts are placed in special heating boxes filled with sterilized sawdust and kept in the greenhouse at 27° C. and high relative humidity for 3 weeks. They are then stored in a cellar, still in boxes and at not less than 0° C., until planting out in the spring. Successful trials made in 1966-1969 with ca. 40,000 plants (including some J. nigra) showed 60 to 70 percent take. Methods used were whip-and-tongue grafts with plastic tubing as binder, and a technique of machine grafting without binding that is to be patented (no details given).

26. Chapelle, A. 1966. [THE TECHNIQUE OF GRAFTING WALNUTS IN THE OPEN.] Rev. Hort.,

Paris 138: 1128-1132, illus.
The methods described include cleft grafting, crown grafting, whip-and-tongue grafting a variation of side grafting known as the Cadillac method, rind grafting, and a combination of rind grafting and budding (using patches of bark bearing dormant buds).

27. Clark, F. Bryan. 1966. INCREMENT BORERS CAUSE SERIOUS DEGRADE IN BLACK WALNUT. J. Forest. 64(12): 814, illus.
Boring black walnut trees causes large wounds and butt-log degrade.

28. Clark, F. Bryan. 1966. CULTURE OF IMMATURE TREES. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 42-46, illus.
Recommends early pruning and release from competition in young black walnut plantations to obtain straight, clear stems and good growth.

29. Clark, F. Bryan. 1967. POLE-SIZED BLACK WALNUT RESPOND QUICKLY TO CROWN RELEASE. J. Forest. 65(6): 406-408, illus.
After 4 years black walnut trees given complete crown release were growing twice as fast as trees not released.

30. Clark, F. Bryan. 1969. FACTORS AFFECTING THE PRODUCTION OF FIBROUS ROOTS ON BLACK WALNUT SEEDLINGS. Dissert. Abstr. 29B(7), (2252).
In a series of greenhouse studies of seedlings of J. nigra, the production of fibrous roots was affected by changes in the moisture and bulk density of the soil, the addition of organic materials, and the soil type. Root initiation was studied in 1-year seedlings planted against glass. Field plantings showed slightly better growth for fibrous-rooted seedlings and seedlings root-pruned in the nursery beds.

31. Clark, F. Bryan. 1969. GROWING BLACK WALNUT TIMBER. In Handbook of North American nut trees. Richard A. Jaynes, Ed., Geneva, New York: W. F. Humphrey Press, Inc. p. 212-223, illus.
Dual crops of nuts and timber are suggested for the black walnut grower. The nut culturist must sacrifice some early nut production to produce at least one 8-1/2-foot log with clear wood to meet minimum industry standards for utilization. Site selection, planting, weed control, spacing, pruning, and harvesting are discussed.

32. Clark, F. Bryan. 1970. MEASURES NECESSARY FOR NATURAL REGENERATION OF OAKS, YELLOW-POPLAR, SWEETGUM, AND BLACK WALNUT. In The silviculture of oaks and associated species. USDA Forest Serv. Res. Pap. NE-144, p. 1-16. Northeast. Forest Exp. Sta., Upper Darby, Penn.
Reports present knowledge of factors needed to regenerate the oaks, yellow-poplar, black walnut, and sweetgum. Concludes that the information now available is sufficient to make substantial improvements in practices to control composition.

33. Clark, F. Bryan. 1971. PLANTING BLACK WALNUT FOR TIMBER. USDA Forest Serv. Leafl. 487 (Rev.), 10 p., illus.
A brief step-by-step description of how to select the site, prepare the planting area, plant the seedlings, and tend the plantation.

34. Condat, G. 1965. [AN INTERESTING EXPERIMENT: THE WALNUT PLANTATION AT SAUZÉ-VAUSSAIS.] Rev. for. franc. 17(7): 525-533. [In French.]
Discusses the declining importance and reduction in numbers of walnut trees on the fringes of the Massif Central, attributable to various factors, including severe storms and frosts in recent years, root diseases, damage by farm machinery, and felling; also describes the establishment in 1960-63 of a new experimental plantation at Sauzé-Vaussais, of selected strains of Juglans regia in mixture with J. nigra, both spot-sown.

35. Cooper, Glenn A., Erickson, Robert W., and Haygreen, John G. 1970. DRYING BEHAVIOR OF PREFROZEN BLACK WALNUT. Forest Prod. J. 20(1): 30-35, illus.
Shrinkage, strain and set development, moisture gradients and drying rate, drying defects, and changes in extractive availability were measured in 2- by 4- by 36-inch surfaced dimension parts of black walnut (Juglans nigra L.) prefrozen at -10°, -100°, and -320° F. Shrinkage in both set-free slices and boards was reduced by prefreezing. Prefreezing apparently had an effect on wood fiber hygroscopicity and shrinkage, and an accompanying effect on board-set development due to altered rheological properties. Drying behavior indicated that much of the effect of prefreezing was dependent on the free-water fraction.

36. Cummins, James N. 1969. SCREEN-GIRDLING OF TRENCH-LAYERED BLACK WALNUT TREES. Plant Propagator 15(4): 17-21.
Gagnon's system of automated girdling was effectively applied using hardware cloth of 3, 4, or 6 mesh per inch to juvenile eastern black walnut seedlings that were trench-layered.

37. Cummins, James N., and Ashby, W. C. 1969. ASEPTIC CULTURE OF JUGLANS NIGRA L. STEM TISSUES. Forest Sci. 15(1): 102-103.
Explants of black walnut stem tissues were cultured aseptically on agar media for 15 weeks. A modified White's medium with vitamin supplement was used, with additional naphthaleneacetic acid (NAA) and kinetin. Transfers of callus did not grow on an auxin-free medium; on NAA-containing medium, growth continued for about a month. No organogenesis was observed.

38. Davis, B., II. 1965. A FURTHER REPORT ON ENGLISH WALNUT BUD DORMANCY. N. Nut Growers Ass. Annu. Rep. 56: 111-114.
When Juglans regia scions were budded on J. nigra rootstocks, the buds survived well but only 20 to 30 percent of them broke into growth the following spring. Out of 15 treatments tested to overcome this problem, promising but inconclusive results were obtained with breaking over the tops of the rootstocks 9 days after budding instead of immediately after budding, and with painting the bud shields with indolebutyric acid (IBA), naphthaleneacetic acid (NAA), or gibberellic acid (GA).

39. David, C. 1968. TO STRATIFY PERSIAN WALNUT SEED. N. Nut Growers Ass. Annu. Rep. 58: 77-78.
Describes two methods: winter stratification by burying nuts in a container, and spring stratification by soaking the nuts in water before sowing.

40. Dawson, R. E., Usher, E. G., Jr., and Mitchell, H. L. 1962. STABILIZED WOOD GUNSTOCKS IN MARINE CORPS MARKSMANSHIP COMPETITION. USDA Forest Prod. Lab. Rep. 2245, 12 p., illus.
Polyethylene glycol treatment of black walnut stocks maintains rifle accuracy under widely fluctuating conditions of service.

41. Day, B. E., Lange, A. H., and Jordan, L. S. 1966. DIURON AND SIMAZINE FOR WEED CONTROL IN WALNUT ORCHARDS. Calif. Agr. Exp. Sta. Ext. Serv. Leafl. 194.
Recommends rates, dates, and methods of herbicide application.

42. Dickson, Richard E. 1970. THE EFFECTS OF SOIL MOISTURE, TEXTURE AND NUTRIENT LEVELS ON THE GROWTH OF BLACK WALNUT (JUGLANS NIGRA L.) UNDER GREENHOUSE CONDITIONS. First N. Amer. Forest Biol. Workshop Abstr. 18.
Black walnut plants were grown from seed in a clay loam and in a sandy soil under two soil moisture regimes and three nutrient levels. Fertilization increased growth only under moist conditions. Under drought conditions, fertilization had no effect in the clay loam soil, but reduced growth in the sandy soil. Without fertilization, seedling growth was greater under moist conditions. These growth differences were accentuated the second growing season, thus indicating the importance of the past environment on the present year's growth of black walnut.

43. Dingle, Richard W. 1952. SURVIVAL AND GROWTH OF FOREST PLANTATIONS IN MISSOURI. J. Forest. 50(11): 845-849, illus.
Black walnut survival averaged only 31 percent; poor site preparation, erosion, and poor plantation care were responsible for much of the loss.

44. Dorodneva, V. I. 1967. [IDENTIFICATION OF THE CAROTENOIDS OF JUGLANS REGIA LEAVES BY SPECTROPHOTOMETRY AND THIN-LAYER CHROMATOGRAPHY.] Rast. Resursy, Moskva 3(2): 266-268. [In Russian.]
β-carotene, lutein, violaxanthin, neoxanthin, flaxoxanthin and cryptoxanthin were identified.

45. Englerth, George H. 1966. MACHINING AND OTHER PROPERTIES OF FAST- VERSUS SLOW-GROWN TREES. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 77-82, illus.
Limited tests on black walnut indicate that wood from fast-grown trees is equal or superior in planing, shaping, and turning qualities to wood from slow-grown trees. Fast-grown material had a higher specific gravity and was tougher.

46. Erdmann, Gayne G. 1966. PLANTING. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 28-31, illus.
Describes methods for planting and direct seeding black walnut in forest plantations.

47. Erdmann, Gayne G. 1967. CHEMICAL WEED CONTROL INCREASES SURVIVAL AND GROWTH IN HARDWOOD PLANTINGS. USDA Forest Serv. Res. Note NC-34, 4 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.
In a plantation of four hardwood species on a silt loam soil planted to 1-0 stock, 4 pounds of active atrazine or simazine controlled weeds effectively without injuring the trees. Chemical weed control was more effective on plowed and disked ground than on unprepared ground. Yellow-poplar and white ash grew faster on prepared ground. Black walnut and red oak did not respond to ground preparation treatments. Guides are presented for proper use of the chemicals in

establishing hardwood plantations.

48. Erdmann, Gayne G., and Green, LeeRoy. 1967. CHEMICAL WEED CONTROL IN A TWO-YEAR-OLD WALNUT PLANTING. USDA Forest Serv. Res. Note NC-28, 4 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.
Six herbicide mixtures were sprayed directly on broadleaf weeds and grasses competing with black walnut trees. Mixtures of paraquat (1/2 pounds/acre) with simazine (4 pounds/acre) or atrazine (4 pounds/acre), and amitrole (2 pounds/acre) plus simazine (4 pounds/acre) gave satisfactory weed control, which resulted in significantly better tree height and diameter growth.

49. Erickson, R. W., Haygreen, J., and Hossfield, R. 1966. DRYING PREFROZEN REDWOOD WITH LIMITED DATA ON OTHER SPECIES. Forest Prod. J. 16(8): 57-65.
Prefreezing samples 1.25 by 2 by 6 inches at -25° C. resulted in decreased shrinkage of redwood, black walnut, black gum, tanoak, golden chinkapin, and rosewood. Prefrozen black walnut also dried faster than controls.

50. Erickson, R. W., and Petersen, H. D. 1969. THE INFLUENCE OF PREFREEZING AND COLD WATER EXTRACTION OF WOOD. Forest Prod. J. 19(4): 53-57.
Prefreezing with dry ice (-79° C.) reduced the radial shrinkage of 4/4 black walnut boards 20 percent, and tangential shrinkage about 10 percent. These reductions developed almost entirely after average moisture content dropped below the fiber saturation point. There was no significant difference in the drying rate and strain patterns of prefrozen and control boards. Prefreezing at -25° C. did not have a significant effect on the shrinkage of 4/4 walnut boards.

51. Farmer, Robert E., Jr. 1971. ROOTING BLACK WALNUT CUTTINGS. Plant Propagator 17 (2): 7-9.
Two-year-old seedlings were lifted from nursery beds in February, planted in loam-filled pots, and pruned back to the root collar. Pots were then placed in a greenhouse dark chamber where etiolated shoots subsequently developed. When shoots were approximately 20 cm. long, some were girdled at the base with copper wire. Several days later, plants were moved to a greenhouse bench where they were grown under 16-hour photoperiods for 1 week prior to making cuttings. When removed from the dark chamber, the bases (4 cm.) of all girdled shoots and some ungirdled shoots were covered with aluminum foil. Apical cuttings were 20 to 30 cm. long with three to four fully expanded leaves; the leaves were pruned to about one-half their original area. Cuttings were dipped in the indolebutyric (IBA)-talc, planted in pots filled with a sand:peat (3:1) medium, and placed under intermittent mist. From 36 to 40 percent of the cuttings rooted.

52. Fayret, J. 1967. NATURAL AND IN VITRO BIOLOGICAL CYCLE OF GNOMONIA LEPTOSTYLA (FR.) CES. AND DE NOT. Acad. Sci. Compt. Rend. Ser. D, 265(13): 908-911. [In French.]
Causal agent of anthracnose on J. regia.

53. Ferell, Raymond S., and Bentley, William R. 1969. PLANTATION INVESTMENT OPPORTUNITIES IN BLACK WALNUT. J. Forest. 67(4): 250-254.
Presents an economic ranking of alternative opportunities for black walnut (Juglans nigra L.) plantation investments in the central hardwood region. The rankings indicate that high sites, thinning, and wide spacing definitely produce higher values. Pruning may also become a more profitable alternative, given probable changes in markets, grading, and technology.

54. Finn, Raymond F. 1966. MINERAL NUTRITION. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 35-41.
Describes the results of several studies of black walnut aimed at eventually determining (1) the amount of available nutrients needed for satisfactory tree growth and development, (2) the foliar deficiency symptoms for each element, and (3) the reactions of a 1-year-old black walnut plantation to applications of nitrogen and phosphorus.

55. Foott, J. H., and Heinicke, D. R. 1967. WHITEWASH FOUND HARMLESS IN APPLICATION ON WALNUT LEAVES. Calif. Agr. 21(3): 2-3.
Whitewash applied to the leaves of Persian walnut trees of the variety Payne to provide shade caused no apparent injury to the leaves and did not interfere with photosynthesis. These studies also indicated that temperatures above 90° F. were very detrimental to photosynthesis and at 95° or above it stopped completely. The application of whitewash to the upper leaf surfaces only resulted in a higher net assimilation rate than application to both surfaces or to the lower surfaces only.

56. Forcy, Andre, Lantelme, J., and Freychet, A. 1965. ESSAIS SUR L'ENRACINEMENT DES BOUTURES DE NOYER. C. R. Acad. Agr. Fr. 51 (18): 1183-1190.
The combination of mist, rooting hormones, and fungicide makes it possible to root a reasonable number of cuttings of black walnut taken from specially prepared seedlings.

However, the transition from rooted cutting to young tree is difficult.

57. Freeman, Eugene E., Jr. 1966. QUALITY REQUIREMENTS FOR SAWLOGS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 68-71.
Discusses some of the factors that relate to sawlog quality and that affect the value of trees that will be growing in the future.

58. Funk, David T. 1966. SEED ORCHARDS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 62-65.
Discusses (1) size of black walnut orchards needed to meet the demand of nurseries for seed of improved genetic quality, (2) the number of orchards needed according to climatic zones, (3) site quality requirements, and (4) orchard establishment and management.

59. Funk, David T. 1969. GENETICS OF BLACK WALNUT (JUGLANS NIGRA). USDA Forest Serv. Res. Pap. WO-10, 13 p., illus.
Reviews reproductive development, seed handling and nursery practice, cytogenetics, natural variation, hybridization, and inheritance as they apply to genetic improvement of black walnut. Suggests a breeding program including objectives, selection, mating systems, and seed-orchard design and management.

60. Funk, David T. 1971. POT SIZE, POT SHAPE, AND SOIL MIX ALL INFLUENCE BLACK WALNUT SEEDLING GROWTH. Plant Propagator 17(1): 10-14.
For black walnut seedlings grown in pots for one season in the greenhouse, height, shoot weight, and especially root weight were strongly dependent on pot volume. In conventionally shaped pots, seedlings grew taller when a soil mix containing three parts fine sand to one part ground peat was used; when grown in containers about three times as tall as wide, taller seedlings were produced when the pots were filled with equal parts of sand and peat. Walnut seedlings grown in conventionally shaped pots containing the 3:1 sand-peat mix had about 40 percent greater shoot:root ratio than those grown in other pot-soil mix combinations.

61. Gagnaire, J., and Vallier, C. 1968. [VARIATIONS IN THE POTASSIUM CONTENT OF LEAVES OF GRAFTED WALNUTS, JUGLANS REGIA ON J. NIGRA, GROWN UNDER NATURAL CONDITIONS.] C. R. Acad. Agr. Fr. 54: 81-86. [In French.]
Presents data on variations in the K content of the leaf and fruit during July-October 1967 in walnut (J. regia cv. 'Franquette') grafted on J. regia and J. nigra. The ages of the trees studied ranged from 6 to 100 years. The foliar K content in the J. regia/J. nigra combination was consistently lower in trees over 30 years old and suffering from the black line disorder than in younger trees. It was also lower than in J. regia/J. regia trees of the same age or older. The K content of the whole fruit was high (over 20 g. percent dry matter) in all types of trees in July and August; it decreased markedly in September in fruit of J. regia/J. nigra only.

62. Gerasimenko, A. G. 1967. THE BIOLOGY OF FLOWERING AS A BASIS FOR WALNUT SEED PRODUCTION. In Conf. on Forest-Tree Genetics, Selection, and Seed Production. (Edited by G. M. Kozubov, et al.) Clearinghouse for Federal Scientific and Technical Information, Springfield, Va., TT 69-55067. p. 136-137.
Flowering phenology as related to dichogamy.

63. Gervais, Camille. 1963. UN NOUVEL HYBRIDE NATUREL CHEZ JUGLANS. Ann. Ass. Canad. Franc. Avance. Sci. 29: p. 45.
Describes a putative J. nigra x J. cinerea hybrid.

64. Gesto, M. D. V., Vazquez, A., Mendez, J., Vieitez, E., and Seoane, E. 1967. GROWTH SUBSTANCES ISOLATED FROM WOODY CUTTINGS OF QUERCUS ROBUR L. AND JUGLANS REGIA L. Rep. from P. L. 480 Project E25-FS-16, 14 p., illus.
Describes a study of growth substances in Juglans regia L. made by extraction with methanol, paper and thin layer chromatography, ultraviolet and flourescence spectroscopy, and Avena coleoptile straight growth test. From J. regia vanillic, syringic and three other not yet identified acids (one close to p-coumaric, one similar to salicylic and the other an inhibiting hydroxyaliphatic acid) were isolated and studied in their growth properties.

65. Gibson, M. D. 1968. THE MANREGIAN WALNUT. N. Nut Growers Ass. Annu. Rep. 58: 105-109.
Describes the history and origin of this clone of Juglans regia from a tree in China and the performances of its sibs in Oregon and elsewhere. Winter hardiness genes are carried by Manregian forms, and it is thought that very winter-hardy trees could be obtained by crosses involving varieties of Carpathian or German descent, which are even hardier than Manregian forms.

66. Gilbert, Barry, L., Baker, James E., and Norris, Dale M. 1967. JUGLONE (5-HYDROXY-1, 4-NAPHTHOQUINONE) FROM CARYA OVATA, A DETERRENT TO FEEDING BY SCOLYTUS MULTISTRIATUS. J. Insect Physiol. 13: 1453-1459.
Not seen.

67. Gilyarov, M. S. 1949. [THE NOXIOUS SOIL FAUNA OF WALNUT FORESTS OF KIRGHIZIA.] Tr. Yuzhno-Kirg. Eksp. Akad. Nauk SSSR, Vol. 1. [In Russian.]
Not seen.

68. Glenn, E. M. 1965. INCOMPATIBILITY IN THE WALNUT. East Malling Res. Sta. Annu. Rep. 53: p. 102.
Describes three cases of delayed incompatibility of Juglans regia grafted on J. nigra.

69. Graves, David L. 1966. GRAFTING OF WALNUTS. Int. Plant Propagators Soc. Proc. 15: 281-284.
In northern California, Juglans regia scions are grafted onto 1-year seedling rootstocks of at least 1/2-inch caliper. Scions are cut from dormant 1-year-old wood in January and February, using only the more mature basal portion of the shoot; the wood is held in storage at 33° to 35° F. Stock plants are cut back to 16 to 18 inches about March 1 and allowed to "dry out" for 10 to 14 days, then cut back another 1 to 2 inches and whip grafted. Two or three cuts are made at the base of the stock to allow premature sap flow to escape.

70. Green, R. J., Jr., and Pratt, R. G. 1970. ROOT ROT OF BLACK WALNUT SEEDLINGS CAUSED BY PHYTOPHTHORA CITRICOLA. Plant Disease Reporter 54(7): 583-585, illus.
Describes a serious root rot disease of black walnut seedlings in a State tree nursery caused by Phytophthora citricola. This disease also occurs on at least two species of oaks, but is much less severe. Black walnut seedlings are usually infected in the seedbed, where young seedlings are usually killed, or infection may continue to develop in overwinter storage and cause losses in the spring during handling and shipping. Soil moisture is critical for infection and the disease is usually more severe after periods of heavy rain or high soil moisture levels.

71. Grente, J., and Averseng, P.-J. 1966. [A SOLUTION TO THE PROBLEM OF WALNUT DECLINE. I. ADVANTAGES AND DISADVANTAGES OF JUGLANS NIGRA.] C. R. Acad. Agr. Fr. 52: 553-560.
The advantages of using J. nigra rather than J. regia as a rootstock for walnuts include resistance to Armillaria and Phytophthora cinnamomi, easy grafting, smaller, more manageable trees, probably larger nuts, and earlier fruit (5 to 6 years after grafting). The chief disadvantage is the occurrence of black line, caused by a loss of affinity between stock and scion after about 30 years. Juglans nigra will not grow successfully in a poor or badly drained soil or in very dry situations, but on the whole is considered preferable to regia.

72. Griggs, William H., Forde, Harold I., Iwakiri, Ben T., and Asay, Richard N. 1971. EFFECT OF SUBFREEZING TEMPERATURE ON THE VIABILITY OF PERSIAN WALNUT POLLEN. HortScience 6(3): 235-237.
Viability of walnut (Juglans regia L.) pollen was not diminished by storage at subfreezing temperature, as previously indicated. Pollen stored 20 days at -19° C. effected high percentages of fruit set in the orchard in 1969. Fruit set of the bagged flowers was relatively low in 1970, but the set effected by pollen stored a year at -19° C. was not significantly different from that effected by fresh pollen. Laboratory tests indicated less than 1 percent germination for both freshly dehisced and stored pollen, and were unreliable for indicating the ability of walnut pollen to effect fertilization.

73. Grishin, Yu. F. 1966. [THE USE OF PERSIAN WALNUT IN PROTECTIVE AFFORESTATION.] Sadov. Vinogradarstvo Vinodelie Moldavii 9: 11-13. [In Russian.]
Not seen.

74. Hacskaylo, J., Finn, R. F., and Vimmerstedt, J. P. 1969. DEFICIENCY SYMPTOMS OF SOME FOREST TREES. Ohio Agr. Res. & Develop. Center Res. Bull. 1015, 68 p., illus.
Describes and illustrates appearance of black walnut, black locust, cottonwood, and sweetgum leaves from plants grown in nutrient solutions deficient in a single essential element. Includes abbreviated tables of chemical analyses comparing the concentration of the deficient element in the leaves, stems, and roots of the plants grown in nutrient-deficient and complete nutrient solutions.

75. Hall, Geraldine C., and Farmer, Robert E., Jr. 1970. "IN VITRO" GERMINATION OF BLACK WALNUT (JUGLANS NIGRA L.) POLLEN. First North American Forest Biology Workshop Abst. p. 20.
Black walnut pollen was germinated on liquid and agar-based media containing 20-percent sucrose. Boron slightly enhanced germination. Germination occurred only in dense (150 grains/mm.^{2}) populations of pollen on the agar medium. Germination in the sparse areas was promoted by high boron concentrations (300 to 600 p.p.m. boric acid). Wide tree-to-tree variation in germination percent was observed. Vacuum-drying periods, ranging from 5 to 60 minutes, resulted in a gradual reduction of viability. Complete loss of viability occurred after drying for 30 minutes.

Pollen was stored at 4° C., -30° C., and -196° C. for several weeks without major loss of viability.

76. Hall, Geraldine C., and Farmer, Robert E., Jr. 1971. IN VITRO GERMINATION OF BLACK WALNUT POLLEN. Can. J. Bot. 49(6): 799-802.
Black walnut pollen was germinated on liquid and agar-based media containing 20-percent sucrose, a requirement for germination and normal tube development. Boron (100 p.p.m. boric acid) added to this medium slightly enhanced germination. Germination occurred only in dense (150+ grains/mm.²) populations of pollen on the agar medium. This population effect was not overcome by the addition of Ca^{2+} to the medium, but germination in the sparse areas (<30 grains/mm.²) was occasionally promoted by high boron concentration (600 p.p.m. boric acid). Wide tree-to-tree variation in percentage of germination was observed. Vacuum-drying periods, ranging from 5 to 30 minutes, resulted in a gradual reduction of viability. Pollen was stored at -30° C. and -196° C. for 3 months without major loss of viability.

77. Hart, J. H. 1965. FORMATION OF DISCOLORED SAPWOOD IN THREE SPECIES OF HARDWOODS. Mich. Quart. Bull. 48(1): 101-116.
Sapwood, heartwood, and discolored sapwood were compared to determine if sapwood is transformed into heartwood upon wounding. An increment borer was used to induce discolored sapwood in white oak, Quercus alba L., silver maple, Acer saccharinum L., and black walnut, Juglans nigra L. Whereas discolored sapwood in the three species studied was morphologically similar to but not identical to normal heartwood, it was, from a chemical standpoint, much different and should not be considered a precocious development of normal heartwood.

78. Hay, C. John, and Donley, David E. 1966. INSECTS PESTS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 83-87.
Covers 17 of the more important insects and mites of Juglans nigra L. and J. cinerea L. in groups by type of injury.

79. Heffernan, T. 1967. OXYDEMETRONMETHYL IMPLANTED TO ENGLISH WALNUTS FOR CONTROL OF WALNUT APHID (CHROMAPHIS JUGLANDICOLA). J. Econ. Entomol. 60(3): 890-891.
Injections of demetron successfully controlled aphids resistant to foliar spray.

80. Hendricks, L. C., Jr., Davis, C. S., and Batiste, W. C. 1968. TWO-SPOTTED MITE CONTROL IN WALNUTS. Calif. Agr. 22(6): 12-13.
Omite EC was the most effective acaricide in Merced County, California, trials to control Tetranychus urticae.

81. Henniger, C. N., and Bolar, Max D. 1966. PLANTING BLACK WALNUTS IN TIN CANS. USDA Forest Serv. Tree Planters' Notes 76: 13-14, illus.
The method is recommended to protect direct-seeded nuts from rodent depredation.

82. Herrera Atter, S. 1968. [ROOT ROT IN SEEDLINGS OF PINUS RADIATA, PSEUDOTSUGA MENZIESII AND JUGLANS NIGRA.] Inst. Forest Latinoamer. Invest. Capacitacion. Bol. 26: 33-38. [In Spanish with English summary.]
Caused by Fusarium sp. fungus, in Venezuela.

83. Herrmann, K. 1955. ÜBER DIE FLAVONOLE DER BLÄTTER VON JUGLANS REGIA L. Archiv. Pharm. (Berl.) 288(8/9): 362-364.
Two glycosides, quercetin-3-galactoside and quercetin-3-arabinoside, predominate in English walnut leaves.

84. Houda, J. 1966. [VISCUM ALBUM IN JUGLANS NIGRA.] Ziva 14(4): p. 136. [In Czechoslovakian.]
Not seen.

85. Impiumi, G. and Ramina, A. 1967. [STUDIES ON FLORAL BIOLOGY AND FRUITING IN WALNUTS (JUGLANS REGIA). I. OBSERVATIONS ON FLORAL MORPHOLOGY AND POLLEN TRANSFERENCE.] Riv. Ortoflorofruttic. 51: 538-543, illus. [In Italian with English summary.]
Describes the techniques utilized for assessing pollen transmission. Pollen production averaged about 900 grains per anther and about 1,800,000 per catkin. The number of anthers per flower averaged about 18 at the stalk end and 13 at the tip of the catkin. Much pollen was collected at a distance of 160 m. from the nearest tree.

86. Jacoboni, Nestore. 1959. RICHERCHE SULLA BIOLOGIA FIORALE E DI FRUTTIFICAZIONE DEL NOCE (JUGLANS REGIA, LINN.) IN UMBRIA. Ann. Fac. Agr. Perugia 14: 116-140, illus. [In Italian.]
Describes pollen, flower, and fruit morphology from the taxonomic standpoint. Many photos.

87. Jovanović, B. 1967. [PHENOLOGY OF JUGLANS REGIA, ROBINIA PSEUDOACACIA AND SYRINGA VULGARIS IN DIFFERENT PARTS OF JUGOSLAVIA IN 1952-1961.] Šumarstvo 20 (9/10): 3-20. [In Serbian with French summary.]
Not seen.

88. Kavetskaya, G. A. 1966. [ACCUMULATION OF NUTRIENT SUBSTANCES IN THE PROCESS OF DEVELOPMENT OF ENGLISH WALNUT (JUGLANS REGIA L.) SEEDS.] Ukr. Bot. Z. 23(6): 44-49. [In Ukranian with English summary.]

Fertilized embryo sacs appear on the 6th day after pollination. The cellular endosperm forms on the 16th day after pollination. In the mature seed only one peripheral layer of cells is left of the endosperm. The germ cell divides obliquely transversely into two unequal cells on the 10th to 13th day. Both cells participate in the formation of the embryo. In the mature seed the endosperm and embryo contain fat and aleurones; starch is found only in the young embryo. In the parenchymal layer of the forming seed coat, starch and fat are found, as well as tannic substances. In the coat of the mature seed the reserve substances vanish, while tannic substances are found in the obliterated parenchymal layer.

89. Kenig, A. E. 1966. [INTERACTION OF WALNUT ROOT SYSTEM WITH OTHER SPECIES OF FOREST STANDS IN THE UKRAINE.] Visn. Sil's'kohospod. Nauk. 5:91-95. [In Ukranian with Russian summary.]

Not seen.

90. Kenig, A. E. 1967. [SOME RESULTS IN THE INTRODUCTION OF JUGLANS NIGRA INTO THE UKRAINE.] Ukr. Bot. Z. 24(1): 81-87. [In Ukranian.]

Maps the distribution of J. nigra in the Ukraine, with data on age (23 to 100 years), numbers of trees, dimensions, and fruiting; concludes that it is a suitable species for this region, being quite fast-growing and winter-hardy, and usually fruiting well.

91. Kolobkova, E. V. 1968. [THE CONTENT OF NITROGENOUS SUBSTANCES IN THE SEEDS OF JUGLANDACEAE.] Bjull. Glavn. Bot. Sada, Moskva 68: 63-68. [In Russian.]

The total N content was determined in the seeds of 28 species belonging to six genera (Juglans, Carya, Pterocarya, Platycarya, Cyclocarya, and Engelhardtia). Each genus had a characteristic N content. Evolutionary inferences are discussed.

92. Koma, S. 1951. [GROWTH OF THE WALNUT FRUIT AND THE CHANGE OF CHEMICAL COMPOSITION IN ITS KERNEL.] Hort. Ass. Japan J. (Tokyo) 20: 134-136. [In Japanese with English summary.]

Fruit development of Juglans sieboldiana and J. regia orientalis was studied at 2-week intervals. Fruits increased in size chiefly within 6 weeks after flowering, while they increased in weight within 9 to 10 weeks after flowering. The soluble nonnitrogen substances in the kernel, which were abundant at the earlier stage, decreased gradually with fruit growth, but fat increased rapidly after the fruit reached maximum weight. Protein increased gradually until the end of growth.

93. Komanič, I. G. 1966. [CHARACTERISTICS OF WALNUT GRAFTING.] Izv. Akad. Naulk Mold. SSR, Ser. viol. him. Nauk 7: 30-35. [In Russian.]

In greenhouse walnut grafting, optimum conditions for callus formation and union were a temperature of 25° to 27° C. and a relative humidity of 70 to 80 percent. Temperature fluctuations between 15 and 32° C. and a short-term reduction of the relative humidity to 40 percent did not reduce graft take markedly. A sharp drop in temperature below 10 to 15° C. greatly reduced take.

94. Krajicek, John E. 1966. GROWING SPACE REQUIREMENTS. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 47-49.

Discusses the pros and cons of planting walnut at wide and narrow spacings. Suggests an alternative method involving mixed plantings and thinnings that exploits the advantages of both wide and narrow spacing.

95. Krajicek, John E. 1969. WEED CONTROL IN BLACK WALNUT PLANTINGS. N. Nut Growers Ass. Annu. Rep. 60: 30-35, illus.

Controlling weed competition is essential to the successful establishment of black walnut plantings. Chemical control has been found superior to mechanical control. Methods of weed control, formulation for an all-purpose herbicide, application rates and times, and methods of application are discussed.

96. Krajicek, John E., and Bey, Calvin F. 1969. HOW TO "TRAIN" BLACK WALNUT SEEDLINGS. USDA Forest Serv., N. Cent. Forest Exp. Sta. 5 p., illus.

Describes and shows how to prune black walnut seedlings planted for timber production.

97. Krajicek, John E., and Phares, Robert E. 1971. HOW TO CONTROL WEEDS IN BLACK WALNUT PLANTINGS. USDA Forest Serv. Leafl., 8 p. N. Cent. Forest Exp. Sta., St. Paul, Minn.

Provides up-to-date recommendations on use of pre-emergent herbicides and mechanical methods for controlling weeds in black walnut plantings. Also presents safety precautions in using herbicides.

98. Krasil'nikov, P. I. 1949. [ROOT SYSTEMS IN WALNUT.] Tr. Yuzhno-Kirg. Eksp. Akad. Nauk SSSR. Vol. 1. [In Russian.]

Not seen.

99. Kulov, K. D., and Tikoev, M. A. 1966. [JUGLANS REGIA IN NORTHERN OSSETIA.] Les. Hoz. 19(6): 17-22. [In Russian.]
Tabulates data on growth and nut yield up to 9 years in this part of the N. Caucasus. J. regia did best on leached chernozem and on north slopes. On rich, deep chernozems and alluvial soils, spacing should be 12 by 12 m., with interplanting of bush fruits on dwarf stocks. On dark-grey forest soils and other less rich soils, the spacing should be 8 by 8 or 10 by 10 m., and Cydonia oblonga, Prunus persica, P. divaricata, etc., could be interplanted.

100. Lange, A. H., Crane, J. C., Fischer, W. B., Roberts, K. O., and Elmore, C. L. 1969. PRE-EMERGENCE WEED CONTROL IN YOUNG DECIDUOUS FRUIT TREES. J. Amer. Soc. Hort. Sci. 94(1): 57-60.
On clay loam soil with 6 percent organic matter, simazine, diuron, and prometryne applied at 4 pounds per acre provided good weed control without damaging 1/2-inch caliper 'California' black walnut (J. hindsii?) seedlings. On coarse, sandy soil with only 0.6 percent organic matter, simazine and diuron at 1 pound per acre controlled weeds well without harm to walnut transplants; higher rates and other herbicides, especially Bromacil, damaged the walnuts.

101. Lange, A. H., Day, B. E., Jordon, L. S., and Russell, R. C. 1967. PRE-EMERGENCE HERBICIDES FOR WEED CONTROL IN WALNUTS. Calif. Agr. 21(1): 2-4.
Diuron and simazine were field tested in California's major walnut producing districts. Tests were continued at three locations for 2 years and at one location for 3 years. Simazine and diuron in the range of 2 to 4 pounds/acre resulted in greater than 90 percent weed control. Both herbicides were generally more effective in southern California than in the northern areas. Diuron can injure walnut trees on some sandy soils and should be used only in established plantations.

102. LaPorte, Juan. 1966. NUMEROS CROMOSÓMICOS Y ALGUNAS OBSERVACIONES BIOLOGICAS SOBRE TRES ESPECIES AMERICANAS DEL GÉNERO JUGLANS. [CHROMOSOME NUMBERS AND OTHER BIOLOGICAL OBSERVATIONS ON 3 AMERICAN SPECIES OF THE GENUS JUGLANS.] Darwiniana 14(1): 156-160, illus.
The chromosome number of both J. australis and J. boliviana is n = 16.

103. Lebedinova, N. S. 1968. [THE MOISTURE REGIME OF DARK-BROWN SOILS UNDER THE CANOPY OF DIFFERENT TYPES OF JUGLANS REGIA FORESTS IN FERGANA (SOVIET CENTRAL ASIA).] Pcovoved. 1: 32-41. [In Russian.]
Distinguishes four main categories of sites: (1) where part of the precipitation is lost as run-off--site class never better than IV; (2) where inflow equals run-off--site class III to IV; (3) where inflow exceeds run-off--site class II; and (4) where there is a slow and continuous accession of moisture to the surface, but at a rate that does not cause waterlogging--site class I.

104. Lee, K. C., and Campbell, R. W. 1969. NATURE AND OCCURRENCE OF JUGLONE IN JUGLANS NIGRA L. HortScience 4(4): 297-298.
Seems probable that the toxic juglone comes from both the above and underground part of black walnut trees, although juglone toxicity as suggested by MacDaniels et al. is controlled by multiple factors rather than by concentration alone.

105. Lindmark, Ronald D., and DeBald, Paul S. 1969. BLACK WALNUT ON NONFOREST LAND IN KENTUCKY. USDA Forest Serv., Res. Bull. NC-16, 18 p., illus. Northeast. Forest Exp. Sta., Upper Darby, Penn.
A report of a survey of black walnut timber found on nonforest land in Kentucky. These trees add substantially to the State's overall supply of black walnut. Although the trees growing under nonforest conditions tend to be short-boled, many of them have large diameters and contain quality timber.

106. Link, H. 1961. [INFORMATION ON THE FLOWER BIOLOGY OF THE WALNUT TREE, JUGLANS REGIA.] Diss. Landw. Hochsch., Hohenheim, 78 p., illus. [In German.]
The vigor of the test trees (four walnut seedlings) differed and was affected by environmental factors such as late frost. The optimal shoot length for the formation of male flowers was 5 to 25 cm. and for female flowers 15 cm. and above. The relative male:female inflorescence ratio of each tree changed with increasing vegetative development in favor of the female; combined with this was a reduction in the total inflorescence number.

107. Losche, Craig K. [n.d. Circa 1970]. WALNUT SITE SELECTION AND SOIL MANAGEMENT. Northeast. Area Nurserymen's Conf. Proc., Carbondale, Ill., Aug. 20-21, 1969: 55-58.
Discusses the relation of height and diameter growth of plantation-grown black walnut on floodplains of southern Illinois to the thickness of silty soil material over a chert gravel layer and the depth to mottling. Also discusses the relation of

soil properties to various cultural operations in plantations.

108. Lowe, William J., and Beineke, Walter F. 1969. COMPARING GRAFTING TECHNIQUES FOR BLACK WALNUT. South. Conf. Forest Tree Impr. Proc. 10: 231-235.
The bark inlay technique is the most appropriate method to use when the root stock has sufficient diameter (greater than 1 inch at grafting point). When a smaller-sized root stock (less than 1 inch at grafting point) is used, the cleft graft gives satisfactory results. Either method produces a satisfactory percentage of successes to be used in the establishment of black walnut seed orchards. Whip grafting, T-budding, and patch budding were totally unsuccessful under the conditions of this investigation.

109. Lur'e, I. G. 1952. [REPLACEMENT OF TRANSPLANTATION BY SOWING OF GERMINATED SEEDS WITH PRUNING OF THE RADICLE.] Sad i Ogorod, No. 2. [In Russian.]
Not seen.

110. McDaniel, J. C. 1969. OUTLINE OF NUT TREE POLLINATION. N. Nut Growers Ass. Annu. Rep. 59: 51-55.
Most interspecific walnut hybrids having Juglans regia as one parent shed little or no viable pollen. Some hybrid walnuts also have a high degree of female sterility. Extremely early or late female flowers are often poorly pollinated.

111. McGinnes, E. A. 1968. EXTENT OF SHAKE IN BLACK WALNUT (JUGLANS NIGRA). Forest Prod. J. 18(5): 80-82.
Shake was found in 4.3 percent of more than 10,000 butt logs examined in Missouri, with ring and wind shake being most common.

112. McKay, J. W. 1967. LATE-FLOWERING WALNUT HYBRIDS. N. Nut Growers Ass. Annu. Rep. 57(1966): 70-75.
Five Juglans regia x J. nigra hybrids produced in 1940 flower late and are virtually immune from damage by late frosts. One hybrid is late in spring growth but its nuts mature early. The hybrids show marked heterosis.

113. McKay, J. W. 1966. VEGETATIVE PROPAGATION. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 58-61.
Describes grafting and budding techniques used in growing black walnut trees for nut production.

114. Maeglin, R. R., and Nelson, N. D. 1970. SURFACE SOIL PROPERTIES OF BLACK WALNUT SITES IN RELATIONSHIP TO WOOD COLOR. Soil Sci. Soc. Amer. Proc. 34(1): 142-146.
Various soils that supported black walnut in Indiana and Missouri were analyzed for surface pH, organic matter, available P, exchangeable K, Ca, Mg, total N, silt plus clay content, cation-exchange capacity (CEC), and depth to mottling or to impervious layer. Quantitative color values of heartwood of walnut trees grown on these soils were determined by reflectance spectroscopy. The soil properties analyzed were moderate to high for most soils studied. The range of observed site quality was rather limited; however, poor sites showed a tendency toward darker, redder heartwood.

115. Majackaja, A. D. 1969. [DICHOGAMY AND FRUITING IN WALNUTS.] Les. Hoz. 2: 32-35. [In Russian.]
Of 1,024 fruiting walnut trees studied, 52 percent were protogynous and 48 percent protandrous. The type of dichogamy in the same tree did not change with time. The flowering period of male and female flowers on protogynous trees was longer than on protandrous trees, and this created better conditions for fertilization. The productivity of protogynous trees was 10 to 15 percent higher than that of protandrous trees.

116. Manning, Wayne E. 1957. A BOLIVIAN WALNUT FROM PERU GROWING IN COSTA RICA. Brittonia 9(2): p. 131.
Identified as Juglans boliviana. The nuts, sown in Costa Rica in 1948, were collected in Peru.

117. Marking, L. L. 1970. JUGLONE AS A FISH TOXICANT. T. Am. Fish. Soc. 99(3): 510-514.
Juglone, a biologically active chemical occurring in various parts of walnut trees, was tested for its toxicity to fish. The 96-hour LC50 values obtained from static bioassays at 12° C. ranged from 27 to 88 parts per billion for rainbow trout, northern pike, goldfish, carp, white suckers, black bullheads, channel catfish, green sunfish, and bluegills. The toxicity of juglone to rainbow trout and bluegills was not altered significantly in water of different temperature or hardness. Standard (pH 7.4) and buffered (pH 9.0) solutions of juglone aged for 1 week effectively killed rainbow trout although approximately three times as much juglone was required at the higher pH. According to other investigators, juglone is easily reduced to less toxic components by factors in the natural environment. However, juglone is sufficiently persistent to eliminate target fish prior to its degradation.

118. Martin, C. G., Mason, M. I. R., and Forde, H. I. 1969. CHANGES IN ENDOGENOUS GROWTH SUBSTANCES IN THE EMBRYOS OF JUGLANS REGIA DURING STRATIFICATION. J. Amer. Soc. Hort. Sci. 94(1): 13-17.
No cytokinins or gibberellins were found, but an inhibitor believed to be abscisic acid, which decreased in concentration during stratification, was isolated.

119. Mathers, Robert. 1966. QUALITY REQUIREMENTS FOR VENEER. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 66-67.
Walnut growers should produce veneer logs at least 14 inches in diameter (at small end) and free of serious defects for at least one 8-1/2-foot log. Time of year is important. Tells how to minimize danger of stains and splits or checks due to summer harvest.

120. Maurer, K. J. 1967. [PROBLEMS OF AFFINITY AND UNION IN WALNUT GRAFTING.] Mitt. Klosterneuburg 17: 481-491, illus. [In German with English, Spanish, and French summaries.]
Graft compatibility in walnuts depends not only on the species of seedling rootstock chosen, but also on the clone or source of the seed parent. Describes symptoms of incompatibility, which are visible only along the grafting cuts and are not usually apparent externally.

121. Maurer, K. J. 1969. [WALNUTS GRAFTED IN THE OPEN GROWN WITHOUT A SNAG ON THE ROOTSTOCK.] Mitt. Klosterneuburg 19: 313-314, illus. [In German with English, Spanish, and French summaries.]
Describes a method whereby the snag that is normally left on the rootstock is cut back before the graft starts into growth, and the graft is bound immediately to a stake; the wound then heals during the first year.

122. Mazur, O. P. 1965. [THE EFFECT OF SOIL MOISTURE AND MINERAL SUBSTANCES ON THE INTENSITY OF ENDOTROPHIC MYCORRHIZA FORMATION IN WALNUTS (JUGLANS REGIA).] Dokl. Akad. Nauk. tadž. SSSR. 8(10): 44-48. [In Russian with Tadžik summary.]
In soil culture experiments with 1-year-old walnut seedlings, forest soil from walnut stands was added to each container and maintained at 25, 40, 55, and 70 percent water-holding capacity. Mycorrhizae developed best at 40 to 50 percent moisture content, and seedling development (foliation, height, stem diameter, and root system) was positively related to the intensity of mycorrhizae formation.

123. Meza, N. 1968. [PROSPECTIVE WALNUT HYBRIDS.] An. Inst. Cerc. Pomicult., Pitesti 1: 65-75, illus. [English, French, German, and Russian summaries.]
Three hybrids resistant to Xanthomonas juglandis, Gnomonia leptostyla and low temperature were selected from breeding experiments conducted between 1958 and 1967. They bear early and are very productive. Other fruit characteristics are described.

124. Mikhaleva, E. N., and Konovalov, I. N. 1967. [ON THE PHYSIOLOGICAL HETEROGENEITY OF SHOOTS IN THE PERSIAN WALNUT.] Akad. Nauk. SSSR. Bot. Inst. Tr. Ser. 4, Eksp. Bot. 19: 206-215. [In Russian with English summary.]
The 1-year-old shoots of Persian walnut (Juglans regia L.), differing in their growth characteristics and location in the tree crown, are characterized by the different level of physiological processes (the rate of growth, photosynthesis and respiration, the content of carbohydrates).

125. Minovski, D. 1967. [THE EFFECT OF TIME AND METHOD OF WALNUT GRAFTING ON ITS SUCCESS IN SKOPJE.] Annu. Fac. Agr. Sylvic. Skopje, Agr. 20: 147-159, illus.
In seedling rootstock production, stratified nuts gave 68 percent germination compared with 20 percent for unstratified nuts. Cleft grafting with active scions and cleft grafting with dormant scions gave the best results. As rootstocks, 1- to 2-year-old Juglans regia should be used; J. nigra gave poor results.

126. Mitchell, H. L. 1960. NEW ANTISHRINK TREATMENT IMPROVES WOOD FOR GUNSTOCKS, OTHER USES. Wood & Wood Prod. 65(11): p. 50, 52, 102.
Polyethylene glycol treatment.

127. Mitchell, H. L. 1963. PEG-TREATED WALNUT LIMBWOOD MAKES HANDSOME DECORATOR CLOCKS. Forest Prod. J. 13(9): 416, illus.
Gives directions for stabilizing and curing disks cut from waste walnut limbwood. The disks are suitable for mounting clock movements and for making other specialty items.

128. Mitchell, H. L. 1966. PROFITABLE USE OF LOW-GRADE TIMBER. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 72-76.
Discusses products and processes which could contribute to much closer utilization of available raw material now largely wasted. Discusses some specialized, high-value products that can be profitably produced from sawmill and logging residue.

129. Mittempergher, L. 1969. [A NEW METHOD OF GRAFTING WALNUTS IN THE NURSERY.] Riv. Ortoflorofruttic. 53: 189-202, illus. [In Italian with English summary.]
This method of cleft grafting was delayed until the latter half of May to ensure a minimum temperature of 10° C. and an average temperature of 18 to 20° C. Dormant stocks and scions were stored at 2 to 3° and almost 100 percent relative humidity from the end of February. Juglans nigra and J. regia seedling walnuts were grafted with several walnut varieties, the stock being well-rooted and equal in diameter to the scions. The gradual reduction of shade was necessary for 6 weeks after grafting. With 480 grafts, successes reached 81.7 percent in spite of some of the scions being below standard. The only disadvantage of the method is the limited growth and ripening of the grafted plant in the first year.

130. Momot, N. M. 1940. [WALNUTS AND ASSOCIATED SPECIES IN SOUTHERN KAZAKHSTAN.] Vses. Nauch. Issled. Inst. Sukhikh Subtrop. [In Russian.]
Not seen.

131. Moore, John A. 1971. A $1,000 PER YEAR PER ACRE CROP? N. Nut Growers Ass. Annu. Rep. 61: 123-133.
Intensive early care is essential, but growth rate of pole-size and small sawtimber walnuts on good sites in central Indiana suggests that 22-inch veneer timber can be produced on a 60-year rotation.

132. Moslemi, Ali A. 1967. QUANTITATIVE COLOR MEASUREMENT FOR BLACK WALNUT WOOD. USDA Forest Serv. Res. Pap. NC-17, 16 p., illus. N. Cent. Forest Exp. Sta., St. Paul, Minn.
Black walnut (Juglans nigra L.) veneer specimens with wide variations in color were evaluated by a quantitative method of color measurement. The internationally adopted CIE system of colorimetry was used to analyze the data. These data were converted to also show them in the Munsell system. Color differences among the walnut veneer specimens were also numerically specified.

133. Nachev, P. 1965. [NEW ENEMIES OF THE PLUM CULTURE AND THE WALNUT-TREE IN BULGARIA.] Gradinarska Lozarska Nauk. 2(5): 581-587, illus. [In Bulgarian with English summary.]
Lists and illustrates five insect pests on walnut trees, and two insect parasites.

134. Naughton, Gary G. 1970. BLACK WALNUT DEFORMED BY SHOOT MOTH. J. Forest. 68(1): 28-29, illus.
On the basis of observations made in southeastern Kansas in 1967 and 1968, the cause of death of the terminal shoots of black walnut during the growing season is shown to be due in part to the larvae of Gwendolina concitatricana Heinrich. This is also a major factor in the cause of walnut seedling stem deformity.

135. Naughton, Gary G. 1970. GROWTH AND YIELD OF BLACK WALNUT PLANTATION. Kan. State Univ. Ext. Serv., Manhattan. 11 p.
Presents tables for site quality evaluation, growth and yield, crown width, spacing, and basal area, and nut yield.

136. Nedev, N. 1968. [RESULTS FROM INOCULATING THE WALNUT (JUGLANS REGIA) WITH BUDS KEPT IN VARIOUS NUTRIENT SOLUTIONS.] Gradinarska Lozarska Nauk. 5(5): 3-6, illus. [In Bulgarian with French summary.]
Not seen.

137. Nedev, N. 1969. [STUDIES ON THE DURATION OF THE STAGES OF UNION IN WALNUT BUDDING.] Gradinarska Lozarska Nauk. 6(2): 3-9, illus. [In Bulgarian with Russian and French summaries.]
In buds grafted on 5, 15, and 25 August the callus began to form on the rootstock in 5 days, whereas in those budded on 5 and 15 September it took 10 days. The isolation layer, in the first few days a deep brown line, began to be reabsorbed in some places after 20 to 30 days, and had disappeared 40 to 45 days after budding. Vascular elements began to form 20 to 25 days after budding; the differentiation of the scar tissue was most active close to the two sides of the bud shield, and the vascular tissue differentiated more slowly inside the callus. Medullary rays started to join up 30 to 40 days after budding, and complete union was obtained in 60 to 65 days.

138. Nelson, N. D., Maeglin, R. R., and Wahlgren, H. E. 1969. RELATIONSHIP OF BLACK WALNUT WOOD COLOR TO SOIL PROPERTIES AND SITE. Wood and Fiber 1(1): 29-37.
Larger differences were found between black walnut trees in heartwood luminance (lightness) than in dominant wavelength (hue) or purity. Indiana-grown walnut heartwood had higher luminance than Missouri-grown walnut. The relationship of heartwood color to soil properties was greater than it was either to tree age or to diameter-growth rate.

139. Newbold, Ray A. 1967. THE COLLECTION AND STRATIFICATION OF BLACK WALNUT SEED. M.S. thesis, South. Ill. Univ. 72 p.

Seed was collected from five trees in Jackson Co., Illinois, between August 26, 1966, and February 23, 1967. Seed collected between November 5 and November 18 germinated best. Stratification at fluctuating temperatures for 60 days or more produced better germination than constant temperature stratification. Maximum germination was achieved by stratification for 120 days with temperature alternated daily between 37° and 52° F.

140. Oprea, C. 1967. [DATA ON THE BIOLOGY OF WALNUT POLLEN.] Lucrari Stiint., Inst. Agron. N. Balcescu, Ser. B, 10: 253-263. [In Rumanian.]
The length of walnut (Juglans regia?) catkins was found to vary with the sex of the tree. The number of flowers was directly proportional to the length of the catkin, which was not shed until the last flower had opened. The pollen could germinate in concentrations of sugar ranging from 5 to 25 percent, but tube elongation was greatest in the 10 to 20 percent range. Viability lasted for 100 hours at 14° to 15° C., but only for 55 hours at 22° to 25° and 0°. Temperatures >25 percent and humidity <30 percent during pollen maturation caused sterility.

141. O'Rourke, F. L. S. 1967. PRESENT STATUS OF THE CARPATHIAN WALNUT IN NORTH AMERICA. Amer. Nurseryman 125(3): 15, 127-129, illus.
Discusses the distribution and low temperature responses of Juglans regia with notes on the 10 main varieties.

142. Ozol, A., and Zukovska, Z. 1953. [PROSPECTS FOR THE CULTIVATION OF JUGLANS REGIA AND OTHER SPECIES OF WALNUT IN THE LATVIAN SSR.] Sborn. Trud. Inst. Biol. Akad. Nauk Latviiskoi SSR, Vol. 1. [In Latvian.]
Not seen.

143. Painter, John H., and Raese, J. Thomas. 1965. MINERAL CONTENT OF WALNUT (JUGLANS REGIA L.) HULLS, SHELLS, AND KERNELS. Amer. Soc. Hort. Sci. Proc. 87: 226-228.
Hulls, shells, and kernels of Persian walnuts from eight locations in Oregon were analyzed to determine mineral composition. Ovendry hulls contained on the average the following percentages: 9.6 K, 0.8 N, 0.08 P, 0.5 Ca, and 0.1 Mg. Ovendry kernels contained 3.2 N, 0.4 P, 0.5 K, 0.07 Ca, and 0.2 Mg. Ovendry shells contained 0.2 N, 0.01 P, 0.4 K, 0.2 Ca, and 0.03 Mg.

144. Panfilova, T. S. 1940. [FUNGAL DISEASES OF WALNUT FORESTS IN SOUTHERN KIRGHIZIA.] In Sbornik "Gretskii orekh Yuzhnoi Kirgizii." Vses. Nauch.-Issled. Inst. Sukhikh Subtrop. [In Russian.]
Not seen.

145. Park, Kyo Soo. 1967. [NEW METHOD OF JUVENILE TISSUE GRAFTING OF SOME SPECIAL-USE-TREES. I. STUDIES ON THE JUVENILE TISSUE GRAFTING OF SOME CROP-TREE SPECIES (WALNUT, CHESTNUT, AND OAK).] Inst. Forest Genetics (Korea) Res. Rep. 5: 75-84, illus. [In Korean with English summary.]
Juvenile-tissue grafting of Juglans mandshurica and other walnuts was 60 to 100 percent successful using newly elongated shoots from either germinated seed or older plants as both scion and stock. New shoots are at about the right stage for grafting when they bear four ordinary leaves.

146. Perevertajlo, B. I. 1969. [ROOT SYSTEM OF JUGLANS NIGRA IN YOUNG PLANTATIONS.] Lesn. Z., Arhangel'sk 12(2): 151-154, illus. [In Russian.]
In 7-year-old black walnut plantations grown at 2 by 6 m. spacing, the depth of branching of the taproot was 23 cm. Height averaged 5.2 m., and diameter 7.9 cm. When grown in mixture with ash at 2 by 1-1/2 m. spacing, walnut height was reduced to 4.6 m. and diameter to 5.7 cm.; when mixed with maple, walnut height and diameter were virtually unchanged. In the walnut-ash plantation, the ash overtopped the walnut trees causing the walnut crowns to be deformed, although their stems were straight. When mixed with maple, the walnut crowns generally completely overtopped the maple. The fine roots of the 7-year-old walnut trees extended to a depth of 100 cm. but are most common between 10 and 20 cm., with lesser concentrations between 0 to 10 and 20 to 30 cm. In contrast, roots of herbaceous plants in walnut plantations did not extend below 30 cm. and were primarily concentrated between 0 to 20 cm.

147. Perry, S. F. 1967. INHIBITION OF RESPIRATION BY JUGLONE IN PHASEOLUS AND LYCOPERSICON. Bull. Torrey Bot. Cl. 94: 26-30.
The effect of aqueous juglone solutions on the leaf respiration of beans and tomatoes was determined. Concentrations of less than about 10^{-6} M had little or no effect. At higher concentrations the percentage inhibition increased more or less linearly with the log of the juglone concentration, with a 50 percent inhibition occurring at about 10^{-4} M. The two species reacted similarly; hence, their differential reactions to walnut poisoning in the field are not due to any difference in the effect of juglone on their respiration.

148. Petrosjan, A. A. 1965. [THE BIOLOGICAL

CHARACTERISTICS OF FLOWERING AND POLLINCATION IN WALNUTS AND PROBLEMS IN THE DEVELOPMENT OF NATIVE VARIETIES OF THIS CROP.] Agrobiologija 4: 569-571. [In Russian.]
Studies on the floral biology of walnuts showed that normal trees bore seven to eight times more male than female flowers. However, self-pollination was not satisfactory when the two types of flowers did not open at the same time. Describes methods of estimating the self-fertility of individual trees by (1) observing the phenological phases of the male and female flowers over a 3-year period, and (2) by observing the percentage fruit set on branches bearing both male and female flowers that are isolated in sealed paper containers through which foreign pollen cannot penetrate. Trees showing a percentage fruit set of 70 percent or more were regarded as self-fertile.

149. Petrosjan, A. A., and Antonenko, G. A. 1968. [WINTER HARDINESS IN WALNUT TREES.] Sadovodstvo (Horticulture) 10: 28-29. [In Russian.]
Of eight ecotypes subjected to a warm autumn and winter followed by sudden frost of -20° to -22° C. at Krasnodar, the hardiest were those from the plain of the Kuban, the steppe around Ejsk, the Central area of Stavropal' territory, the vicinity of Krasnodar and the Bostandyk district of Uzbekistan. All ecotypes varied in the extent of the damage to individual trees, this being attributed to heterozygosity and the segregation of different cold-resistance types.

150. Phares, Robert E. [n.d. Circa 1970]. THE NURSERYMAN'S ROLE IN THE CULTURE OF BLACK WALNUT. Northeast. Area Nurserymen's Conf. Proc., Carbondale, Illinois, Aug. 20-21, 1969: 59-65.
Nurserymen can help landowners achieve better planting success by producing larger seedlings, avoiding seedling damage during lifting and shipping, and maintaining better control over where seed is collected and where seedlings from a given seed source are shipped.

151. Polishchuk, L. K., Dibrova, L. S., Zablotskaya, K. M., and Lapchik, V. F. 1968. [THE SIGNIFICANCE OF OXIDATION-REDUCTION PROCESSES IN PLANT FROST RESISTANCE.] Rost. Ustoichivost'Rast. 4: 122-129. [In Russian.]
Not seen.

152. Posenkov, A. K., and Rihter, A. A. 1965. [BREEDING WALNUTS FOR FROST-HARDINESS UNDER CRIMEAN CONDITIONS.] Agrobiologija 4: 562-568, illus. [In Russian.]
Selection and crossing late-flowering walnut varieties with pecans.

153. Prutenskii, D. I., and Ryk-Bogdaniko, M. G. 1940. [PESTS OF WALNUT FRUIT FORESTS OF SOUTHERN KIRGHIZIA.] In Sborn. "Gretskii orekh Yuzhnoi Kirgizii," Vses. Nauch.-Issled. Inst. Sukhikh Subtrop. [In Russian.]
Not seen.

154. Quigley, Kenneth L., and Lindmark, Ronald D. 1966. TIMBER RESOURCES. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 6-12.
Gives the extent of the black walnut resource and its growth characteristics, and an assessment of the present and anticipated drain on the resource.

155. Quigley, Kenneth L., and Lindmark, Ronald D. 1967. A LOOK AT BLACK WALNUT TIMBER RESOURCES AND INDUSTRIES. USDA Forest Serv. Res. Bull. NE-4, 28 p., illus. Northeast. Forest Exp. Sta., Upper Darby, Penn.
Shows that current annual cut of all grades of walnut timber is slightly less than the growth accruing annually on commercial forest land. However, the annual cut of high-quality material exceeds the annual growth by almost 50 percent. The outlook for high-quality walnut timber in sufficient quantity to supply the current and increasing demand is not promising. Both growth and cut in future years must inevitably be lower until new management efforts begin to show results.

156. Rambo, Richard W. 1966. TECHNIQUES OF STOCK PRODUCTION. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 13-15.
Lists the main nursery operations for growing black walnuts in the Indiana State nurseries.

157. Ramina, A. 1969. [STUDIES OF THE FLORAL BIOLOGY AND FRUITING OF WALNUTS (JUGLANS REGIA). 2. FLOWER BUD DIFFERENTIATION.] Riv. Ortoflorofruttic. 53: 480-489, illus. [In Italian with English summary.]
Buds of the walnut variety Sorrento were examined from the spring of 1967 to the autumn of 1968 at 10-day intervals. Branches were defoliated at 10-day intervals from April through October 1967. The differentiation of male flower buds was first detected 35 to 45 days after bud burst. Female buds began to differentiate 125 to 135 days after bud burst. All the floral organs were differentiated before winter dormancy began, and the formation of pollen grains and embryo sacs occurred in the following spring.

The differentiation of buds remained reversible for 25 to 35 days for males and 115 to 125 days for female buds.

158. Randall, Charles Edgar. 1967. BLACK WALNUT--OUR VANISHING MONEY TREE. Amer. Forests 73(10): 14-17, 38-40, illus.
Discusses numerous uses of walnut wood and nuts and encourages planting to meet increased domestic and foreign demand.

159. Rastvorova, O. G. 1966. [THE WATER REGIME IN SOILS BENEATH PLANTATIONS OF CERTAIN WOOD SPECIES IN THE FOREST-STEPPE ZONE.] Vestnik Leningr. Univ., Leningrad (Serija Biologii) 15(3): 135-146. [In Russian.]
Describes a study of soil moisture under 25-year pure crops of Quercus robur, Larix sibirica, Phellodendron amurense and Juglans mandshurica in Belgorod province, USSR. Although P. amurense and J. mandshurica are biologically less drought-resistant than Q. robur, their earlier leaf fall and smaller accumulation of litter permit greater infiltration of rainfall; in practice they withstand drought as well as oak, provided they are planted in pure stands or in broad belts.

160. Ruckij, I. A., and Nikolaev, E. A. 1969. [DEFOLIATION OF WALNUT SEEDLINGS WITH POTASSIUM IODIDE.] Himija sel'. Hoz. 7(9): 56-57.
Potassium iodide at 0.25 percent effectively defoliated 2-year-old walnut seedlings, increased their winter hardiness, and improved subsequent shoot growth. A 1 to 10 percent KI caused rapid leaf fall but reduced winter hardiness and shoot growth and delayed bud break.

161. Russell, T. E. 1968. TESTS OF REPELLENTS FOR DIRECT-SEEDING BLACK WALNUTS IN TENNESSEE. USDA Forest Serv., Res. Note SO-73, 4 p. South. Forest Exp. Sta., New Orleans, Louisiana.
Arasan-endrin provided fair protection for direct-seeded black walnuts on forested sites of the Cumberland Plateau.

162. Sander, Ivan L. 1966. NATURAL REPRODUCTION. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 18-19.
Describes natural reproduction as related to (1) effect of cutting method, (2) seed source, (3) height growth, and (4) management implications.

163. Sartori, Elvino. 1967. THE USE OF JUGLANS AUSTRALIS IN ARGENTINA AS A ROOTSTOCK FOR ENGLISH WALNUT (JUGLANS REGIA). Plant Propagator 13(1): 4-7.
Juglans regia was budded onto 1-year-old J. australis seedlings using T-budding and patch budding; results were all negative. Two years later, part of these seedling rootstocks were again budded on primary branches while others were grafted, putting the scions directly onto the trunk. About 50 trees were topworked by each method. Patch budding was done at the end of February (late summer), while grafting was done in October (spring). Both methods gave excellent results in this trial.

164. Schaad, Norman W., and Wilson, E. E. 1970. STRUCTURE AND SEASONAL DEVELOPMENT OF SECONDARY PHLOEM OF JUGLANS REGIA. Can. J. Bot. 48(6): 1049-1053, illus.
In Persian walnut, a small (0.5 mm.) amount of secondary phloem is functional for only one season and a large amount is nonfunctional. In 1968 in Central California the cycle of phloem development began in late February and ended sometime before mid-October. The phloem annual ring was composed of distinctive tangential bands, allowing easy distinction of seasonal growth increments. Early-season phloem, composed principally of large sieve tubes, was separated from late-season phloem by a band of fibers. The late-season phloem was composed of a mixture of narrow sieve tubes, parenchyma cells, and occasionally an incomplete tangential band of fibers.

165. Schaad, Norman W., and Wilson, E. E. 1970. PATHOLOGICAL ANATOMY OF THE BACTERIAL PHLOEM CANKER DISEASE OF JUGLANS REGIA. Can. J. Bot. 48(6): 1055-1060, illus.
Erwinia rubrifaciens Wilson, Zeitoun, and Fredrickson invades sieve tubes and parenchyma cells of the nonfunctional secondary phloem of Persian walnut, Juglans regia L. Because the sieve plate pores are great enough in diameter to allow passage of the bacteria, the nonfunctional phloem system provides an avenue along which the bacteria move long distances up and down the bark. Functional phloem, on the other hand, does not exhibit symptoms of the disease nor is it found to contain the bacteria. Although the bacteria invade the ray parenchyma and move radially through these elements to the outer xylem, bacteria are not found to enter the xylem vessels. Pressure from wound callus induces vertical cracks in the bark. A slimy substance containing the bacteria exudes through the cracks to the bark surface, thereby allowing dispersion of the bacteria.

166. Schanderl, H. 1965. [FLOWER BIOLOGY AND SEED FORMATION IN COMMON WALNUTS AND BLACK WALNUTS.] ErwObstb. 7: 149-154, illus. [In German.]

Parthenogenesis was strongly marked in 12 of the 38 European walnut types investigated. Fruit set and the degree of parthenogenesis were directly related. In Juglans nigra, however, a large proportion of the unfertilized ovules aborted, giving empty fruits. Walnut pollen grains contain sucrose and germinate without liquid in a saturated atmosphere, the tube being coated with an oily secretion.

167. Schneider, G. 1969. BIOMASS AND MACRONUTRIENT CONTENT IN A 31-YEAR-OLD BLACK WALNUT PLANTATION. Mich. Acad. 11(4): 33-42.
Reports fresh and dry weight, percent moisture, and amounts of five macronutrients for the above-ground portions in a 31-year-old black walnut plantation in southwestern Michigan. Dry weight in a representative tree is 58 kg., 66 percent of which is in stemwood, 12 percent in bark material, 10 percent in branches, and 5.5 percent in foliage. The macronutrient content in a representative tree is 0.94 kg. Calcium is the most abundant chemical element, followed in order by nitrogen, potassium, magnesium, and phosphorus. The stem has the greatest percent of all elements, with amounts decreasing in the following order: bark, leaves, branches, and fruit. The stem, bark, and leaves contain 82 percent of the total nutrient capital.

168. Schneider, G. 1970. MICRO-NUTRIENTS IN A 31-YEAR-OLD BLACK WALNUT PLANTATION. Mich. State Univ. Agr. Exp. Sta. Res. Bull. 29, 8 p.
Reports amounts and distribution of six micronutrients and sodium for the above-ground portions of a 31-year-old black walnut plantation in southwestern Michigan. Iron was the most abundant chemical element followed in order by sodium, aluminum, manganese, zinc, copper, and boron. The stem bark and leaves contain 75 percent of the total elemental content of the above elements.

169. Schneider, G., Khattak, Ghaus, and Bright, John. 1968. MODIFYING SITE FOR THE ESTABLISHMENT OF BLACK WALNUT. N. Amer. Forest Soils Conf. 3: 155-169.
Black walnut seedlings planted on level, wind-swept, open-field sites had less vigorous growth, smaller leaf area, and incurred greater foliage damage than those growing in either forest openings or protected open fields where similar soil conditions prevailed. Mulching and irrigation increased soil moisture, but these treatments did not compensate for lack of wind protection.

170. Segura, B. De. 1970. [RADICULAR PUTREFACTION OF WALNUT (JUGLANS SPP.) CAUSED BY PHYTOPHTHORA CINNAMOMI RANDS. IN TURRIALBA.] Turrialba 20(1): 116-118, illus. [In Spanish with English summary.]
A root disease on Juglans spp. has recently been observed at the Interamerican Institute of Agricultural Sciences, Turrialba, Costa Rica. The disease is produced by the fungus Phytophthora cinnamomi Rands. A survey made 4 months after planting indicates that the Salvador provenance (Juglans olanchana? or nigra?) is highly resistant to P. cinnamomi, whereas the provenances from Ecuador (Juglans neotropica) and Peru-Bolivia (Juglans boliviana) are very susceptible. The Nicaraguan provenance (Juglans olanchana) also shows resistance to the disease.

171. Semahanova, N. M., and Mazur, O. P. 1968. [MYCORRHIZAE OF JUGLANS REGIA AND THE CONDITIONS FOR THEIR FORMATION.] Izv. Akad. Nauk SSR (Ser. biol.) 4: 517-529. [In Russian.]
A study was made of mycorrhiza formation and the anatomy and biology of mycorrhiza development in natural conditions in central Tadzhikistan. J. regia forms endotrophic mycorrhizae of the phycomycete type, and their formation is most intensive in the layer 5 to 30 cm. from the soil surface. The penetration and spread of the mycorrhizal fungus in the host root is described, and also the fungus/host metabolism in the process of phagocytosis. Optimum development of mycorrhizae is observed at 40 to 55 percent of maximum water-holding capacity of the soil, with a moderate P supply.

172. Serr, E. F. 1962. NUTRITIONAL DEFICIENCIES AND FERTILIZATION PRACTICES IN CALIFORNIA WALNUT ORCHARDS. N. Nut Growers Ass. Annu. Rep. 52(1961): 69-74.
Nine nutritional elements have been found separately to limit walnut growth and production in at least one location in California. Only nitrogen is generally needed in regular yearly applications in all districts. Ranges of normal and deficient concentrations are given for eight elements in J. regia leaves, along with visual nutrient deficiency symptoms and recommended treatments.

173. Serr, E. F. 1965. DWARFING THE PERSIAN WALNUT BY USE OF INTERSTOCKS. N. Nut Growers Ass. Annu. Rep. 55: 106-111.
The use of Juglans nigra and J. ailantifolia cordiformis interstocks for trees of J. regia variety Hartley reduced the size of the Hartley tops by one-half after 13 seasons' growth from the time of planting the rootstocks (Paradox hybrids). Yields per unit of cross-sectional trunk area were doubled; this

was large accounted for by an increase in the number of pistillate flowers produced from lateral buds.

174. Serr, E. F. 1965. WALNUT ROOTSTOCK. Int. Plant Propagators Soc. Proc. 14: 327-329.
For grafting J. regia in California, the Paradox hybrid rootstocks are recommended over J. hindsii for four reasons: (1) greater vigor and faster growth especially in mountain districts and on poorer soils and in replant situations; (2) greater tolerance of root lesion nematodes; (3) greater tolerance of high lime content in soil, excess water, or very heavy soil texture; and (4) resistance to crown rot (Phytophthera cactorum). Among four methods of clonal propagation, rooting of hardwood cuttings is recommended to produce clonal rootstocks of the Paradox hybrid.

175. Serr, E. F. 1968. DWARFING INTERSTOCKS FOR PERSIAN WALNUTS. Plant Propagator 14(1): 10-13.
(See also 173 above.)

176. Serr, E. F., and Rizzi, A. D. 1965. WALNUT ROOTSTOCKS. Univ. Calif. Agr. Ext. Serv. Pub. AXT-120, 8 p., illus.
Discusses suitability of five Juglans species, the Paradox hybrid walnut, and Pterocarya stenoptera as rootstocks for J. regia. Disease resistance, soil limitations and effect on scion growth may all influence choice of rootstocks.

177. Shchepotiev, F. L. 1951. [ABNORMAL FRUITS OF WALNUT (JUGLANS REGIA L.).] Dokl. Akad. Nauk SSR 77: 1103-1105. [In Russian.]
Not seen.

178. Shchepotiev, F. L. 1953. [METAXENIA OF THE WALNUT.] Agrobiologija 11. [In Russian.]
Metaxenia was noted in Juglans nigra fruit when pollinated by J. regia or J. mandshurica, but not in J. regia pollinated by J. mandshurica.

179. Shchepotiev, F. L. 1954. [BISEXUAL FLOWERS OF WALNUT.] Priroda 43(3): 92-94. [In Russian.]
Not seen.

180. Shchepotiev, F. L., and Borisenko, T. T. 1949. [THE GERMINATION OF WALNUT POLLEN (JUGLANS REGIA L.) IN AN ARTIFICAL MEDIUM.] Dokl. Akad. Nauk SSR 68: 617-620. [In Russian.]
Not seen.

181. Sika, A. 1964. [RAISING JUGLANS NIGRA IN SOUTHERN MORAVIA.] Cas. Slexks. Muz., Opava (Ser. C, Dendrol.), p. 31-42. [In Czechoslovakian. German summary.]
An account of the history of its introduction and the distribution of existing stands, giving data on performance in relation to site requirements.

182. Sluss, R. R. 1967. POPULATION DYNAMICS OF THE WALNUT APHID, CHROMAPHIS JUGLANDICOLA (KALT.) IN NORTHERN CALIFORNIA. Ecology 48(1): 41-58, illus.
Populations of walnut aphids and associated insects were observed over a 4-year period in several northern California walnut orchards. Temperature, leaflet age, amount of prior aphid feeding, and coccinellid predation were found to be the most important factors influencing walnut aphid population changes. Sharp declines in aphid population levels were correlated with high temperatures, especially when several days occurred with maxima over 100° F. Temperatures may also affect aphids indirectly by directly affecting coccinellid beetles.

183. Sokolov, S. Ya. 1949. [WALNUT OF SOUTHERN KIRGHIZIA AND THE VARIABILITY OF ITS FRUITS.] Trud. Yuzhno-Kirgizskoi Eksp. Akad. Nauk SSR, Vol. 1. [In Russian.]
Not seen.

184. Solignat, G. F., and Grente, J. 1965. RECHERCHES SUR LE NOYER ENTERPRISES PAR L'I.N.R.A. C. R. Acad. Agr. Fr. 51(8): 579-587.
A report on rootstock trials, Phytophthora infection, and frost resistance in Juglans regia grown for nut production.

185. Solignat, G., and Venot, P. 1966. [VEGETATIVE PROPAGATION OF WALNUTS.] C. R. Acad. Agr. Fr. 52: 674-677. [In French.]
When walnut rootstocks were layered and the suckers ringed and earthed up, well-rooted plants suitable for transplanting were obtained within one season (May-November). Light soil or a mixture of soil and river sand was necessary for abundant fibrous root development. Juglans sieboldiana rooted more readily than J. nigra, which in turn rooted better than J. regia. There was also a considerable difference in rooting capacity among individual plants within a species.

186. Spiegl, P., and Chirikdjian, J. J. 1969. [THE DISTRIBUTION OF FLAVONOIDS IN JUGLANS REGIA VAR. REGIA.] Pharmazie 24: 780-781. [In German.]
Includes data on the distribution of quercetin, camphorol, quercitrin, hyperoside, and other flavonoids.

187. Stoičkov, J., et al. 1967. [ON THE BEHAVIOR OF WALNUTS UNDER VARIOUS SOIL

CONDITIONS.] Grad. lozar, Nauka 4(8): 9-23. [In Bulgarian. English and Russian summaries.]
Concludes that high calcium carbonate contents, particularly in the upper soil horizons, are unfavorable to walnut growth and longevity. Dry, free-draining soils are also inimical to good growth, cropping and longevity. Other unfavorable factors are cold winds, low winter temperatures and very hot dry weather.

188. Stone, Donald E., Reich, Julianne, and Whitfield, Sylvia. 1964. FINE STRUCTURE OF THE WALLS OF JUGLANS AND CARYA POLLEN. Pollen et Spores 6(2): 379-392.
Contains other new references.

189. Švidenko, A. I. 1970. [FROST-CRACK DAMAGE TO JUGLANS REGIA IN THE BUKOVINA REGION (UKRAINE).] Lesoved., Moskva 1: 89-90. [In Russian. English summary.]
A survey of frost-crack damage showed that the number of stems affected ranged from 1.1 to 83.4 percent. Stands on fairly moist oak sites on south slopes suffered most. There appears to be scope for selection of resistant individuals.

190. Tyškevič, G. L., and Žadan, V. M. 1969. [WAYS OF INCREASING THE YIELD OF JUGLANS REGIA PLANTATIONS IN MOLDAVIA.] Lesn. Hoz. 22(7): 18-22. [In Russian.]
In recent years in Soviet Moldavia, ca. 8,600 ha. of mixed forest plantations have been established in which J. regia (grown primarily for timber) forms 12 to 25 percent of the number of trees. These plantations are proving unsatisfactory, and (on the basis of trials here described) recommendations are made for intensive cleaning and thinning to convert them into high yielding pure J. regia stands.

191. Van Den Bosch, Robert. 1970. TRIOXYS PALLIDUS...AN EFFECTIVE NEW WALNUT APHID PARASITE FROM IRAN. Calif. Agr. 24(11): 8-10.
A parasitic wasp has been effective in controlling the walnut aphid, Chromaphis juglandicola, in California. One wasp strain from France has been established in the southern part of the State; an Iranian strain is better adapted to the more severe climate of central California.

192. Veresin, M. M., and Ulyukina, M. K. 1967. IMPROVEMENT OF WINTER HARDINESS IN WALNUT BY SELECTION AND HYBRIDIZATION AT THE EDUCATIONAL-EXPERIMENTAL LESKHOZ OF THE VORONEZH FORESTRY INSTITUTE. In Conf. on Forest-Tree Genet., Selection, and Seed Prod. (Edited by G. M. Kozubov, et al.) Clearinghouse for Fed. Sci. & Tech. Inform., Springfield, Va., TT 69-55067, p. 62-64.
Early tests of hybrids.

193. Vinogrudov, N. P. 1967. [FOR HIGH YIELDS OF WALNUT IN KIRGIZIA.] Les. Hoz. 4: 34-38. [In Russian.]
In the "forest orchards" (natural stands used as orchards) of Kirgizia, 200 valuable trees for use in seed nurseries were located. Eight other biotypes have been propagated vegetatively and are currently undergoing trials.

194. Vogel, A., Jr., and Reischauer, C. 1856. [A NEW ORGANIC CONSTITUENT IN THE PERICARP OF JUGLANS REGIA.] Neues Repertorium Für die Pharmacie 5: 106-110.
Not seen.

195. White, Donald P., Schneider, G., and Lemmien, Walter. 1970. HARDWOOD PLANTATION ESTABLISHMENT USING CONTAINER GROWN STOCK. USDA Forest Serv. Tree Planters' Notes 21(2): 20-25, illus.
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196. Whitson, John, John, Robert, and Williams, Henry Smith, eds. 1915. THE PRODUCTION OF A QUICK-GROWING WALNUT. In Luther Burbank--his methods and discoveries and their practical application. 11: 193-237, illus. New York and London: Luther Burbank Press.

197. Williams, Robert D. 1966. PLANTING STOCK GRADES. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 16-17, illus.
Recommends planting seedlings of 7/32-inch or larger on cleared forest sites and strip-mined banks.

198. Williams, Robert D. [n.d. Circa 1970]. IMPORTANCE OF SEEDLING SIZE FOR SURVIVAL AND GROWTH. Northeast. Area Nurserymen's Conf. Proc., Carbondale, Ill., Aug. 20-21, 1969: 30-36, illus.
Black walnut seedlings 8/32-inch diameter and larger survived and grew better than smaller ones on cleared forest sites, strip-mined sites, and cultivated old-field sites. The superiority of the large seedlings was most evident on the poorer sites.

199. Williams, Robert D. 1970. PLANTING

LARGE BLACK WALNUT SEEDLINGS ON CULTIVATED SITES. USDA Forest Serv. Tree Planters' Notes 21(2): 13-14, illus.
Planting 10/32- and 12/32-inch seedlings resulted in the best survival (98 percent) at the end of 2 years, while 4/32-inch seedlings showed the poorest survival. Seedlings 8/32-inch and larger in diameter grew faster than smaller seedlings and were taller at the end of the experiment. Recommends planting healthy seedlings 8/32-inch and larger in diameter for best results.

200. Wilson, E. E., Zeitoun, F. M., and Fredrickson, D. L. 1967. BACTERIAL PHLOEM CANKER, A NEW DISEASE OF PERSIAN WALNUT (JUGLANS REGIA) TREES. Phytopathology 57(6): 618-621.
The disease, caused by Erwinia rubrifaciens, produces necrotic streaks in phloem, cambium, and inner xylem.

201. Witt, A. W. 1938. A SURVEY OF THE INVESTIGATIONS ON THE PROPAGATION AND TESTING OF WALNUTS AT THE EAST MALLING RESEARCH STATION. E. Malling Res. Sta. Ann. Rep. p. 259-265, illus.
Describes characteristics of several Juglans species used as rootstocks for J. regia. Pinching the tip of strong shoots can stimulate flower bud formation in J. regia.

202. Wood, Milo N. 1932. DICHOGAMY--AN IMPORTANT FACTOR AFFECTING PRODUCTION IN THE PERSIAN WALNUT. Amer. Soc. Hort. Sci. Proc. 29: 160-163.
All Juglans regia varieties tested are both inter-fertile and self-fertile; they can also be crossed with J. hindsii, J. californica, and J. sieboldiana. Dichogamy is stronger in young trees than older ones. Warm weather during the flowering season stimulates staminate (catkin) development more than pistillate flowering.

203. Wright, Jonathan W. 1966. BREEDING BETTER TIMBER VARIETIES. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 53-57.
Improvement work needs to be planned on a long-term, many-generation basis. Discusses breeding better walnuts as approached from (1) species hybridization, (2) provenance testing, (3) selective breeding, and (4) polyploidy and mutation breeding.

204. Wylie, John E. 1966. NUTS AND WOOD--DUAL CROPS FOR MANAGEMENT. In Black walnut culture. USDA Forest Serv., N. Cent. Forest Exp. Sta., St. Paul, Minn. p. 91-94, illus.
Walnut can be grown intensively for dual crops to economic advantage whenever there are steady markets for the nuts or such markets can be developed.

205. Yasnykova, O. O., and Tolmachov, I. M. 1967. [TRANSFORMATION OF STORED SUBSTANCES IN JUGLANS DURING THE FALL AND WINTER.] Visn. Sil's'kohospod. Nauk. 1: 68-71. [In Ukranian with Russian summary.]
Not seen.

206. Zaharik, D. A. 1966. [ACCELERATED PRODUCTION OF JUGLANS MANDSHURICA [PLANTING STOCK].] Les. Hoz. 19(2): 47-48. [In Russian.]
In trials made in 1959-1962 in Belorussia, field germination of seeds sown while still unripe (immediately after collection in August) was 3 to 21 percent greater than that of seeds collected in September-October, and 52 to 57 percent greater than that of seeds stratified for 198 to 210 days. It is concluded that all pretreatment of seed can be eliminated, and the delay involved in raising planting stock thus reduced.

207. Zarger, T. G., Farmer, R. E., Jr., and Taft, K. A. 1970. NATURAL VARIATION IN SEED CHARACTERISTICS AND SEED YIELD OF BLACK WALNUT IN THE TENNESSEE VALLEY. S. Conf. on Forest Tree Improv. Proc. 10: 34-40.
Seed yields and seed characteristics of individual black walnut trees vary widely in the Tennessee Valley; much of this variation is attributable to individual tree differences unrelated to tree size or geographic location. This variation pattern, which is also evident in oaks, suggests that seed yield may be under fairly strong genetic control and thus subject to effective field selection.

208. Zatykó, J. M. 1967. [VEGETATIVE PROPAGATION OF THE WALNUT VARIETY FERTÖDI E. I. BY WAY OF ROOTING.] Acta agron. hung. 16: 297-302, illus. [In Hungarian.]
The split-stem method of propagation, which has previously been confined to walnut seedlings, was attempted on the scions of grafted plants. The roots of grafted plants were severed on one side, the plants were laid on their sides and the new shoots that developed from the horizontal stems were gradually earthed up and etiolated. The etiolated shoots, at least 15 mm. thick, were split and wedged in September or May. Two types of soil with good and poor water-holding capacity were compared; far more shoots developed and rooted in the moister, less sandy soil.

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Research at the Institute of Forest Genetics, Rhinelander, Wisconsin, by Richard M. Jeffers. USDA Forest Serv. Res. Pap. NC-67, 31 p., illus. 1971.

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Storm Flow from Dual-Use Watersheds in Southwestern Wisconsin, by Richard S. Sartz. USDA Forest Serv. Res. Pap. NC-69, 7 p., illus. 1971.

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USDA Forest Service
Research Paper NC-71
1971

The whirlwind formation over flat terrain

DONALD A. HAINES
GERALD H. UPDIKE

North Central Forest Experiment Station
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ACKNOWLEDGMENTS

We wish to thank a number of individuals for contributing suggestions or information used in this study: David Jacobson, Area Forest Ranger, Wisconsin Department of Natural Resources, for his help in describing the Burnett County burn; Otto Eggert, Regional Staff Forester, Minnesota Department of Natural Resources, for information on the Littlefork burn; and Harold Carter, USDI Necedah National Wildlife Refuge, for his photographs of the Necedah burn, as well as T. Allan Johnson of the same organization for his observations of that situation. Others who have contributed suggestions include Clive Countryman, Howard Graham, and Charles Roberts, USDA Forest Service; Steven Such, Supervisor, Forest Fire Experiment Station, Michigan Department of Natural Resources; Virgil Hendricks and Ronald Haug, Fire Weather Meteorologists, National Oceanic and Atmospheric Administration (NOAA); and Earl Kuehnast, NOAA State Climatologist for Minnesota.

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(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication August 18, 1971

FIRE WHIRLWIND FORMATION OVER FLAT TERRAIN

Donald A. Haines and Gerald H. Updike

Fire suppression crews face formidable problems when confronted with unusual forms of fire behavior. Such phenomena as firebrand showers or long-distance spotting are often unexpected, and the fire fighter usually is ill-prepared to deal with them. Within this erratic behavior category, one can surely include the fire whirlwind. This phenomenon may display symptoms as mild as a quick swirl on a campfire or it can be incredibly ominous, as described by Pernin (1872) during the 1871 Peshtigo, Wisconsin, conflagration: a "... great black object, like a balloon, whirling with intense rapidity in the air ... (touching) it burst with a loud explosion, like a bomb filled with powder ... (and) streams of fire scatter(ed) off in all directions."

There are only a small number of published field observations of fire whirlwinds, and fewer with photographs. This is surprising, as this fire phenomenon is comparable to the tornado in its potential destructive importance.

Graham (1957) listed some of the physical characteristics of a number of fire whirlwinds and also (1952) described a spectacular event in detail. Pirsko *et al.* (1965) published a well-documented report, including photographs, of a violent fire whirlwind that resulted in four injuries, along with the destruction of two homes, a barn, three automobiles, and an orchard. Countryman (1964, 1969) has done the most extensive work on field characteristics of this type of vortex. He consequently has verified a number of suspected fire whirlwind properties.

Almost all of these published events occurred either in hilly or mountainous country. In mountain areas, the atmospheric lapse rates over the fire area can only be inferred, and consequently lapse rate contribution to formation and maintenance can only be estimated. Also, in mountains or even in low, hilly country, terrain features are often dominant factors in fire-whirlwind formations. Most of the fire whirlwinds observed by Countryman (1969) and Graham (1957) developed on lee slopes. Countryman feels that these vortices resulted from an unstable condition in which thermal wind and the fire blocked incoming cool air. These phenomena tend to develop in areas where wind shear or natural eddies occur.

It would be interesting to know how fire whirlwinds form under less complex field situations, such as in flat terrain with moderate burning conditions and with a known atmospheric lapse rate. Here, among other things, the role of atmospheric stability might be evaluated. Unlike investigations conducted in mountainous terrain, we could easily obtain representative upper-air data and more accurately measure stability. Byram and Nelson (1951) analyzed flat-terrain fire whirlwinds in South Carolina along these guidelines with interesting results. Much of their information complements the observations reported in this paper.

Byram and Martin (1970) state that three conditions appear to be essential for the formation of most fire whirlwinds as well as other types of thermally driven vortices. First, vortex formation requires a generating eddy possessing angular momentum. The heat source will create this eddy in the thermal drive situation. The flow becomes spiral because the horizontal flow toward the base is almost invariably off balance. Second, a fluid sink must be present within this eddy. It is usually produced indirectly by the heat source. The convective column over that source is the fluid sink, and it may be largely controlled by atmospheric stability. And third, some friction or drag must restrict the movement of air so that the inward radial component of air flow does not vanish as the system approaches a steady state. Emmons and Ying (1967) feel that normally the ground slows the rotational motion of the air and therefore the imposed radial pressure gradient pushes the boundary-layer air toward the axis.

Necessary conditions for fire-whirl formation can be easily met in the laboratory using inexpensive equipment. A plastic, cylindrical chamber does the job quite nicely (fig. 1). A number of researchers have investigated laboratory-created fire-whirls in detail and found a number of important features (Emmons and Ying 1967, Blackshear *et al.* 1968, Lee and Garris 1969, and Byram and Martin 1970).

Figure 1.—A laboratory-created fire-whirl in a plastic chamber. The plastic is joined along the seam with nut-bolt bracing that leaves a ½-inch space along the entire length, allowing air to enter. The air becomes a generating eddy as it is forced to spin around the inside of the chamber gaining vorticity. Lighter fluid in the small cup provides the fuel source. Intense heat generated by the whirl has caused the inexpensive plastic cylinder to buckle. The direction of spin can be reversed by inverting the cylinder.

FIELD FIRE-WHIRLWIND OBSERVATIONS

Well-documented field observations are mor difficult to find than laboratory descriptions. Bu information on three recent fire-whirlwind situa tions in Wisconsin and Minnesota is availabl (table 1). In this paper we will not be concerne with the relatively small fire-whirls that some times appear briefly in a flame front, but rathe with the large fire whirlwinds that extend ten or hundreds of feet in height, sometimes mov considerable distances, and visually resemble th desert dust devil or tornado.

Necedah

One of the authors observed these condition at the Necedah National Wildlife Refuge (fig.2. on August 21, 1970. At that time, refuge person nel were conducting a prescribed burn of 40 acres on a flat plain.

The burn began at 10 a.m. c.s.t. on Augus 20 in an area of oak and jack pine slash. Unde backing winds, only a small portion was comple ed by evening, but burning continued slowl throughout the night. A number of small dus whirls began at 11 a.m. on the 21st, mostly i the burned sectors (fig. 3). Skies were clear a this time, with the temperature in the mid 70 and relative humidity in the 30's. A very ligh wind (under 5 m.p.h.) was evident from th southwest. In the following 3 hours an estimate 200 dust whirls were seen. These whirls generall moved northwest toward standing timber whe they dissipated in the trees. Observers noted th the larger dust whirls (fig 4A) struck the tre with a force comparable to that caused by a win velocity of about 35 m.p.h. Interestingly, th dust whirls skirted hot spots, following a coole track. The ground colors were predominant white (ash) and black (charcoal), which ma have helped to determine the path they followe

Near noon large fire whirlwinds, spinnin counterclockwise (fig. 4B), developed in th heavy slash fire region. During the following ho and a half, about 20 of them were seen. The fire whirlwinds often exhibited a concentrate whirling motion throughout their vertical exte when they began (fig. 4C), but in a few minut (fig. 4D) the upper region developed more turb lent motion. At this time, the fire in the ma

Table 1.—Meteorological features during fire whirlwinds

Item	Location			
	Necedah, Wis.	Burnett County, Wis.	Littlefork, Minn.	Virginia, Minn.
Date	August 21, 1970	August 25, 1969	August 11, 1965	July 1, 1970
Time (c.s.t.)	12 p.m.	2 p.m.	2 p.m.	3 p.m.
Temperature (°F.)	75	88	90	86
Relative humidity (Percent)	35	38 and falling	62	22
Surface wind velocity	Under 5 m.p.h.	Very light	Very light	Gusts to 19 m.p.h.
Sky	Clear	Clear	Clear	Clear
General surface synoptic situation	Just west of high pressure center	Just west of high pressure center	Somewhat nondescript, frontalysis occurring in weak system to the north	Behind a cold front
Closest representative upper-air station	(STC) St. Cloud, Minn.	(STC) St. Cloud, Minn.	(INL) International Falls, Minn.	(INL) International Falls, Minn.
Depth and lapse rate of shallow ground layer	340 feet 1.5° F./100 feet	310 feet 1.5° F./100 feet	625 feet 1.7° F./100 feet	360 feet 2.3° F./100 feet
Depth and lapse rate of next higher layer	2,625 feet .66° F./100 feet	5,250 feet .60° F./100 feet	10,105 feet .43° F./100 feet	3,410 feet .52° F./100 feet
Temperature difference between 850-500 millibar surfaces	24.7° C. (44.5° F.)	24.7° C. (44.5° F.)	31.4° C. (56.5° F.)	26.4° C. (47.5° F.)
Area burned or burning (Acres)	408	90	65	30

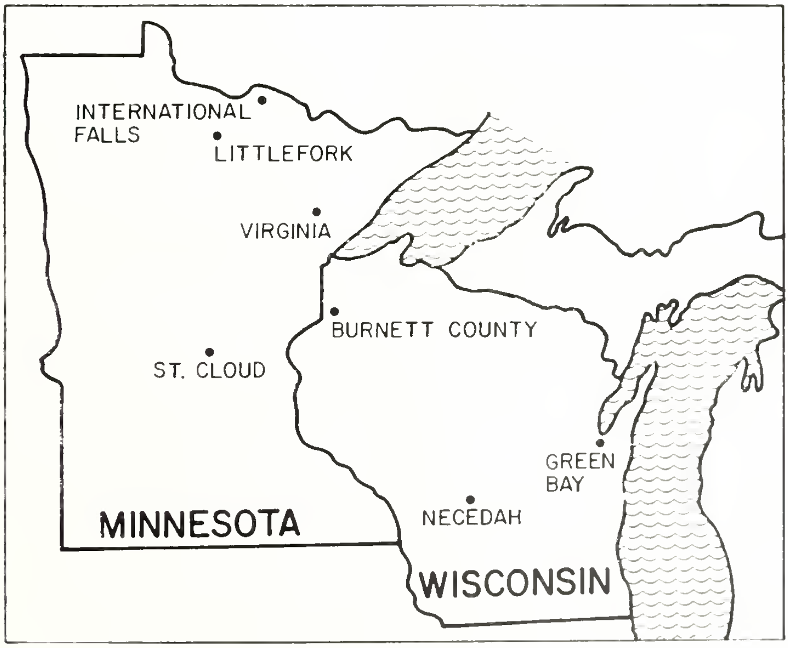


Figure 2.—Location of the fire whirlwind sites. Upper-air weather stations are also shown in the figure.

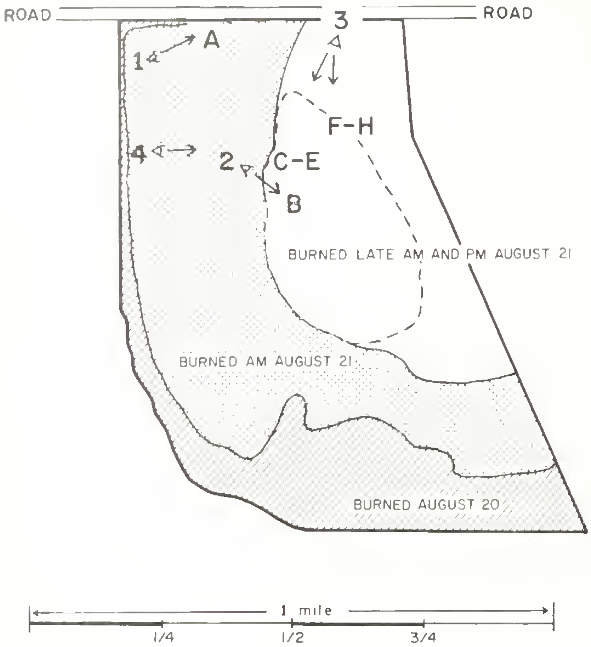


Figure 3.—Area of the Necedah fire whirlwinds. The area enclosed by dashed lines indicates the main portion of the heavy slash burn. Photograph A (fig. 4) was taken from position 1; B from position 2; C, D, E, G, and H from position 3; and F from position 4.

flame region began to roar much like a blast furnace. As the individual fire whirlwinds picked up in intensity, they created a noise like a fast-moving freight train.

At the peak of activity the scene appeared as in figure 4E; seemingly, any burning area was a threatening source for fire-whirlwind genesis. The largest fire whirlwind developed at this time; it was about 40 feet in diameter, with the highest vertical development estimated at 2,500 feet (fig. (4F). The funnel was characterized by a well-developed vortex, looking much like a typical tornado. Closer photographs of it (taken from position 3, fig. 3) show the lower section in or near steady state (fig. 4G) and a thicker, blacker section with more turbulent flow about two-thirds of the way up (fig. 4H).

Burnett County

Another well-documented fire-whirlwind situation occurred in Burnett County, Wisconsin (fig. 2), on August 25, 1969. The Wisconsin Department of Natural Resources was conducting a prescribed burn on a 90-acre tract. Weather conditions included clear skies, temperatures in th high 80's, a relative humidity of 38 percent an falling, and a light, variable wind. By 2 p.m. c.s most of the perimeter had been ignited and intense burn was in progress.

Small dust whirls began to form over th burned area. One of these dust whirls increas in size until it reached a diameter of 15 feet a a height of 150 feet, becoming a fire whirlwi as it picked up hot ashes and embers. It cross the south control line, scattering sparks and f for a distance of 100 yards.

At 2:25 p.m. another large fire whirlwind d veloped, traveled parallel to the north contr line, then suddenly crossed it. A tractor-pl unit and tank truck crew attempted to control immediately, but there was little they could d Observers state that the whirlwind seemed to e plode, building to an estimated height of 1,0 feet with a wavering tip of flame at the to Burning snags, 5 inches in diameter and up 9 feet long, were thrown out of the vortex li flaming arrows at a height of 300 feet. The sou in the column was comparable to a jet aircra directly over the tree tops. The tanker opera directed a water stream at the whirl base at distance of 60 feet for about 1 minute, but t water was sucked up into the funnel. The verti lifting vector of the fire whirlwind was larger th the horizontal velocity vector of the water strea plus gravitation, as no water reached the base f the vortex. The crew used a pumper unit th delivers 100 to 125 p.s.i. of water in a straig stream with a ½-inch nozzle, about 75 gallo per minute.

At a distance of several hundred feet, t wind velocity flowing into the Burnett Coun fire whirlwind was estimated at 30 m.p.h. In ally, it had the appearances shown in figure 4 After crossing the control line and assum smooth funnel characteristics, it became tall a narrow as in figure 4G. After genesis, this f whirlwind stayed in a turbulent state for abo 4 minutes. After crossing the line and chang to steady state, it was able to maintain its for approximately 10 minutes longer.

According to observers, the path of the whirlwind later looked as if a giant vacuum cle er had swept it. There was nothing but b mineral soil left, with no trace of the burn visib.

This observation is strikingly similar to that given by the National Oceanic and Atmospheric Administration (NOAA) State Climatologist for Nebraska when he described the effects of one of the 1965 Palm Sunday tornadoes in that State, "The path gave the impression that an enormous vacuum cleaner had swept the ground clean of vegetation, loose soil, all other movable objects" (Fujita *et al.* 1970).

Littlefork

Another fire-whirlwind situation occurred near Littlefork, Minnesota (fig. 2), on August 11, 1965. The Minnesota Department of Natural Resources was conducting a prescribed burn of 65 acres in a cutover black spruce area that had slash concentrated in windrows. Ignition began at 1:30 p.m. c.s.t. with the air temperature near 90°F., clear skies, almost no wind, and a surprisingly high relative humidity (62 percent). The minimum relative humidity during the day was 52 percent.

Beginning at 2 p.m., about 15 fire whirlwinds (probably resembling figure 4D) occurred, interspaced over the next hour. They had an average duration of 5 to 10 minutes. A number of smaller (40 to 50 feet high) ash whirls also began. The largest fire whirlwind was 100 feet in diameter and several hundred feet high. One of these followed a circular path one-eighth mile in diameter within the control perimeter, then came out the northeast corner, setting about 25 spot fires. Observers stressed the fact that winds were light, usually blowing into the fire from around the perimeter. Fire whirlwinds often moved against this light wind, seeming to follow a green vegetation track. The orientation of the windrows probably contributed to this tracking effect as the channels between them were the main formation areas.

Two other large vortices came over the line, and Mr. Otto Eggert, Minnesota Regional Staff Forester, found himself inside one of them. Mr. Eggert[1] states, "There was considerable small debris, mainly ash and charcoal; some of the latter retained glowing embers, not large, but capable of igniting combustible material. I was able to see my way by holding my head down so my face was somewhat shielded by my hard hat . . . the wind, near the (vortex) perimeter, was almost horizontal, with very little vertical lift. Nearer the center, wind velocity seemed to be higher, with a strong vertical lift, and it was also where the larger debris was being picked up." Mr. Eggert did not note an area of downdraft, but this fire whirlwind was erratic. Kaimal and Businger (1970) found in an instrumented study of a similar atmospheric phenomenon, a dust devil, that there was a strong updraft around the vortex and a downdraft within the core. They believe this is a general characteristic of most well-developed, concentrated vortices in the atmosphere. The area of the downdraft, however, is fairly narrow. Evidence for vortex central-core downdraft has also appeared in tornado photographs (Kuehnast and Haines 1971).

Mr. Eggert was not thrown to the ground or injured, but he did have a number of holes burned in his clothing. This vortex did not achieve the type of steady state shown in figure 4F. Schaefer (1961) and Byram and Martin (1970) believe that the velocities of fully developed fire whirlwinds reach tornado intensities. This appears justified in view of the destruction caused by at least one fire whirlwind (Pirsko *et al.* 1965), as well as the high-frequency sound emitting from the Burnett County vortex.

SUPPLEMENTAL DATA

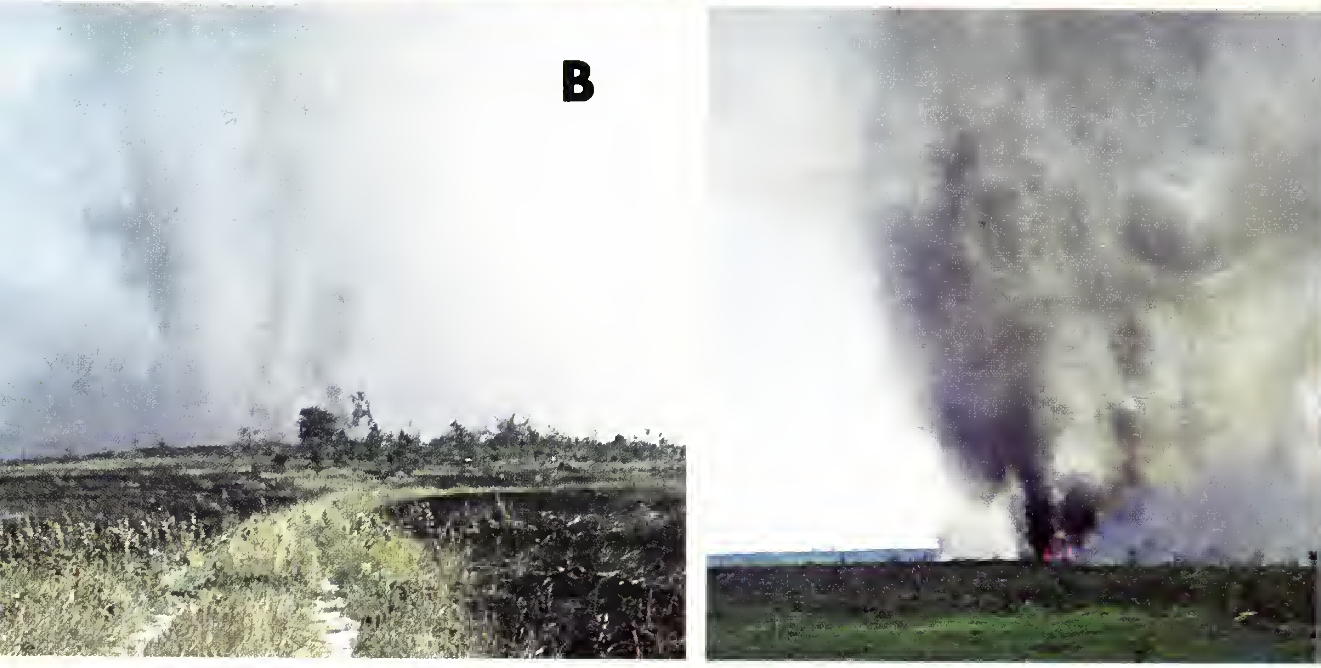
The Virginia Burn

Meteorological data from an experimental fire conducted on 30 acres of the Virginia District of the Superior National Forest, Minnesota, are included in table 1. Although no fire whirlwinds developed during this burn, the data are useful for comparing conditions under which fire-whirls develop with those under which they do not. The fire was set in heavy slash on July 1, 1970, using nearly simultaneous area-ignition methods, and hence was extremely intense. Skies were mostly clear, temperature 86°, and the relative humidity 22 percent. Windspeed averaged 7 m.p.h. with gusts to 12 m.p.h. at the start, but gustiness increased to as high as 19 m.p.h. 15 minutes after ignition and continued through the burn period. Although no general ground fire-whirlwind development occurred, the main smoke column

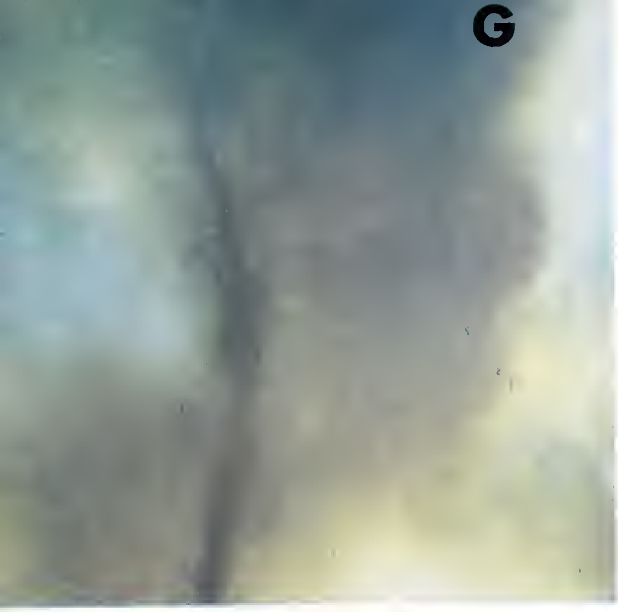
[1] *Personal correspondence with Mr. Otto C. Eggert, Minn. Dep. Nat. Resources. 1971.*

A

B



C



showed brief whirling action during the height of activity (fig. 41). One of a series of experimental burns conducted on the Virginia District during the 1970 fire season, this fire resulted in the greatest fuel reduction by far. Almost all fuels up to 3.5 inches in diameter were completely consumed, indicating a very hot fire.[2]

The Atmospheric Vortex

Although there is not a large amount of field data available on fire whirlwinds, this is not true for other types of vortices. Most investigators of the fire whirlwind have come to the conclusion that there are strong dynamic and geometric similarities between it and other atmospheric vortex types (waterspouts, dust devils, tornadoes, and even hurricanes). These similarities extend well beyond gross features. Emmons and Ying (1967) feel that the fire whirlwind and the dust devil are especially closely allied in that hot gasses rise and then concentrate vorticity already existing in the air into a small-diameter core: "The air, in the case of a hot desert, brings added buoyancy to the very spot required for added dust-devil violence. In the case of the fire-whirl, the radial component of ground wind not only brings added buoyancy to the core, but more important, it also brings added fuel which continues to add to the buoyancy as it burns while rising in the fire-whirl core."

The dust devil has another environmental feature that makes it similar to the fire whirlwind—extreme instability at low levels. Ryan and Carroll (1970) have examined the atmospheric temperature structure during dust-devil formation and found that it consists of a number of layers.

[2] *Roussopoulos, P. J. Results of four prescribed burns at Virginia, Minnesota. Paper presented at USDA Forest Service R-9 Fire Control Meeting, Combined Air Officers and Fire Staff, Springfield, Missouri, April 26-30, 1971.*

Figure 4.—A, *Dust whirl at the Necedah, Wisconsin, burn;* B-H, *fire whirlwinds at the Necedah burn;* I, *main smoke column during the Virginia, Minnesota, burn; the photograph was taken from a tower 1 mile north of the site. Height of the smoke column was about 2,500 feet. Strong entrainment into the base was apparent and whirl motion was evident about half way up. (Photos C, D, E, G, and H courtesy of Mr. Harold Carter, USDI Necedah Refuge.)*

The first layer extends from the surface to a height of 0.3 meter or less and is extremely superadiabatic, with lapse rates as much as 9,000 times the dry adiabatic. The second layer, from 0.3 to about 10 meters, is normally 20 to 40 times the dry adiabatic. A ground surface covered with hot ashes or fire will, of course, create the same or even more highly magnified lapse conditions.

Because the two vortex types are closely related, we can use dust-devil observational findings as they apply to the fire whirlwind. A large amount of dust-devil observational information is available in the literature. The most exhaustive study was recently published by Sinclair (1969). He observed over 1,200 dust devils in the Tucson, Arizona, area, and a statistical computation produced the following information:

1. The highest dust-devil frequency occurs with the lowest atmospheric stability and not necessarily with the highest shelter air temperature. Maximum activity peaks between 1 and 2 p.m. local standard time, which is approximately the time of maximum soil surface temperature and convective heat flux. But intense surface heating and superadiabatic lapse rates usually occur together, although the latter is not necessarily dependent on the former. Therefore, it is obviously most important to check vertical lapse rate rather than the air or even the surface soil temperature.

2. Most of the cloud activity in the Tucson area is cumuliform. On days with cumulus cloud cover, dust-devil activity is suppressed or terminated. A change of from 0.2 to 0.4 average cloud cover results in approximately a 20- to 40-percent reduction in the average number of dust devils observed per day.

3. Typical windspeeds occurring with the greatest dust-devil activity are somewhere between 1 and 10 m.p.h. Occurrence was considerably suppressed by increasing windspeeds. Byram and Martin (1970) found that in the open-air thermal method of fire-whirl production, the generating eddy is easily distorted by light winds: "Even when the rate of heat output per unit length of arc is fairly high, a light wind can cause enough distortion either to prevent the formation of the vortex or to cause it to form only intermittently."

DISCUSSION

All the described fire periods occurred durin the summer and in the early afternoon (table 1) Air temperatures ranged from 75° to 90° F. and relative humidities from a high of 62 percent a Littlefork to a low of 22 percent at Virginia. Skies were essentially clear in all cases. Stability structure of the lower atmosphere is shown in detai in figure 5. The temperature soundings looked much the same as they did during the 1950 South Carolina fire-whirlwind cases (Byram and Nelson 1951). The atmosphere was characterized by a shallow layer of very unstable air that departed dramatically from the dry adiabatic lapse rate of .54° F./100 feet (table 1, fig. 5). The low layer depth was roughly 350 feet, although it increased significantly in the Littlefork situation to 625 feet. Only at Virginia did the lapse excee the critical value of the autoconvective lapse rate 1.87° F./100 feet. Above this value, a spontan eous initiation of convection is possible in th atmospheric layer because overlying air is now more dense than the air nearer the surface.

Except for the Littlefork case, the tempera ture lapse was near the dry adiabatic through th next higher significant layer, which means tha this layer could also have been very unstable. W might caution that it is sometimes risky to extra polate the structure of layers as shallow as a fe hundred feet over relatively long horizontal di tances. Consequently, here we are assuming un form surface conditions.

It did not appear advantageous to examin stability at higher levels. Although some studi of erratic and mass fire situations have tried t involve the positions of high-level jet streams, th general synoptic situation in these cases does n seem to lend itself to that type of analysis. Son western region meteorologists use a 850-500 mil bar, "25° stability rule." When the temperatu difference (°C.) between 850 and 500 milliba is less than 25° C., there is usually little extren fire behavior. They have found that viole behavior seems to increase as the temperatu difference increases beyond 25° C.[3] Howeve

[3] *Personal correspondence with Clive M. Cou tryman, USDA Forest Service, Pacific Southwe Forest and Range Exp. Sta., Riverside, Cali 1971.*

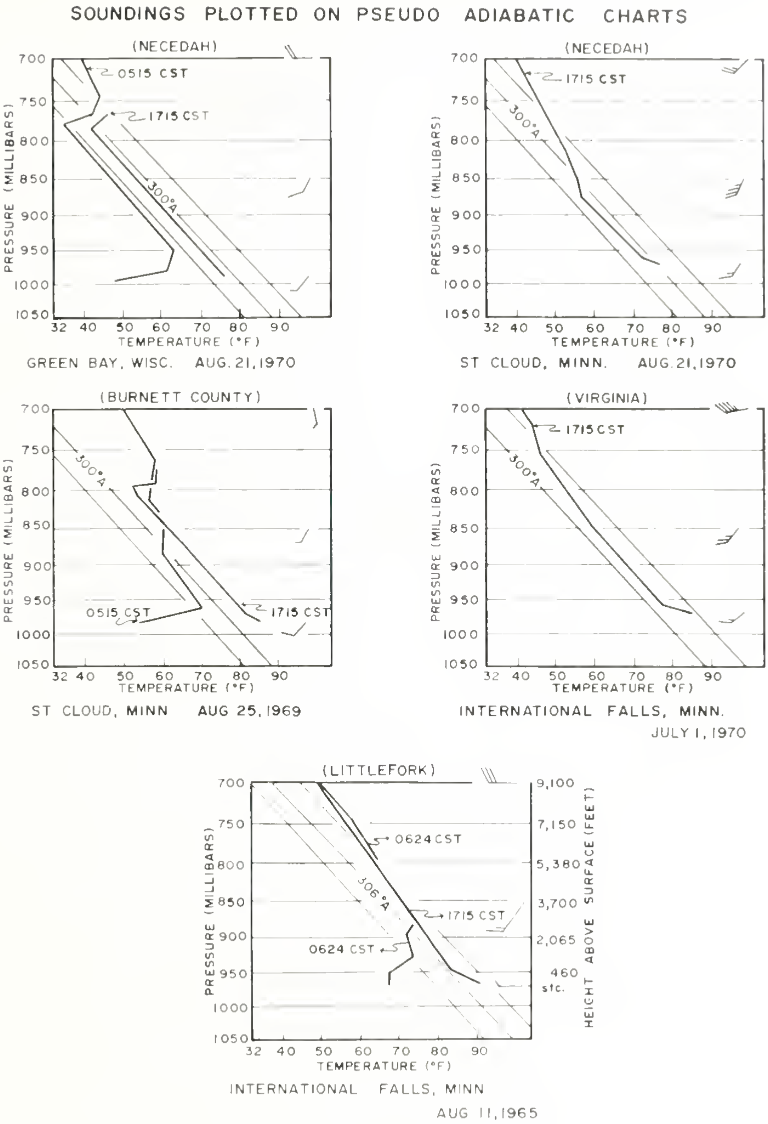


Figure 5.—Upper-air soundings taken near the time of fire whirlwinds. A plot of height is included on the bottom graph (Littlefork) to give some idea of the height of the pressure surfaces. This height does not remain static but varies in time as well as with geography; therefore, it is not the same for all of the included graphs but is roughly so. The straight sloping lines measured in degrees absolute (°A) are the dry adiabates. One can determine the stability of the air by measuring how much the actual temperature sounding departs from these lines. The late-afternoon temperature sounding is plotted on all graphs and the morning sounding (all identified by the Central Standard Time (CST) of release) is included on three of them. Wind velocities at surface, at 850 mb., and at 700 mb. (all measurements at NOAA upper-air station) are also included. The barbed end of the main shaft represents the compass direction from which the wind was blowing, with north at the top of the graph. A half barb represents 5 m.p.h. and a full barb 10 m.p.h.

only in the Littlefork fire-whirlwind situation was there a significant temperature difference between these pressure levels. This forecast rule is probably more applicable at high elevations.

The winds at surface, at 850 mb., and at 700 mb. (fig. 5) reflect the upper-air stations but are not necessarily representative of conditions at the fire-whirlwind site. This is why conditions at two U.S. NOAA stations are shown for Necedah. A high pressure area (fig. 6) was moving rapidly to the east at that time, and the winds over Green Bay were probably more representative of Necedah conditions than those at St. Cloud.

These data do not indicate whether a certain synoptic pattern is most conducive to flatland fire-whirlwind occurrence. There are, of course, a number of synoptic patterns associated with certain types of fire behavior (Schroeder 1969), but there is no clearcut evidence that links them with flatland fire-whirlwind formation.

It may be valuable to try to determine why fire whirlwinds did not develop at the Virginia prescribed burn. Air temperature was high at Virginia and relative humidity was much lower than it was in all other cases, although these do not appear to be important variables. Skies were clear. The lapse rate was autoconvective in the lowest layer, the only instance when this occurred in these case studies. Perhaps if the lapse rate over the region is too steep, it could suppress development. Resultant convective activity with its attendant momentum transfer might, in some cases, inhibit the formation of a generating eddy. However, if we disregard this possibility, there are three remaining features to examine: the intensity and acreage of the burn, and the windspeed. As Countryman (1964) points out, it is not known how much fire area and heat production are necessary to generate vortices. In his field tests of mass fire, however, he produced fire whirlwinds on test plots covering less than 100 square feet. The Virginia burn was intense, yet no whirlwinds formed. Thus, size and intensity do not appear to be controlling factors here. We are apparently left with the probability that gusty surface winds did not allow a generating eddy to form. The heat sink was sufficiently strong, however, to allow brief whirls to appear occasionally in the main fire column.

From case studies examined, it would seem that optimum conditions for development of flat-terrain, fire whirlwinds should include the following:

1. A fire of sufficient acreage and intensity t create the heat source. Methods of burning ar also important as they determine total heat prc duction as well as vorticity generation. Interest ingly, Countryman (1969) found that too grea a fire intensity may prevent fire-whirl formation because of turbulence. Most of the vortices h observed formed in the later stages of a fire.

2. A superadiabatic lapse rate through th lower 300 to 400 feet with a lapse near the dr adiabatic for 2,000 to 5,000 feet above, or jus a deeper, lower layer containing a superadiabati or perhaps even a dry adiabatic lapse rate.

3. Little or no wind; the fire produces enoug air movement to start a generating eddy.

4. Clear skies. Although fire whirlwinds hav occurred under overcast conditions and even a night, clear skies are optimum.

How often are these conditions met at a give location in the Midwest? To answer this ques tion, late-afternoon, upper-air soundings were ex amined (from St. Cloud, Minnesota) for each da during the period July 1 to August 31, 1965-1969 All of the information was taken from forn WBAN-31A, the adiabatic chart. Minimum cr teria were set at:

1. A ground layer, superadiabatic lapse of an depth or strength, or a dry adiabatic lapse rat to at least 860 mb.

2. Winds of 3 meters per second or less (6. m.p.h.).

3. Opaque cloudiness less than 4/10.

Of the 310 days involved in the study, 253 day or 81 percent had lapse rates that qualified. dry adiabatic lapse to at least 860 mb. occurre on only 7 days, so all others had low-level, supe adiabatic conditions. The following tabulatio gives the percentage of afternoons that a supe adiabatic lapse rate exists to various heigh above the surface (this height usually represen the top of the strongest superadiabatic layer i the atmosphere):

Height above surface (feet)	*Percent of afternoons*
None	21
240 to 300	20
300 to 400	20
400 to 500	12
500 to 600	8
600 to 1,000	7
Greater than 1,000	12

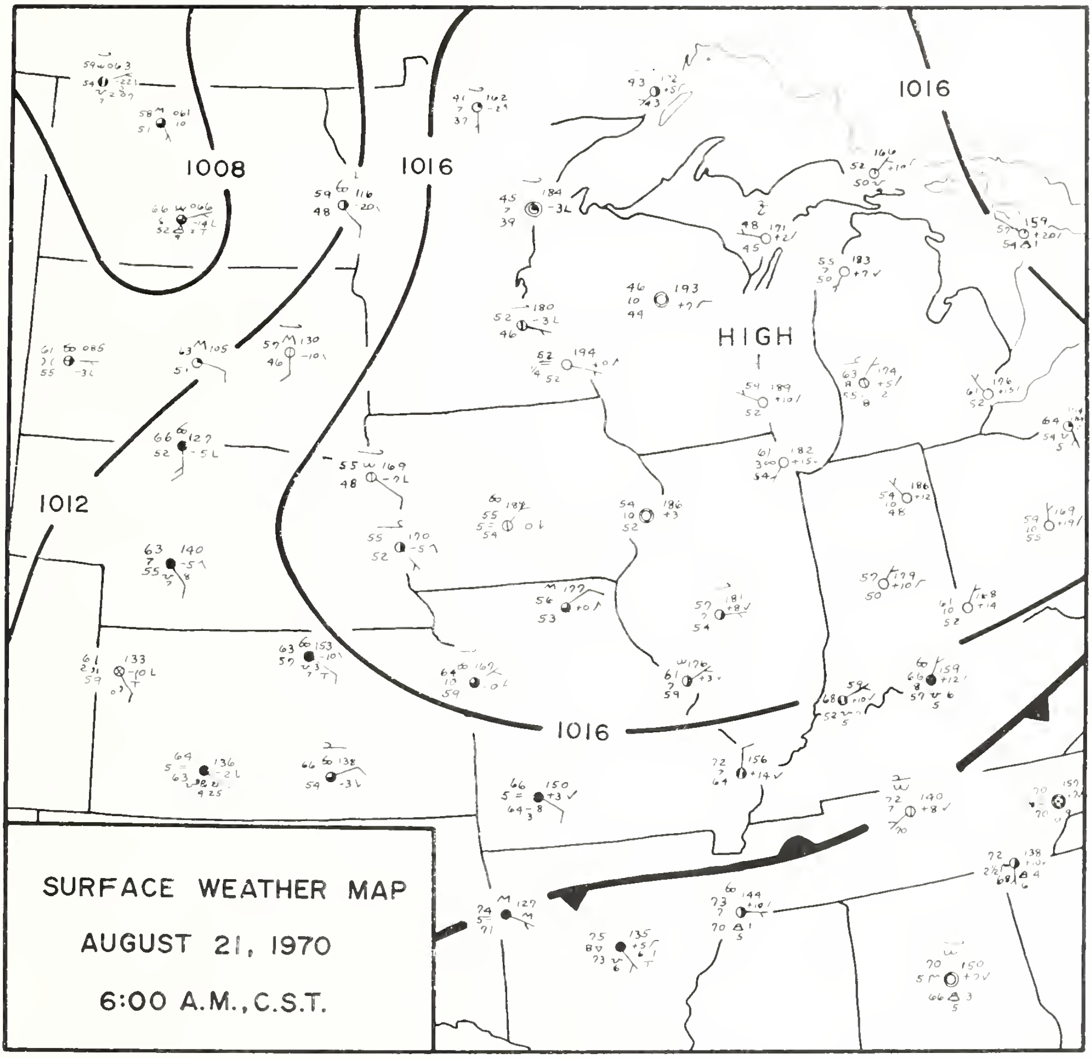


Figure 6.—Morning synoptic features on the day of the Necedah fire whirlwind. Weather symbols and analysis were taken from the Daily Weather Map series of the U.S. Department of Commerce.

Under the opaque cloudiness guidelines, 60 ercent of the days were favorable. Interestingly, nly 24 percent of the afternoons had favorable indspeeds. The tabulation below shows freuency of occurrence of surface windspeeds durng the afternoon upper-air release, July and ugust 1965-1969.

Windspeed (Meters per second)	*Frequency of occurrence (Percent)*
1	2
2	7
3	15
4	19
5	24
6	10
7	11
8	6
9	2
10	3
11	1

In all, even with generous guidelines, only 32 days or 10 percent of the total had conditions that might favor fire-whirlwind development. This probably is a maximum estimate, because not all of the included lapse rates were sufficiently strong to produce low-level overturning, and winds of 6.7 m.p.h. are probably too high to allow flatland fire-whirlwind development. They were included to this velocity because Simard (1969) has shown that in Canada the average forestry station to airport windspeed ratio varies between 0.26 and 0.66. Also, it is important to remember that vegetative and fuel conditions were not considered in this analysis. If the fuels will not burn, winds, clouds, and temperature lapse rates are of no concern.

SUMMARY

Assuming that fuels are in a receptive state, fire-whirlwind genesis over flat terrain requires (1) a low-layer, superadiabatic lapse rate, (2) little or no wind, and (3) for optimum conditions, clear skies. Weather data from St. Cloud, Minnesota, show only a small percentage of days that fulfill these requirements (less than 10 percent).

In fighting fires on days with fire-whirlwind formation, igniting an additional area or perimeter as a control measure or to widen a fireline may be hazardous. Adding more fire to the danger area increases the possibility of fire-whirlwind occurrence. Vortices have crossed burning firelines with spectacular results, often picking up firebrands and throwing them over wide areas. The possibility of control by using water in the form of a spray or stream is an intriguing idea but requires testing. It would be especially interesting to observe the effects of a plane making a water drop on a fire whirlwind. At this point there is no way to predict the results. Therefore, when confronted with fire whirlwinds, about the only thing one can do is wait for the activity to subside, then move in as quickly as possible to control spot fires.

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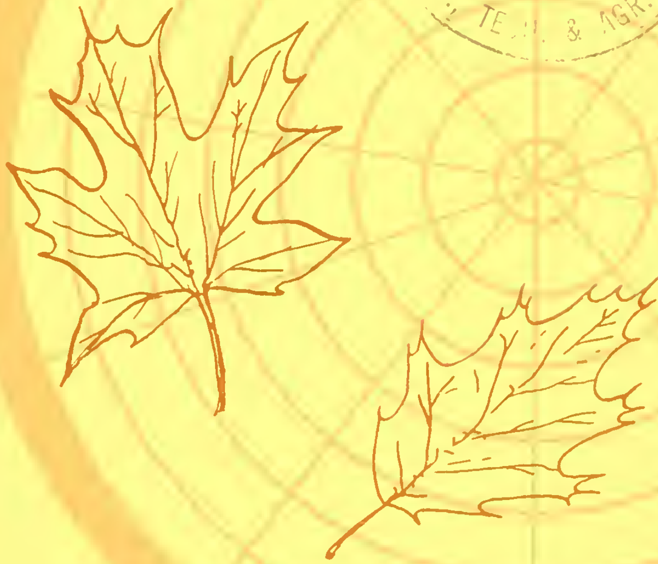
The Changing Hardwood Veneer and Plywood Industry



# of Michigan and Wisconsin

Gary R. Lindell and
Lewis T. Hendricks

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
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(Maintained in cooperation with the University of Minnesota)
Manuscript approved for publication October 21, 1971

THE CHANGING HARDWOOD VENEER AND PLYWOOD INDUSTRY OF MICHIGAN AND WISCONSIN

Gary R. Lindell and
Lewis T. Hendricks

Domestic consumption of hardwood veneer and plywood has been rapidly expanding; however, the industry of Wisconsin and Michigan has not fully shared in this growth. For example, *Census of Manufactures*[1] data show that the value of shipments from Wisconsin hardwood plywood mills (the 1958 Census showed no plywood plants in Michigan) increased about 40 percent between 1958 and 1967, whereas national shipments increased over 80 percent. During this period Wisconsin fell from first to third in value of shipments. Also, total industry employment fell in the two-state area.

Thus, important changes are taking place in the hardwood face veneer and plywood industry of the northern Lake States. Unfortunately, little is known about the nature of these changes and the manner in which they influence and are influenced by the declining industry. To better evaluate trends within this important regional industry, surveys were conducted in 1964 and 1969. This report will describe and evaluate the changes that occurred during this period.

PROCEDURE

Through extensive investigations and interviews with industry personnel, Hendricks developed a detailed picture of the operations of the hardwood face veneer and plywood industry of Michigan and Wisconsin in 1964.[2] These mills were resurveyed in 1969. In the remainder of this report we will describe important characteristics of the industry as of 1969 and highlight changes that occurred between the two surveys.

THE INDUSTRY

In 1969, the industry consisted of the following:[3]

Type:	*Number in:* Michigan	Wisconsin	*Total number of mills:*
Face veneer mills	4	5	9
Veneer and plywood mills	1	11	12
Plywood mills	3	10	13

[1]*U.S. Bur. Census, Dep. Commerce. 1967 Census of manufactures. 1970.*

[2]*Lewis T. Hendricks. A study of the hardwood face veneer and plywood industry in Michigan and Wisconsin. 1967. (Unpublished Ph.D. thesis on file at Dep. Forest Products, Mich. State Univ., East Lansing.)*

[3]*Note that container mills and box factories were not included in the study.*

Face veneer mills were not equipped with presses to manufacture plywood; hence the distinction. Veneer and plywood mills were fully integrated and could peel the logs and manufacture plywood. Plywood mills did not peel veneer but purchased all their veneer for manufacturing plywood. Most mills were located within a 100-mile radius of Green Bay, Wisconsin (fig. 1).

Several changes took place between the two surveys. Two veneer mills added pressing facilities, and thus were classified as veneer and plywood mills in the 1969 survey. One former plywood mill discontinued manufacturing plywood and was not active in 1969. Several mills changed ownership; the general pattern was for mills to be purchased by national, integrated firms. No new mills entered the industry between the two surveys. However, a new veneer and plywood mill was under construction in 1969 in Upper Michigan and production was initiated in 1970. Finally, the ever-threatening fire completely gutted three mills, which were subsequently rebuilt or under reconstruction during the recent survey.

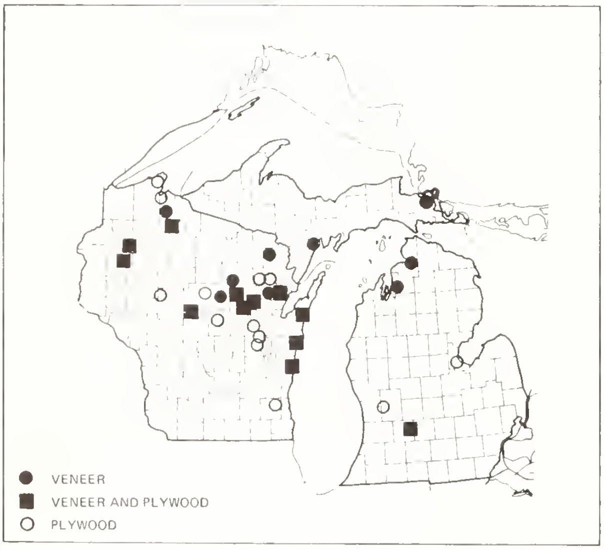

Figure 1.–Location of hardwood veneer, veneer-plywood, and plywood mills in Michigan and Wisconsin, 1969.

VENEER-LOG CONSUMPTION

Veneer-log consumption varied considerably over the 1964-1969 period, ranging from a high of about 32.4 million board feet in 1967 to a low of 24.1 million in 1968 (fig. 2).[4] Important changes also occurred in the species utilized, with red oak and hard maple replacing yellow birch as the major species used. These three species accounted for about two-thirds of total log consumption during the study period.

People involved with the regional forest products industry have speculated on the adequacy of the timber resource in the Lake States to meet future requirements, particularly of the veneer industry. Recent forest surveys show substantial increases in the growth of such important species as hard maple. However, the question still remains as to whether the forests can produce an adequate supply of logs of the size and quality suitable for veneer, at least in the next 5 to 10 years. To give an indication of the severity of this problem, officials of each firm were asked several questions concerning current or expected material shortages (if any).

Apparently the availability of veneer logs has not posed a major problem to the regional industry because officials of only two firms remarked that they were experiencing or were expecting to have difficulty obtaining veneer logs in the near future. These two firms, located in Michigan, were having difficulty obtaining yellow birch logs and found it necessary to enlarge their supply area. Of course many mills experienced seasonal supply difficulties, but these were generally caused by adverse weather conditions and weight restrictions on roads rather than by a shortage of timber.

Mill officials also were questioned about the specifications they were imposing on logs in 1969 and how these might have changed over the preceding 5 years. We thought the mills might have been forced to ease their specifications to obtain an adequate supply of logs. However, such changes were not common. All mills were essentially using the standard veneer-log specifications as promulgated by the USDA Forest Service and the Northern Hardwood and Pine Manufacturers Association. Moreover, practically all the officials interviewed indicated that the specifications had changed little, if any, over the preceding 5 years. The minor changes in specifications that did occur resulted

[4] *Data supplied by Lake States Hardwood Veneer Association; these figures represent approximately 80 percent of the total regional hardwood face veneer production.*

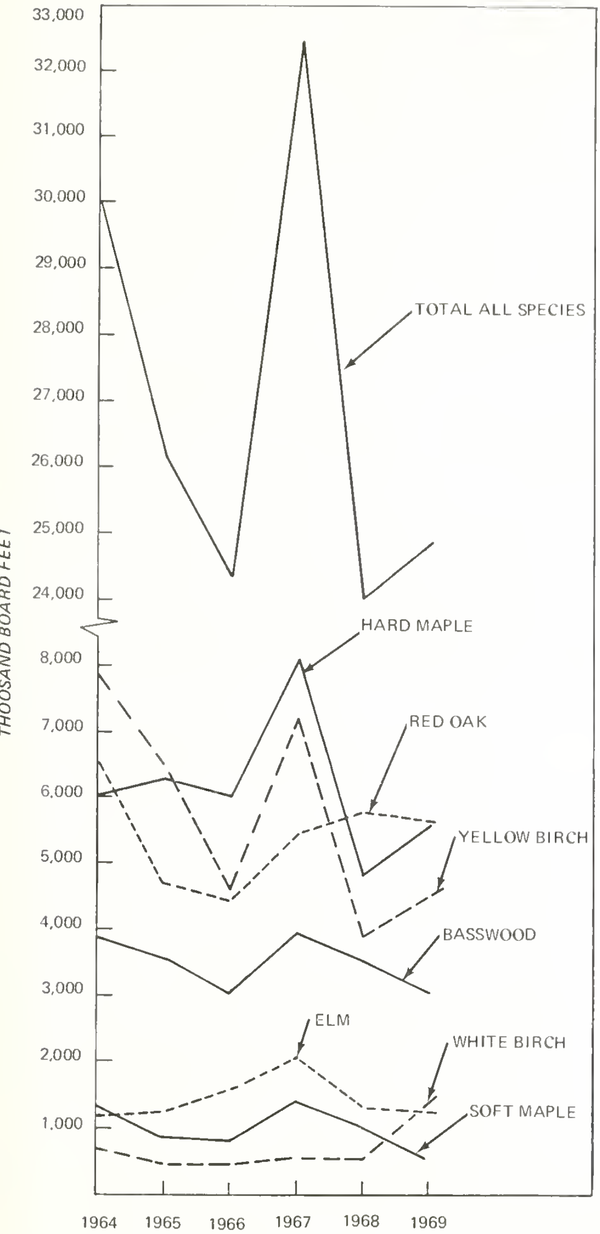

Figure 2.–Veneer-log consumption by hardwood veneer and veneer-plywood mills in Michigan and Wisconsin, 1964-1969.

rom seasonal surpluses or shortages of logs. But, in eneral, mill officials felt that an adequate log supply vas not an important problem. The relatively small price hanges for veneer logs in Wisconsin in recent years further substantiate this conclusion.[5] Thus, markets were more important in determining the species and type of log used than were log supplies.

Officials from mills that produced plywood also were asked if veneer procurement posed any important difficulties. All of the officials interviewed indicated that adequate supplies of veneer at suitable prices were no problem. However, many mills were purchasing corestock from the southern United States or the tropics. Apparently the regional mills find it to their advantage to specialize in the production of faces and backs and purchase the inner plies.

VENEER PRODUCTION

Veneer production in 1969 was slightly higher (12 percent, surface measure) than in 1964. Probably most of this increase was due to cutting thinner face veneer. Veneer 1/26-inch thick replaced 1/24-inch as the most common face ply (fig. 3). Most of the veneer produced by the two classes of mills that peel was of the common face thicknesses (1/20-inch and thinner).

Veneer and plywood mills (those with integrated operations) produced a larger percentage of core (1/12-inch to 7/32-inch) and crossband (1/16-inch) plies than did veneer mills. Generally, these inner plies were to supplement their own plywood manufacturing operations. Both classes of mills showed a trend away from the production of corestock but a slight increase in the proportion of crossband material. Veneer mills apparently find it more advantageous to specialize in faces (and backs) because practically all of their production was in the common face thicknesses. Ninety-six percent of the veneer was rotary cut (figs. 4, 5). Half-round and sliced veneers comprised the remaining 4 percent.

PLYWOOD PRODUCTION

Because of the wide variety of thicknesses and types of plywood produced, it is difficult to compare volumes produced in 1964 and 1969. Based on surface measure, the volume recorded for 1969 was about 35 percent below that for 1964.

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[5] *T. A. Peterson. Wisconsin forest products price review. Dep. Forest., Univ. Wis. 1967-1969.*

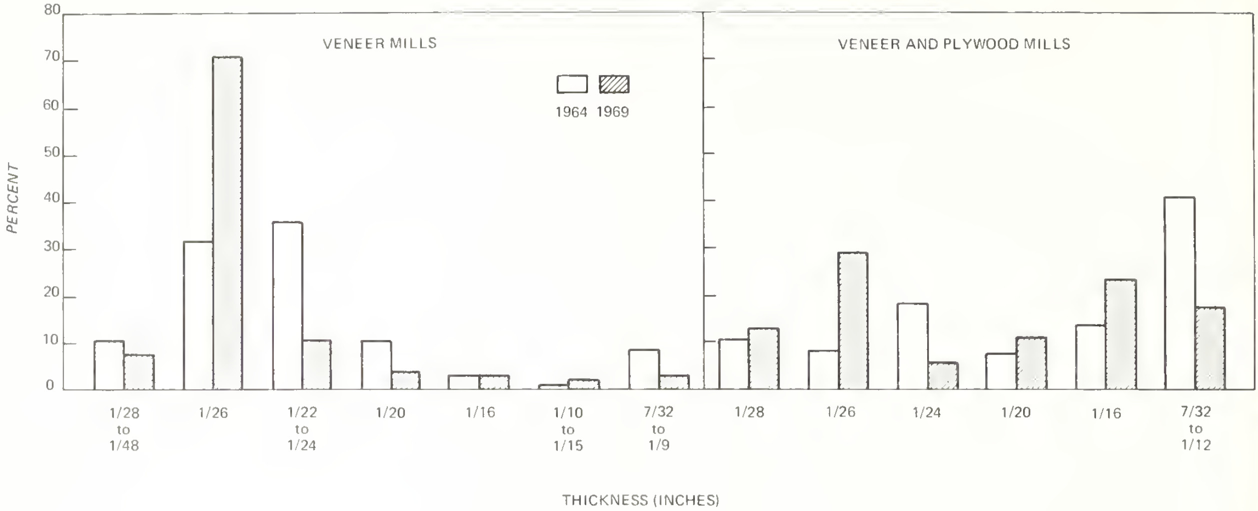

Figure 3.–Thicknesses of veneer cut by hardwood veneer and veneer-plywood mills in Michigan and Wisconsin, 1964 and 1969.

More than 90 percent of the plywood was of all-veneer construction, with the number of plies ranging from 2 to 43 for specialty items. Three-and five-ply were the most common thicknesses.

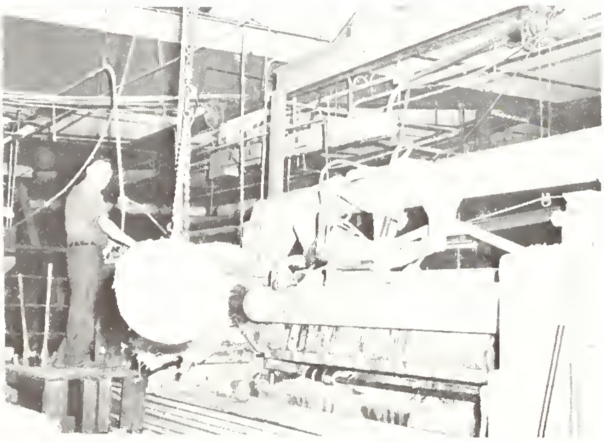

Figure 4.–Veneer bolt ready for chucking on rotary lathe.

Contrary to the apparent national trend, the regional industry experienced a definite shift away from the use of particleboard as corestock between the two surveys. The reason for this is unknown, but one mill manager reported that widely fluctuating and generally rising prices for particleboard corestock prompted him to switch to other materials. Plywood of lumber core construction took up some of the slack.

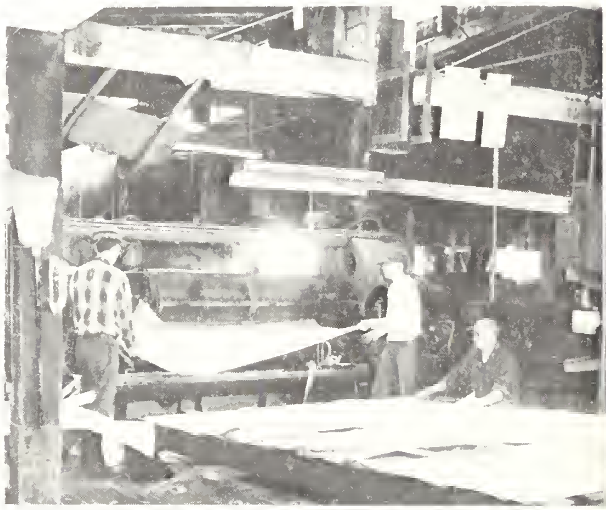

Figure 5.–Sheets of rotary-cut veneer coming off th lathe.

VENEER MARKETS

As noted previously, veneer is produced by both veneer mills and those with integrated operations (veneer anc plywood). Although there is some exchange betweer mills, veneer produced by mills that also produce plywood is generally intended for use within their ow plywood manufacturing operations. In addition, these mills are primarily self-sufficient, generally purchasin only a small portion of their required veneer. Consequently, the following discussion of markets pertains only to veneer produced by veneer mills; it is assumed that all the veneer produced by veneer and plywood mills is used internally and will be reflected in plywood markets, to be discussed later.

The major end market or product for regional veneer mills was wall paneling (fig. 6). About two-thirds of the veneer was so destined (fig. 7). Some of this paneling was produced within the region, although in many cases the veneer was shipped to West Coast mills for mounting on softwood or imported cores. Furniture and doors were the next most important markets in 1969.

There was a definite market shift toward wall paneling between the two surveys. The proportion of the total veneer production destined for this use nearly doubled over the 5-year period, whereas the proportion for doors and kitchen cabinets showed a marked decline. This surge in the wall paneling market conforms with the national trend.

PLYWOOD MARKETS

Wall paneling was by far the major market for plywood produced in regional mills, accounting for approximately three-fifths of the 1969 hardwood plywood production (fig. 8). Doors were next in importance with about one-fourth of the plywood production, and a variety of products constituted the remaining 14 percent. In contrast to veneer markets, plywood markets showed little change in relative importance between the 1964 and 1969 surveys; specialty items (athletic equipment, musical instruments) were the only market showing any appreciable decline.

The industry also displayed a trend away from stock items between the two surveys. In 1964, about 25 percent of the veneer and 7 percent of the plywood was stocked pending receipt of orders. However, in 1969, virtually all of the veneer and plywood was produced to fill specific orders.

INDUSTRY VIGOR

To measure the pulse of the industry, we examined the production-to-capacity ratio of plants and the average age of the equipment in use in 1964 and in 1969.

Capacity and Production

Due to plant modernizations, veneer productive capacity[6] was about 14 percent greater in 1969 than in 1964. Veneer mills were making the most effective use of their productive capacity. In 1969 veneer mill production as a percent of capacity was 76 percent, up 4 percent from 1964. Veneer and plywood mills, on the other hand, showed a loss in efficiency between the surveys with the production-to-capacity ratio falling from 67 to 63 percent. The combined ratio for both types of veneer producers stood at 73 percent in 1969, about the same as in 1964.

The addition of plywood presses in two former veneer plants offset the loss of capacity when a plywood plant left the industry. As a result, total plywood productive capacity remained about the same between the two surveys. Excess plywood-producing capacity remains a chronic problem in the industry, because the production-to-capacity ratio for veneer and plywood mills was only 38 percent in 1969, about the same as in 1964. Plywood mills also showed a marked increase in excess capacity, with the capacity utilization ratio falling from 60 percent in 1964 to 43 percent in 1969. The combined plywood production-to-capacity ratio for both types of mills was only 42 percent in 1969, even lower than the 53 percent recorded in 1964.

Although no attempt was made to determine the capacity ratio at which firms prefer to operate, it is apparent that there was an excess of plywood production capacity in the industry. Excess capacity, in turn, implies that at least some firms were operating at less than their least-cost or optimal output position. This inefficient use of capital results in an upward pressure on costs and reduced profits.

Equipment Age

Another important measure of industry vitality is the age and type of machinery being used and efforts at equipment modernization. Results of the two surveys indicate that mills with integrated veneer and plywood operations made noteworthy improvements in equipment during the 5-year period, whereas the veneer mills and

[6]*In this study capacity was defined as the amount of veneer or plywood that a mill could produce within 24 hours using existing plant facilities and three shifts.*

Figure 6.–Wall paneling is the major end market for regional mills although competition is keen, particularly from imports.

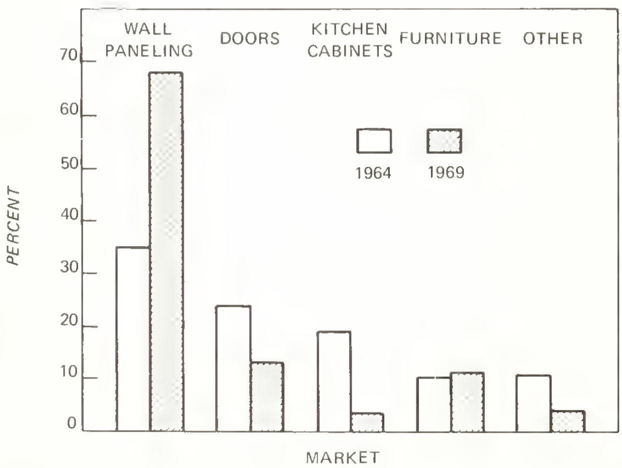

Figure 7.–End markets for veneer produced by hardwood veneer mills in Michigan and Wisconsin, 1964 and 1969.

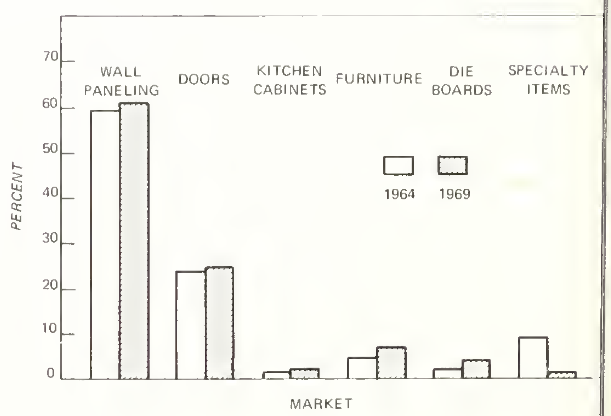

Figure 8.–End markets for plywood produced by venee plywood and plywood mills in Michigan and Wisconsi 1964 and 1969.

the plywood mills made few changes. In 1964 the average age of all equipment in use was 11.9 years, 14.8 years, and 9.4 years for the veneer, veneer and plywood, and plywood mills, respectively (table 1). In 1969 the situation was reversed, with veneer and plywood mills using newer equipment, on the average, than the other two types of plants.

Table 1.—*Average age of equipment in veneer, veneer-plywood, and plywood mills in Michigan and Wisconsin, 1964 and 1969*

(In years)

Type of equipment	Veneer 1964	Veneer 1969	Veneer and plywood 1964	Veneer and plywood 1969	Plywood 1964	Plywood 1969
Veneer manufacture:						
Debarkers	6.3	7.9	9.9	8.5	--	--
Lathes	16.3	19.3	19.2	16.1	--	--
Wet clippers	12.0	16.4	12.1	12.5	--	--
Dryers	20.5	19.3	24.3	23.6	--	--
Plywood manufacture:						
Clippers	10.8	14.2	14.5	13.8	12.2	16.7
Jointers	9.3	6.8	16.2	15.1	12.3	16.8
Splicers	9.5	12.5	13.7	13.8	10.5	16.5
Glue spreaders	--	--	15.4	16.7	8.7	13.7
Presses	--	--	24.6	18.7	17.5	19.1
Trimmers	--	--	15.3	15.1	6.8	10.6
Sanders	--	--	14.2	10.9	4.0	9.0
Average age - all equipment	11.9	15.5	14.8	14.8	9.4	14.9

As a result of periodic replacement of equipment, veneer and plywood mills were able to maintain the average age of equipment at 14.8 years in 1969. However, veneer mills and plywood mills were using primarily the same equipment in 1969 as in 1964, except that it was 5 years older.

The average age of equipment by type and class of mill is presented in table 1. Note that the equipment in use in the important peeling, wet clipping, and drying operations was commonly older than 15 years. Likewise, equipment used in the plywood manufacturing operations was often 14 to 20 years old. It appears that many of the regional mills were operating with outdated equipment, especially in view of such improvements as the dual-spindle lathe and the jet dryer. Three mills had installed or were in the process of installing dual-spindle lathes in 1969. Another three mills had or were installing jet dryers. Although no attempt was made to evaluate the profit capabilities of equipment in use, it seems that many mill managers should take a critical look at their equipment.

DISCUSSION

In general, most mill managers were disappointed with business conditions and their firm's performance in 1969. Whether the situation could be attributed to short-term market fluctuations or longer-term shifts within the regional industry remains to be seen. Residential construction—the best barometer of plywood markets—was down slightly in 1969 from the previous year. A substantial increase in residential construction is forecast for the 1970's, which might improve markets and the outlook for the regional industry. However, it should be noted that several firms were experiencing financial difficulties that transcended several years. At the time of the recent interviews (spring 1970), four mills were temporarily shut down and most mills were operating well below capacity. Several mills appeared to be headed for eventual liquidation.

In general, the industry is not experiencing important raw material shortages, a point that confirms earlier findings.[7] Most plywood mills were purchasing core and crossband material from other sections of the country. Apparently regional mills found it to their advantage to specialize in faces and backs and purchase the required inner plies. For example, one veneer mill was revamped between the two surveys to produce a larger proportion of core and crossband material. However, the parent company found it more economical to purchase this material from other mills and the plant was eventually closed. Several mill managers remarked that raw material costs are now secondary to labor, whereas previously the reverse was true.

One cannot discuss the hardwood plywood situation without mentioning imported plywood, since imports

[7]*Lewis T. Hendricks. Hardwood face veneer and plywood mill closures in Michigan and Wisconsin since 1950. USDA Forest Serv. Res. Note NC-14, 4 p. N. Cent. Forest Exp. Sta., St. Paul, Minn. 1966.*

now supply the bulk of our domestic consumption. Most of the plywood imported in 1969 was paneling from Asia; about 20 percent was Philippine mahogany and birch doorskins.[8] Practically all of the mill managers interviewed remarked that competition from imports—particularly Finnish birch plywood—has intensified in recent years. Finnish plywood is imported primarily in the thicker sizes, which compete for cabinet and furniture markets. Japan—the major exporter of birch plywood to the United States in 1969—is specializing in doorskins, also an important market for regional producers.

On the national scene, domestic producers are moving rapidly into prefinishing of imported plywood. This plywood—practically all paneling—is then marketed together with regular domestic lines.

In addition to the impact of imports, competition between regions has intensified. For example, because of the availability of lower-cost inner plies, the production of "stock panels"—a standard-size veneer core panel, commonly with an unfinished birch or oak face and back —has shifted almost entirely to the West Coast. Previously this was an important item for regional mills.

It appears that most of the problems of the regional veneer and plywood industry are of the marketing nature. Although effective capacity utilization and equipment productivity are continuing problems, the most pressing need is for secure markets.

Veneer mills have rapidly increased the proportion of their product destined for use as wall paneling. This is also where most of the national growth has occurred. However, this market also has the most competition, particularly from imports. It appears as though the region has no important relative advantage in this market; most of the increase in veneer destined for use as paneling apparently was due to increases in the amounts of veneer being shipped to the West Coast for mounting on softwood or imported cores. Plywood mills also showed a slight increase in the proportion of their product destined for use as wall paneling. However, the figures were heavily weighted by one mill that is integrated with a regional marketing chain and specializes in imported paneling.

Probably the most promising markets for regional plywood mills are the low volume-high value specialty products such as athletic equipment, die boards (a form of plywood used by the printing industry), and musical instrument components. Cabinet and furniture stock will probably continue to be important, but again the emphasis will probably be on high quality-low volume items. Likewise, the future opportunities in the paneling market are probably high-value architectural panels. How successfully the regional plywood industry competes may depend on how effectively it can establish and maintain a position in these specialized markets.

[8] *Gary R. Lindell. Hardwood plywood–output and outlook. Woodworking and Furniture Digest, April 1971, p. 39.*

☆ U.S. Government Printing Office, 1972-760-507

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USDA FOREST SERVICE
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1972

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Estimating Force & Power Requirements for Crosscut Shearing of Roundwood

by RODGER A. AROLA

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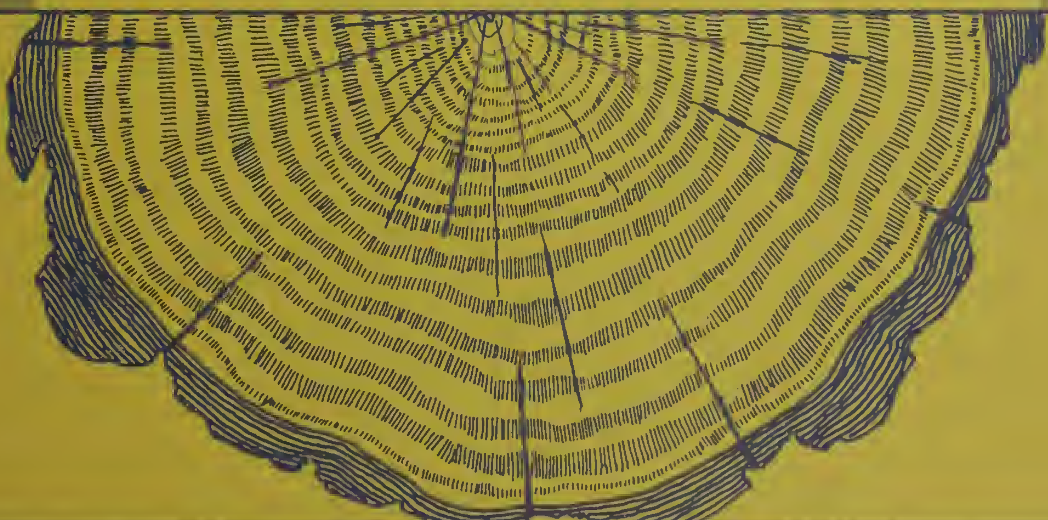

NORTH CENTRAL FOREST EXPERIMENT STATION
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Manuscript approved for publication October 21, 1971.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

ESTIMATING FORCE AND POWER REQUIREMENTS FOR CROSSCUT SHEARING OF ROUNDWOOD

Rodger A. Arola

This paper describes a procedure for estimating the force and hydraulic power required to crosscut shear frozen and unfrozen roundwood of various specific gravities. The designer of prototype equipment can use this method to rapidly estimate the effects of numerous combinations of blade thickness, cutting speed, and hydraulic pressure on the selection of cylinder size, pump delivery, and motor horsepower requirements. Or, if the prime mover has already been selected, the portion of the available horsepower and pump delivery required to effect the cut can be estimated. This is particularly important if other job functions are being performed at the same time as the shearing operation. If maximum component sizes are limited, the designer can determine whether a mechanical advantage between the cylinder rod and shear blade will be required. The owners of existing shear-blade harvesters can estimate the maximum log diameter for each species that can be sheared with their equipment.

The procedure for estimating the force and power requirements is described in the following steps. It is based on a shear study conducted on several northern forest species having specific gravities between 0.30 and 0.65 (Arola 1971). Log diameters in the study ranged from 5 to 10 inches, shear blade thicknesses from ⅛ to ½ inch, and shearing speeds from approximately 2 to 12 inches per second. The effects of shear blade dulling and internal wood temperature on crosscut shearing were also incorporated. A worksheet is provided for the convenience of the estimator.

Step 1.—Determine the following.—

G=specific gravity (based on ovendry weight, green volume) of the species to be crosscut sheared. (Values tabulated in the *Wood Handbook* (USDA Forest Service 1955) can be used for estimating purposes.)

t=shear blade thickness (inches)

D=maximum log diameter to be sheared (inches)

P=desired hydraulic pressure (psi)

V=desired shearing speed (ips) (Recommended range is 2 to 12 inches per second.)

T=estimated lowest temperature of operation (°F.)

Step 2.—Determine the total shear force requirement F_m.—Enter nomograph 1 at the appropriate wood specific gravity *G* and follow this value up to the selected blade thickness *t* (see example). At this intercept follow a horizontal line to intercept the maximum log diameter *D* to be sheared and then along a vertical line to determine the total shearing force F_m required to effect the cut.[1] Based on a previous shearing study (Arola 1971), shearing force values in nomograph 1 have been adjusted to approximate the 95-percent upper confidence limits on a single estimate plus a 15-percent increase in force due to moderate blade dulling (approximated by a 1/32-inch flat along the entire cutting edge).

Step 3.—Correct the shear force for temperature $F_{c/t}$.—The total shearing force as determined in Step 2 is for an approximate temperature of 60°F. This value must be corrected for shearing at lower temperatures—particularly for frozen wood. Increases in force for aspen, white spruce, and hard maple sheared at temperatures down to 0°F. range from 10 to 32 lbs./in. width of cut per °F. drop in temperature (Arola 1971). An average unit value of 20 lbs./in. width of cut per °F. is recommended as a multiplier of the anticipated temperature drop and maximum log diameter. Though not reported in the same manner, this estimate of the effect of low temperatures compares favorably with those of other investigators (Johnston 1968.[2] Thus,

$$F_{c/t} = F_m + 20\ (60\text{-}T)\ D.$$

Step 4.—Determine the cylinder size d.—Locate the maximum shearing force $F_{c/t}$ from Step 3 on nomograph 2 and the desired operating pressure *P*. Place a straight edge along these two values to find the intercept that

---

[1] *Shear force requirements for blade thicknesses greater than ½ inch and log diameters in excess of 10 inches were extrapolated from experimental data.*

[2] *M. Wiklund. Temperature measurement in the living tree. Paper presented at IUFRO Meeting, Madison, Wis. 1971.*

etermines the piston diameter *d*. If this is not a standard ylinder size select the next higher diameter. This selec-on procedure assumes a direct relationship between the ıaximum force requirement and the hydraulic cylinder. f a mechanical linkage is provided that voids this as-umption, the force on the cylinder must be adjusted ccordingly.

Step 5.—Determine the hydraulic oil flow rate).—The intercept for hydraulic oil flow rate *Q* is etermined from nomograph 3 by placing a straight edge n the piston diameter *d* determined from Step 4 and ıe desired shearing speed *V*.

Step 6.—Determine the theoretical motor horsepower equirements HP_t.—To determine the theoretical orsepower of the motor to drive the hydraulic pump assuming 100-percent overall efficiency of the pump), ıe straight line intercept on the horsepower scale nomograph 4) is found by connecting the flow rate *Q* rom Step 5 and the desired hydraulic pressure *P* from Step 1.

Step 7.—Adjust the motor horsepower for the overall efficiency of the pump HP_e.—The horsepower requirement (Step 6) must be adjusted for the overall efficiency *e* of the hydraulic pump (product of volumetric and mechanical efficiencies). The manufacturer's performance curves for the particular pump should be consulted. However, in lieu of the actual performance curves, the approximate values of overall pump efficiency from table 1 can be used for estimating purposes (Kaufman 1968). For mobile equipment applications the balanced vane pump having fixed displacement has become the most universally accepted because of high operational speeds and pressures. The adjusted motor horsepower is determined as follows:

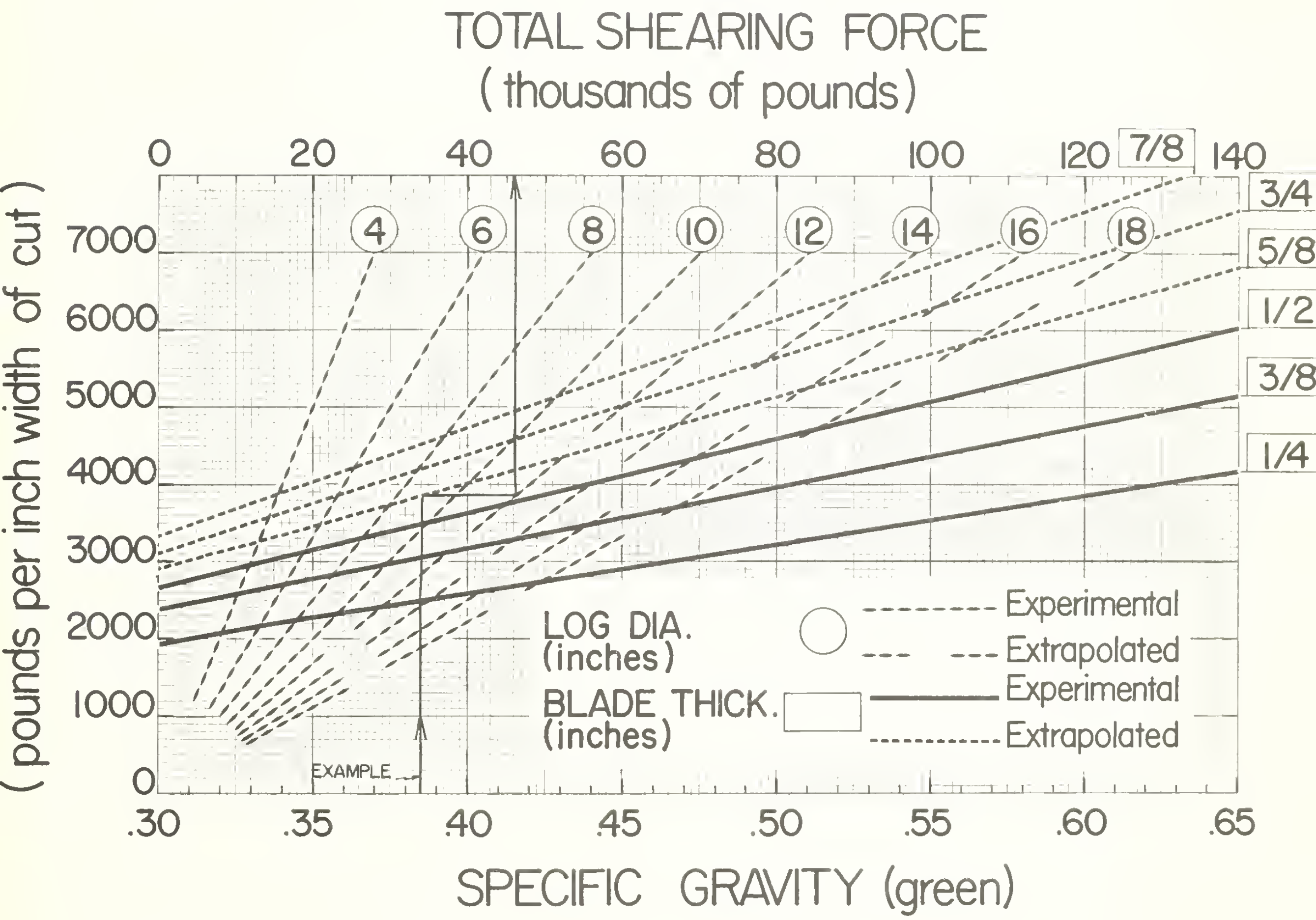
$$HP_e = \frac{HP_t}{e}$$

The estimator should be aware that line losses from the pump to the cylinder may decrease the usable hydraulic pressure in the cylinder by 10 to 25 percent (Anonymous 1967).

Table 1.—*Pump comparison*

Pump type	Pressure rating (P)	Overall efficiency (e)	Weight	Rated speed
	psi	Percent	Lbs. per HP	rpm
External gear	2,000 - 3,000	80 - 90	0.5	1,200 - 2,500
Internal gear	500 - 2,000	60 - 85	.5	1,200 - 2,500
Vane	1,000 - 2,000	80 - 95	.5	1,200 - 1,800
Axial piston	2,000 - 10,000	90 - 98	.25	1,200 - 3,600
Radial piston	3,000 - 10,000	85 - 95	.35	1,200 - 1,800

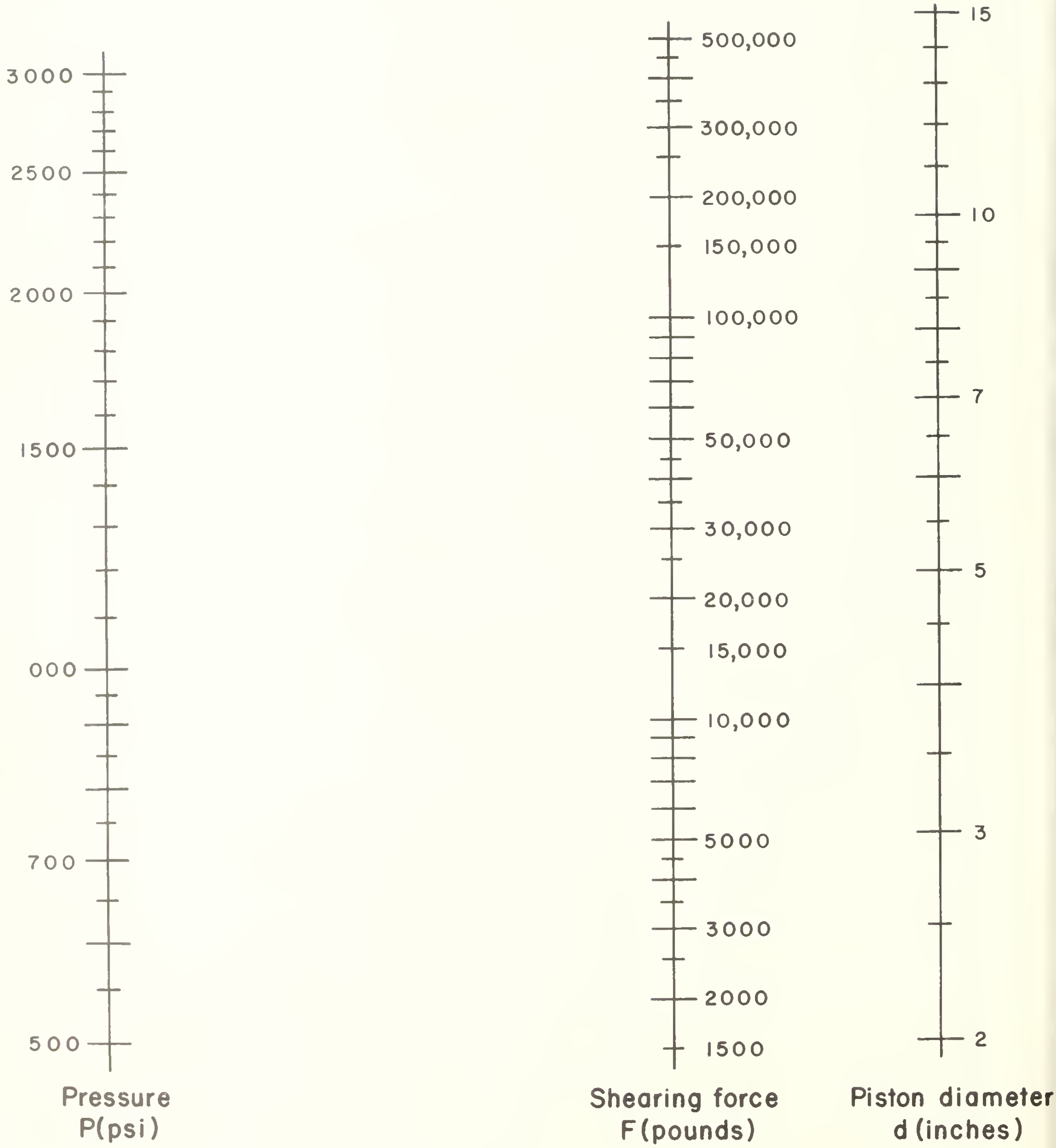
NOMOGRAPH 1


TOTAL SHEARING FORCE
(thousands of pounds)
0
20
40
60
80
100
120
140
7/8
3/4
5/8
1/2
3/8
1/4
4
6
8
10
12
14
16
18
(pounds per inch width of cut)
7000
6000
5000
4000
3000
2000
1000
0
EXAMPLE
LOG DIA. (inches)
BLADE THICK. (inches)
Experimental
Extrapolated
Experimental
Extrapolated
.30
.35
.40
.45
.50
.55
.60
.65
SPECIFIC GRAVITY (green)

NOMOGRAPH 2

CYLINDER SIZE

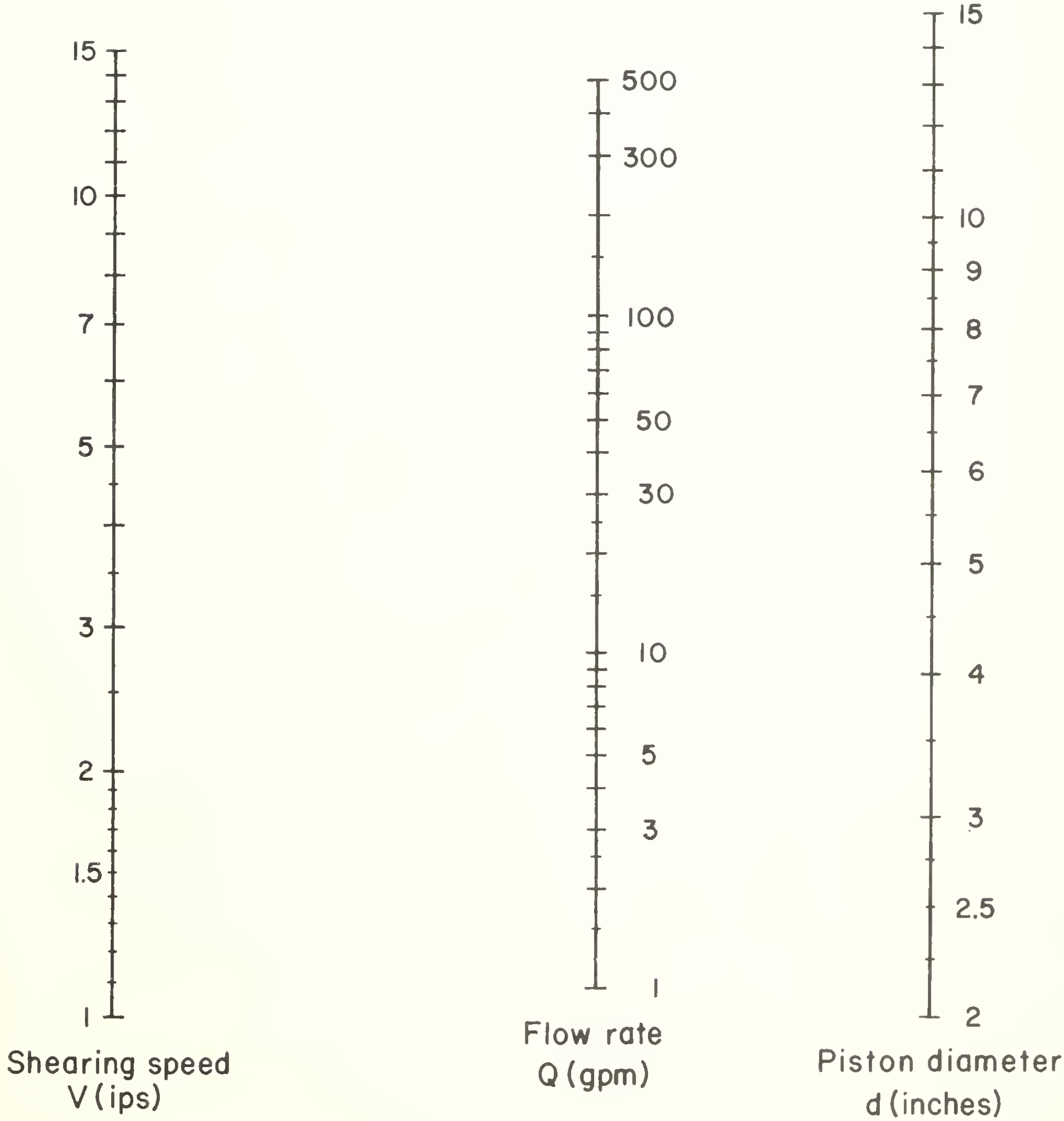
SOLVES: $d = 2\sqrt{\frac{F}{P\pi}}$



NOMOGRAPH 3

FLOW RATE

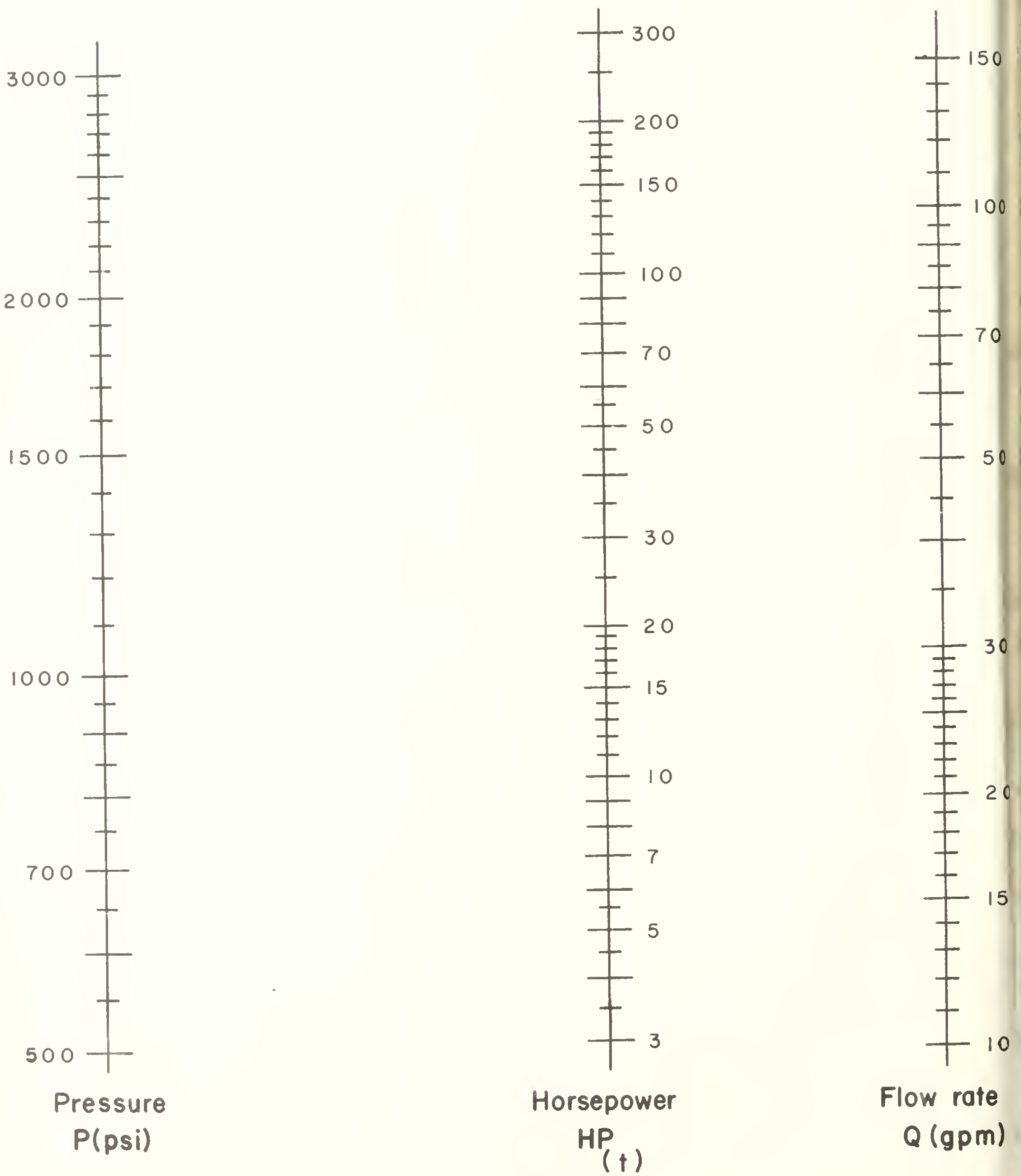
SOLVES: $Q = 0.204\,V d^2$



NOMOGRAPH 4

THEORETICAL PUMP OR MOTOR HORSEPOWER

SOLVES: $HP_{(t)} = \frac{PQ}{1714}$



SHEAR FORCE AND POWER REQUIREMENT WORKSHEET

. Determine advance requirements:

fic gravity of wood to be crosscut sheared (based on ndry weight, green volume) G=________________

blade thickness t=________________ inches

mum log diameter to be sheared D=________________ inches

ulic pressure P=________________ psi

ed shearing velocity V=________________ ips

ated lowest wood temperature to be encountered T=________________ °F.

. Determine total shear force requirements:

Nomograph 1

al shear force F_m=________________ pounds

. Correct shear force for low temperature:

Formula $F_{c/t} = F_m + 20(60 - T)D$

al shear force corrected for temperature $F_{c/t}$ =________________ pounds

. Determine hydraulic cylinder size:

Nomograph 2

ston diameter d=________________ inches

. Determine hydraulic oil flow rate:

Nomograph 3

w rate Q=________________ gpm

. Determine theoretical motor HP requirement:

Nomograph 4

eoretical motor HP HP_t =________________

. Adjust motor HP for overall efficiency of

formula $HP_e = \frac{HP_t}{e}$

justed motor HP HP_e=________________

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A FOREST SERVICE
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EFFECT of TOPOGRAPHY on MICROCLIMATE in SOUTHWESTERN WISCONSIN

RICHARD S. SARTZ

NORTH CENTRAL FOREST EXPERIMENT STATION
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Manuscript approved for publication December 2, 1971

EFFECT OF TOPOGRAPHY ON MICROCLIMATE IN SOUTHWESTERN WISCONSIN

Richard S. Sartz

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That microclimate is important to forest rowth is well known. Because microclimate nfluences soil freezing and snow accumulaion and melt as well as evapotranspiration ate, microclimatic differences on a waterhed may also affect its hydrologic behavior.

Topographic variables that may affect miroclimate are elevation, steepness and direcion of slope, and position on the slope. Although topographic effects on microclimate re more pronounced in mountain areas beause of the greater range in the variables, hese effects can be important wherever the andscape is rough. How southwestern Wisonsin's ridge and valley topography affects microclimate is discussed here. All data are from the Coulee Experimental Forest near La Crosse.

The terrain here is neither mountainous nor hilly, but it is extremely rough. It is best described as a dissected plain. The landscape consists of dolomite-capped ridges of relatively uniform elevation and narrow valleys or "coulees." The coulees lie about 400 feet below the ridgetops and are separated from them by steep wooded slopes (fig. 1). Mean slope of the forest zone is about 40 percent, but individual slopes may range up to vertical scarps.

F-511021

Figure 1. — *Typical Driftless Area landscape as seen from ridgetop.*

PRECIPITATION

From a rainfall study (Sartz 1966) I found that the dissected terrain of the area has little effect on point rainfall. Rain gages on the windward side of a steep slope caught only 3 percent less rain than gages on the leeward side; and the amount of rainfall caught by ridge gages was little more than that caught by valley gages. However, snow accumulation and melt are affected by degree of slope and by aspect.

Steep (greater than 45-percent slope) "goat prairies," which generally slope to the south, never accumulate a snowpack, even in heavy snow years. Sublimation and wind keep these slopes bare most of the time. On less steep slopes where snow does accumulate, south slopes may lose their snowpack 2 to 3 weeks earlier than north slopes. This difference in melting time is beneficial from a flood-runoff standpoint because it tends to even out the flow and reduce the peak. However, the difference does not appear to affect the timing of snowmelt accretions to ground water. Springs on the Coulee Experimental Forest rise and peak at the same time on both north- and south-facing watersheds during snowmelt. However, we are not certain that the ground water tables conform to the surface terrain.

How aspect affects snowpack accumulation on more moderate slopes is shown by meaurements of the late winter snowpack on north and south slopes of 25 percent on the Coulee Experimental Forest (table 1). During a 6-year period, depth and water content of the south slope snowpack were 51 percent and 59 percent, respectively, of the corresponding north slope values. Topographic shading in the ridge and coulee terrain of the area also affects snowmelt, a factor discussed by Lee and Baumgartner (1966). Bottomland on the south side of east-west oriented coulees is shaded by the ridges to the south, so snowmelt in these coulees progresses at a gradually diminishing rate from north to south.

SOIL WATER

Theoretically, the rate of soil water depletion will vary with steepness and direction of slope because of their effect on the radiation balance (Nash 1963). Stoeckeler and Curtis (1960) reported that a forested north slope in southwestern Wisconsin held about twice as much water in the upper 2 feet of soil as a forested south slope. However, soils on an adjacent ridgetop held much more water than the north slope soils; and the amount of depletion in a 90-day summer period on middle and upper slope soils was about the same for both north and south aspects.

Table 1. — *Accumulated snowpack on north and south slopes of 25 percent*

Year	Depth			Water content		
	North	South	S/N	North	South	S/N
	Inches	Inches	Percent	Inches	Inches	Percent
1965	9.1	4.4	48	2.0	1.1	55
1967	17.0	5.8	34	4.3	2.0	47
1969	17.2	12.9	75	4.6	3.5	76
1971	21.7	10.0	46	6.2	3.6	58
Mean	16.2	8.3	51	4.3	2.5	59

Measurements with a neutron meter from 24 soil water tubes on the Coulee Experimental Forest showed the following average amounts of soil water depletion in the top 3 feet of soil over a 51-day summer period: ridgetop, 3.2 inches; north slope, 3.3 inches; south slope, 4.0 inches. The north and south sites are on lower, 25-percent slopes and the soil and old-field vegetation are similar on the three sites. Mean water contents for the three sites at the beginning of the depletion period were: ridgetop, 12.6 inches; north slope, 11.8 inches; south slope, 12.1 inches. From a study on upper slopes, where the soil is generally shallower, depletion by oak-hickory forest in the top 2 feet of soil over a 113-day summer period on the four major aspects was: north, 3.11 inches; south, 3.09 inches; east, 3.38 inches; west, 3.02 inches. The values are means from 12 soil water tubes.

From these data it appears that soil water withdrawal by similar vegetation on similar sites is not strongly affected by direction of slope.

TEMPERATURE AND RADIATION

Surprisingly, temperature did not appear to be strongly affected by aspect, at least on moderately steep slopes. Exposure to the wind may have more effect than direction of slope. Temperatures on north and south slopes of about 25 percent were recorded at two places on the Coulee Experimental Forest — Russlan Coulee and Shelmidine Coulee. In Russlan Coulee, thermographs and maximum-minimum thermometers were housed in small instrument shelters mounted 1 foot above the ground. In Shelmidine Coulee, they were mounted in standard National Weather Service type shelters. Steepness of slope at the gage locations is about the same at both places. In Russlan Coulee, daily maximum and minimum temperatures from the thermograph charts were compared for 20 days in June and July and for 20 days in December and January with the following result, in degrees Fahrenheit:

	June-July		*December-January*	
	North	*South*	*North*	*South*
Maximum	82.0	82.5	22.5	24.3
Minimum	58.6	58.3	5.2	6.2

North-south differences were statistically nonsignificant for June-July but were highly significant for December-January. From 311 daily maximum and minimum temperatures, the mean maximum was 1.2° F. higher and the mean minimum, 0.5° F. higher on the south slope. Both are statistically highly significant.

In Shelmidine Coulee, the north slope had higher maximums but lower minimums than the south slope. From 33 weekly maximum-minimum thermometer readings in standard instrument shelters the means were:

	North	*South*
Maximum	85.2	84.2
Minimum	43.3	44.5

Maximum differences are statistically nonsignificant but minimum differences are highly significant. In one 10-day period in August 1971, the daily maximum temperature on the north slope averaged 3.9° higher, while the daily minimum averaged 2.0° lower than on the south slope. These data are from maximum - minimum thermometers mounted 1 meter above the ground on wooden stakes. The thermometers faced north and were shielded only by the plastic thermometer housing and the 1- by 3-inch wooden stake. Both differences are statistically highly significant. The cooler daytime temperatures on the south slope apparently resulted from its greater exposure to the wind.

Although aspect alone appears to exert a minimal influence on temperature, it does

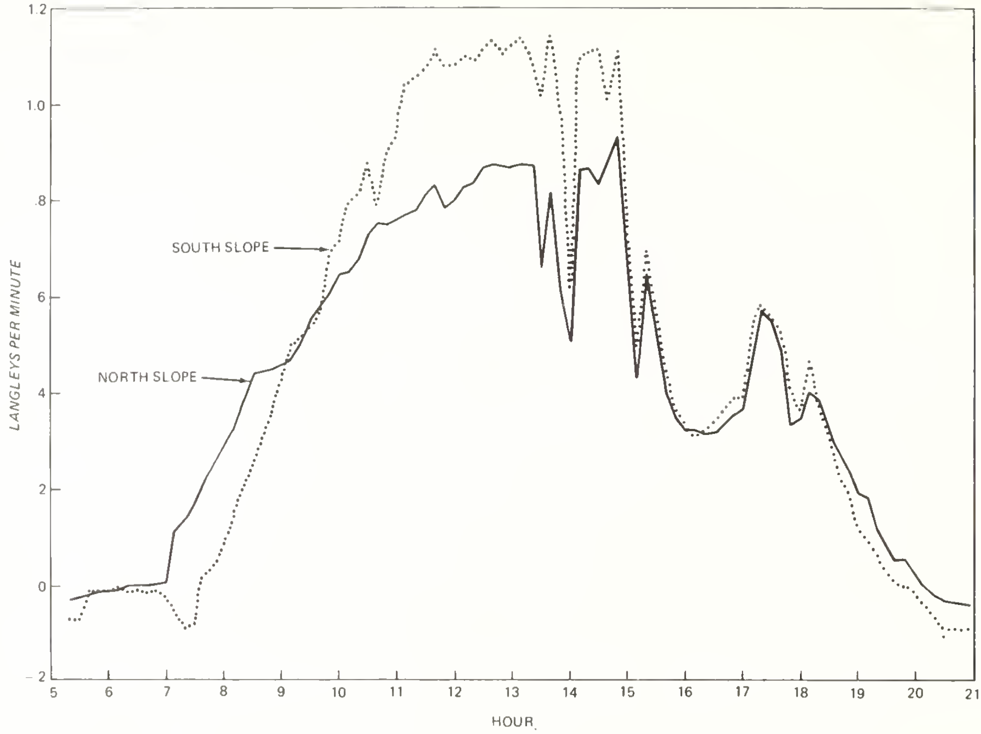

Figure 2. — *Net radiation on north and south slopes, June 25, 1965.*

have a pronounced effect on daytime net radiation (fig. 2). The data plotted in figure 2 are from totalizing net radiometers (Goodell 1962) that were operated on the Shelmidine Coulee slopes where the temperature measurements were taken. The two previously calibrated radiometers were mounted 3 feet above the ground parallel with the slope. The vegetation at both sites was bluegrass and weeds that had been clipped. Radiation, temperatures in a shelter and on the ground surface, and anemometer counts were taken at 10-minute intervals for the period shown. Ground surface temperature was measured with mercury-in-glass thermometers placed unshaded on the clipped grass surface (fig. 3). Ground temperature followed the radiation pattern much more closely than did shelter temperature. Shelter temperature was higher on the north slope most of the day, reflecting the difference in wind. Based on anemometer counts, wind movement on the south slope was about 2½ times that on the north slope.

The effect of ridge and coulee terrain on cold air drainage is shown by the temperature record from thermographs in standard instrument shelters at a ridgetop and a coulee bottom site, both in the open. The two sites are 2,100 feet apart and differ in elevation by 360 feet. Minimum differences for November through March are statistically nonsignificant, but all other minimums and all maximums are highly significant (table 2). The lower minimum temperatures at the valley site result from cold air drainage down the slope. The effect of air drainage is greatest during the growing season, thus it could influence forest site quality as well as survival of planted trees following late spring frosts (Stoeckeler 1963).

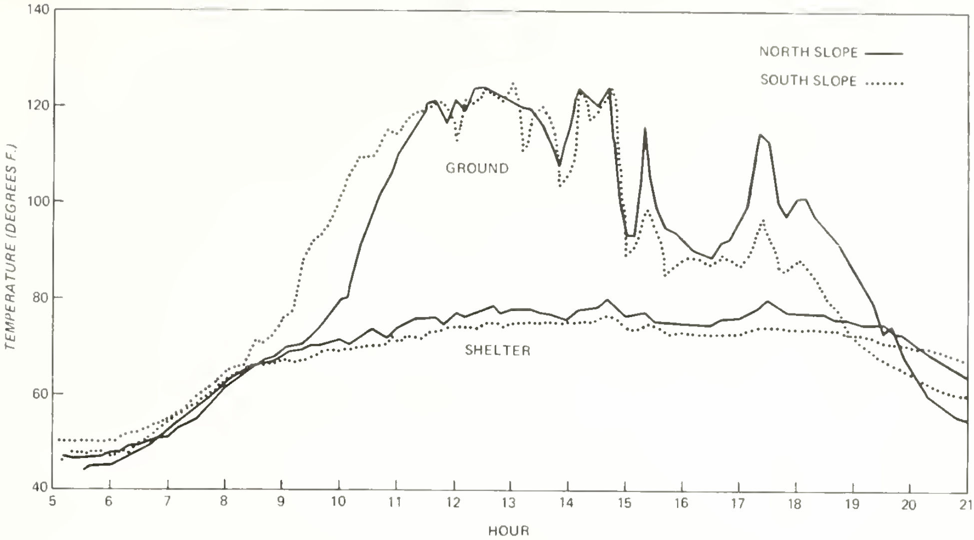

Figure 3. — *Temperature in a standard weather instrument shelter and at the ground surface on north and south slopes, June 25, 1965.*

Table 2. — *Difference in mean daily maximum and minimum temperatures at a ridgetop and a valley site*

Month	Number of observations	Temperature difference[1/]	
		Maximum	Minimum
		Degrees F.	Degrees F.
January	31	3.0	-0.1
February	25	4.6	.8
March	29	4.3	-1.0
April	52	3.7	-2.6
May	93	4.2	-3.6
June	89	3.3	-3.5
July	92	3.4	-5.0
August	83	3.6	-4.1
September	60	4.5	-3.4
October	62	3.6	-3.4
November	30	6.4	.1
December	31	3.8	-0.1
Total or mean	677	4.0	-2.2

1/ Valley reading assumed to be higher.

I also compared the temperature records from the open ridgetop site with those from another ridgetop site that was located in a small (0.1-acre) clearing in the native hardwood forest. The two sites are 2,100 feet apart and the forest site is about 30 feet lower in elevation. Maximum mean daily temperatures were 3.3° F. higher and minimum mean daily temperatures were 2.0° F. higher in the forest clearing than in the open. The values are from 456 daily observations from all months of the year. The means for individual months did not show any seasonal trend.

CONCLUSIONS

Driftless Area topography affects point rainfall only slightly, but it affects snowpack buildup substantially because of the effect of slope climate on sublimation. Although south slopes appear to lose more water, soil water depletion by similar vegetation on similar soils does not vary greatly by aspect. South slopes receive more insolation, but temperature differences between north and south slopes are slight, and may be more affected by differences in wind than in slope direction. Based on temperature measurements in standard instrument shelters, coulees are warmer than ridgetops in the day but cooler than ridgetops at night because of differences in wind and because of downslope air drainage.

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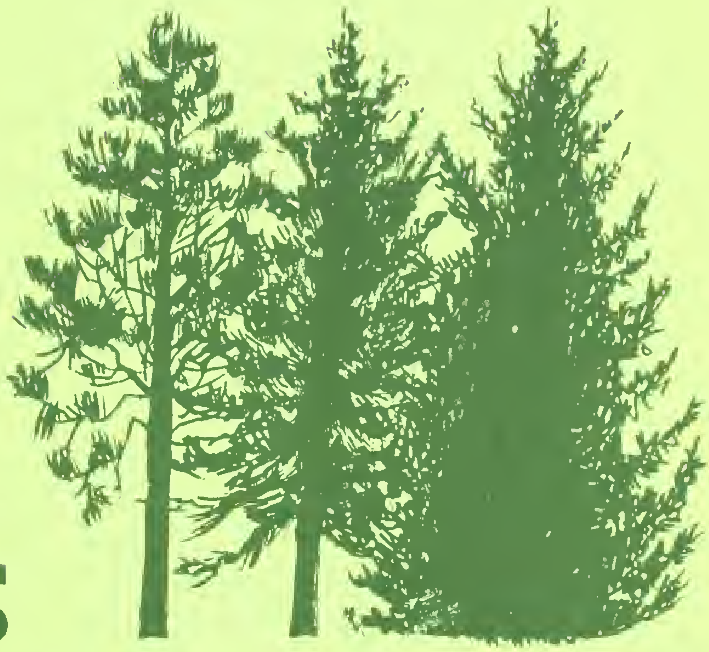

H.M. Steinhilb
John R. Erickson

Weights and Centers of Gravity for Red Pine White Spruce Balsam Fir

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE · U.S. DEPARTMENT OF AGRICULTURE

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Manuscript approved for publication February 14. 1972

WEIGHTS AND CENTERS OF GRAVITY FOR RED PINE, WHITE SPRUCE, AND BALSAM FIR

H. M. Steinhilb and John R. Erickson

The information presented here complements that of a previous publication on aspen.[1] These two publications provide equipment manufacturers with a good range of engineering data on which to base the design of machines to harvest and handle northern pulpwood species. Use of these data will help avoid costly over or under-design of the tree harvesting equipment.

Data were obtained from 71 balsam fir and 58 white spruce trees from a site in Houghton County, Michigan, and 58 red pine trees from a site in Baraga County, Michigan. The spruce and balsam fir came from a mixed stand; the red pine came from a pure stand (table 1).

The "tree" reported here is the entire tree above the stump, while the "bole" is the delimbed stem topped to a 3-inch diameter outside the bark. Weight is reported for both the full tree and the bole. The center of gravity location is the distance in feet from the butt to the point of balance of the bole or tree.

Table 1.—Range of variables for balsam fir, red pine and white spruce

Species	D.b.h.	Tree			Bole		
		Height	Green weight	Center of gravity	Length	Green weight	Center of gravity
	Inches	Feet	Pounds	Feet from butt	Feet	Pounds	Feet from butt
Balsam fir	5.0-13.2	30.4-62.0	225-2,255	11.8-23.5	20.8-54.5	135-1,860	8.6-19.3
Red pine	5.6-14.0	50.0-73.8	304-2,562	19.2-29.0	36.2-63.0	255-2,122	15.4-24.6
White spruce	6.2-16.2	31.2-68.0	271-3,292	13.1-28.0	22.5-62.0	135-2,526	8.8-20.3

[1] *Steinhilb, H. M. and John R. Erickson. Weights and centers of gravity for quaking aspen trees and boles. USDA For. Serv. Res. Note NC-91, 4 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1970.*

FIELD PROCEDURES

Sample trees were selected before cutting to include a maximum range of diameters and heights within the stand. Selected trees. were bored at breast height to determine moisture content. D.b.h. of each tree was measured and the tree felled directionally to minimize damage. Diameters outside bark at the stump, at 2 and 4 feet from the butt, and a 8-foot intervals thereafter were recorded to a top diameter of 3 inches. The total overall length of the tree and bole above the stump was measured to the nearest 0.1 foot.

Within 2 to 4 hours after felling the tree was lifted with a knuckle boom loader and weighed. The tree was then limbed and topped to a 3-inch diameter outside the bark and the bole lifted and weighed. The lifting device was a free swing sling that contained a weight recording transducer. As the trees and boles were weighed the centers of gravity were located (directly below the apex of the sling).

RESULTS AND DISCUSSION

Regression analysis was used to obtain prediction equations for the weights in pounds and the center-of-gravity locations in feet from the butt of both trees and boles. The resulting prediction equations and standard error of estimate are listed below.

Balsam Fir (71 Samples)

Full tree weight $= 10^{0.2935}\ (\text{d.b.h.})^{2}\ (\text{tree ht.})^{0.4}$

Value equiv. to S.E. est. is $10^{\pm 0.0826} = 1.209$ or $\frac{1}{1.209}$ *

Bole weight $= 10.^{0.1749}\ (\text{d.b.h.})^{2}\ (\text{bole length})^{0.4}$

Value equiv. to S.E. est. is $10^{\pm 0.0857} = 1.218$ or $\frac{1}{1.218}$ **

Full tree center of gravity = 4.046 + 0.297(tree ht.)

S.E. est. = 0.0208(tree ht.)

Bole center of gravity = 4.147 + 0.259(bole length)

S.E. est. = 0.0251(bole length)

---

* *To get points corresponding to one S.E. est. above and below the calculated value, multiply the calculated value by* 1.209 *and* 1/1.209 *respectively.*

***Use same procedure to obtain S.E. est. calculations as was used in full tree wt.*

Red Pine (58 Samples)

$$\text{Full tree weight} = 0.115(\text{d.b.h.})^2(\text{tree ht.}) + 1.100(\text{d.b.h.})(\text{tree ht.}) - 4.276(\text{tree ht.})$$

$$\text{S.E. est } 0.0105(\text{d.b.h.})^2(\text{tree ht.})$$

$$\text{Bole weight} = -57.3 + 0.1207(\text{d.b.h.})^2(\text{bole length}) + 0.699(\text{d.b.h.})(\text{bole length})$$

$$\text{S.E. est} = 0.00838(\text{d.b.h.})^2(\text{bole length})$$

$$\text{Full tree center of gravity} = 1.97 + 0.365(\text{tree ht.})$$

$$\text{S.E. est.} = 0.0184(\text{tree ht.})$$

$$\text{Bole center of gravity} = 5.02 + 0.299(\text{bole length})$$

$$\text{S.E. est.} = 0.0127(\text{bole length})$$

White Spruce (58 Samples)

$$\text{Full tree weight} = -81.94 + 10.37(\text{d.b.h.})^2 + 0.0117(\text{d.b.h.})^2(\text{tree ht.})$$

$$\text{S.E. est.} = 0.03996(\text{d.b.h.})^2(\text{tree ht.})$$

$$\text{Bole weight} = 0.0534(\text{d.b.h.})^2(\text{bole length}) + 1.16(\text{d.b.h.})(\text{bole length})$$

$$\text{S.E. est.} = 0.343(\text{d.b.h.})(\text{bole length})$$

$$\text{Full tree center of gravity} = 2.93 + 0.3365(\text{tree ht.})$$

$$\text{S.E. est.} = 0.02503(\text{tree ht.})$$

$$\text{Bole center of gravity} = 2.17 + 0.3159(\text{bole length})$$

$$\text{S.E. est.} = 0.0204(\text{bole length})$$

Tree and bole weights are shown in tables 2-4, and centers of gravity of trees and boles are shown in figure 1. A 95 percent upper tolerance limit is given for each d.b.h. and height class to enable harvesting equipment to be designed for near-maximum loads rather than mean loads and thus avoid the underdesign of harvesting machines.

Table 2.—Balsam fir tree and bole weights
(In pounds)

MEAN[1]

D.b.h. (inches)	Bole length or tree height (feet)								
	20	30		40		50		60	
	Bole	Bole	Tree	Bole	Tree	Bole	Tree	Bole	Tree
5	124	146	192		215		235		
6	178	210	276	236	309	258	338	277	364
7	243	286	375	321	421	350	460	377	495
8	317	373	490	419	550	458	602	492	647
9	402	472	621	530	696	579	761	623	819
10	496	583	766	654	860	715	940	769	1,011
11		706	927	792	1,040	866	1,137	931	1,223
12		840	1,103	942	1,238	1,030	1,353	1,108	1,456
13		985	1,295	1,106	1,453	1,209	1,588	1,300	1,700
UPPER TOLERANCE LIMIT (95 PERCENT LEVEL)[2]									
5	192	229	296		327		367		
6	274	319	425	370	461	420	513	467	572
7	375	425	580	489	620	554	683	616	760
8	496	550	764	624	807	707	878	786	976
9	639	701	978	779	1,027	877	1,102	975	1,219
10	803	876	1,220	959	1,280	1,070	1,360	1,186	1,493
11		1,077	1,495	1,167	1,565	1,287	1,655	1,420	1,801
12		1,228	1,795	1,405	1,885	1,532	1,987	1,679	2,145
13		1,441	2,235	1,670	2,250	1,806	2,355	1,966	2,527

1/ Mean bole weight was determined from equation:
Mean bole weight = $(10)^{.1749}(\text{d.b.h.})^{2}(\text{bole length})^{0.4}$
Mean tree weight was determined from the equation:
Mean tree weight = $(10)^{.2935}(\text{d.b.h.})^{2}(\text{tree ht.})^{0.4}$

2/ 95 percent or more of the trees or boles in a given class should be below this weight.

Table 3.—Red pine tree and bole weights (In pounds)

D.b.h. (inches)	Bole length or tree height (feet)									
	30	40		50		60		70		80
	Bole	Bole	Tree	Bole	Tree	Bole	Tree	Bole	Tree	Tree
	MEAN[1/]									
5	138	203	164		206					
6	199	284	259	370	323		388		452	
7	267	375	363	483	453	591	544	699	635	
8	342	475	476	609	595	741	714	875	833	
9	425	585	598	746	748	907	897	1,068	1,047	
10	515	705	730	896	912	1,087	1,094	1,277	1,277	
11			870	1,058	1,088	1,281	1,305	1,504	1,523	
12					1,275	1,489	1,530	1,747	1,785	
13					1,474	1,712	1,769	2,007	2,064	
14						1,950	2,021	2,284	2,358	
	UPPER TOLERANCE LEVEL (95 PERCENT LEVEL)[2/]									
5	157	224	193		242					387
6	223	310	290	402	363		435		508	581
7	298	408	406	525	507	645	609	766	710	811
8	380	518	530	661	663	809	796	957	928	1,061
9	471	642	665	812	832	988	998	1,165	1,164	1,330
10	572	774	812	979	1,015	1,186	1,218	1,394	1,421	1,625
11			870	1,160	1,215	1,402	1,458	1,645	1,701	1,944
12					1,431	1,637	1,718	1,918	2,004	2,290
13					1,665	1,896	1,998	2,214	2,331	2,664
14						2,164	2,299	2,532	2,682	3,066
15									3,057	3,493

1/ Mean bole weight was determined from the equation:

$$\text{Mean bole weight} = -57.3 + 0.1207(\text{d.b.h.})^2(\text{bole length}) + 0.699(\text{d.b.h.})(\text{bole length})$$

Mean tree weight was determined from the equation:

$$\text{Mean tree weight} = 0.115(\text{d.b.h.})^2(\text{tree ht.}) + 1.100(\text{d.b.h.})(\text{tree ht.}) - 4.276(\text{tree ht.})$$

2/ 95 percent or more of trees or boles in a given class should be below this weight.

Table 4.—White spruce tree and bole weights (In pounds)

D.b.h. (inches)	20	30		40		50		60	70
	Bole	Bole	Tree	Bole	Tree	Bole	Tree	Tree	Tree
				MEAN[1/]					
5	143	213	186	285	189				
6	177	266	304	355	308	444	312	316	
7	215	322	443	429	449	536	455	461	
8	254	381	604	507	612	634	619	627	634
9	295	443	786	590	796	738	805	815	824
10	339	508	990	677	1,001	846	1,013	1,025	1,037
11	384	576	1,215	768	1,229	960	1,243	1,258	1,272
12		648	1,461	864	1,478	1,080	1,495	1,512	1,529
13				963	1,749	1,204	1,769	1,789	1,809
14						1,334	2,065	2,088	2,111
15								2,409	2,435
16									2,782
				UPPER TOLERANCE LIMIT WEIGHT (95 PERCENT LEVEL)[2/]					
5	216	324	275	431	283				
6	263	395	409	526	442	658	480	522	
7	312	468	577	624	612	781	661	717	
8	363	545	783	726	817	908	873	946	1,023
9	416	624	1,022	833	1,061	1,040	1,121	1,208	1,304
10	472	708	1,292	944	1,336	1,180	1,402	1,504	1,621
11	531	796	1,592	1,062	1,644	1,327	1,718	1,834	1,972
12		889	1,922	1,186	1,982	1,482	2,067	2,196	2,357
13				1,317	2,349	1,647	2,446	2,592	2,777
14						1,820	2,857	3,021	3,233
15								3,483	3,722
16									4,245

1/ Mean bole weight was determined from the equation:
Mean bole weight = $0.0534(\text{d.b.h.})^2(\text{bole length}) + 1.16(\text{d.b.h.})(\text{bole length})$.
Mean tree weight was determined from the equation:
Mean tree weight = $-81.94 + 10.37(\text{d.b.h.})^2 + 0.0117(\text{d.b.h.})^2(\text{tree ht.})$

2/ 95 percent or more of trees or boles in a given class should be below this weight.

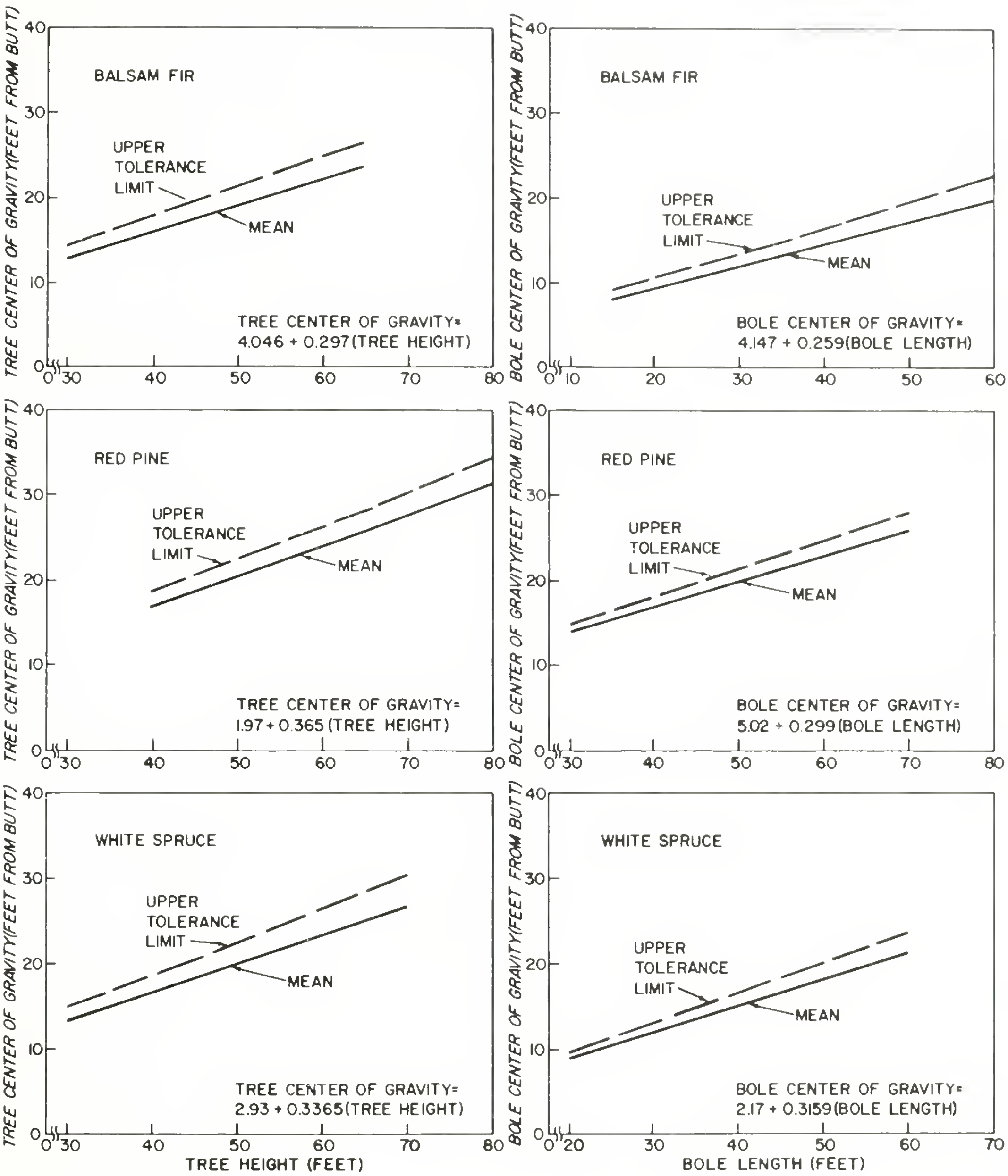

Figure 1.–Centers of gravity for balsam fir, red pine, and white spruce trees and boles.

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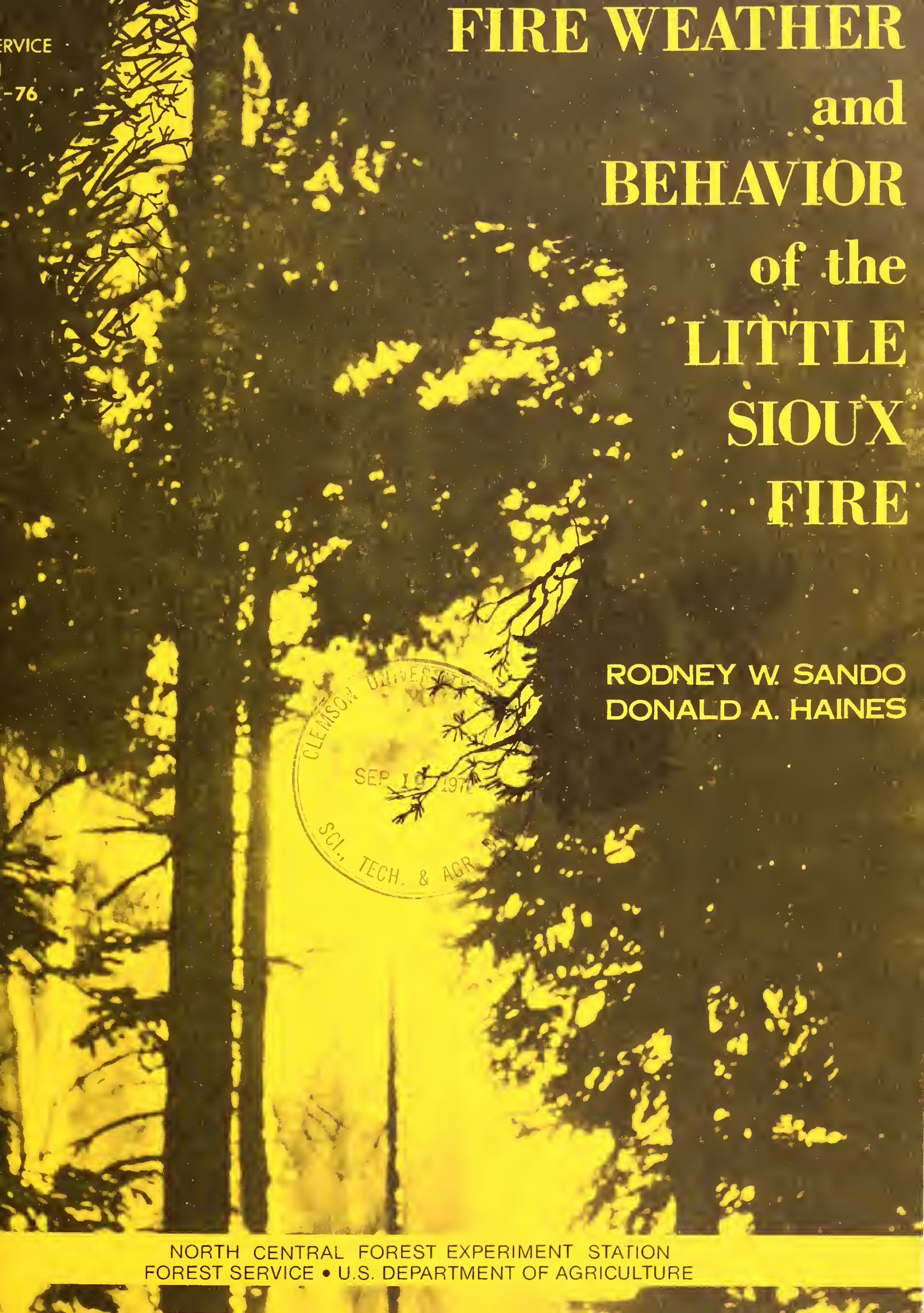

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Manuscript approved for publication February 18, 1972

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FIRE WEATHER AND BEHAVIOR OF THE LITTLE SIOUX FIRE

Rodney W. Sando and Donald A. Haines

Northern Minnesota experienced a period of very severe fire weather during the spring of 1971. Little precipitation fell after mid-April snowmelt and dry, windy weather forced fire danger upward. In mid-May the Little Sioux fire burned 14,628 acres of forest on the Superior National Forest during a 3-day period. This paper documents the fuel and weather conditions that caused this fire to behave as it did.

SETTING THE STAGE

Climatology and Fire Danger Ratings

The Little Sioux, typical of most large fires in this region, followed a period of abnormally dry weather (Haines and Sando 1969). April precipitation was about an inch below normal and only 0.28 inch of rain fell in May at nearby Ely, Minnesota, during the 2 weeks preceding the fire. Normal rainfall during the first half of May is about 1.30 inches. The fire started on May 14. The last significant rainfall occurred May 4 when 0.12 inch fell (table 1). The Buildup Index (BUI), according to the National Fire Danger Rating System (Nelson 1964), was 45 on the day of the fire, which is much above the average of 25 for this date (Sando 1969). The Danger Rating System's Fire Load Index (FLI) was 93, well into the extreme range. From 1936 to 1970 only 5 days had a FLI higher than this at Ely. The fire danger on May 14, therefore, was unusually critical, even though this is normally the most dangerous period of the year (fig. 1).

Table 1.—*Weather and fire danger rating observations at Ely, Minnesota, 1971 (1300 c.d.t.)*

Date (May)	Temperature	Relative humidity	Precipitation	Wind direction	Wind-speed	BUI	FLI
	°F.	Percent	Inches		M.p.h.		
1	41	84	0.07	NE	10	6	1
2	52	25	.07	N	10	9	11
3	60	23		N	4	12	7
4	58	57	.12	NE	4	11	3
5	54	49		NE	8	14	7
6	64	20		SE	4	16	8
7	69	22		NW	9	19	17
8	56	26	T	SE	3	22	6
9	71	15		S	6	27	20
10	75	19		N	6	32	20
11	44	44	.02	NE	13	34	29
12	56	17		NW	10	37	32
13	60	23		NE	11	40	49
14	76	15		SW	16	45	93
15	59	53	.01	SW	11	47	24
16	68	24		NW	8	50	41
17	60	89	.10	SW	10	50	5

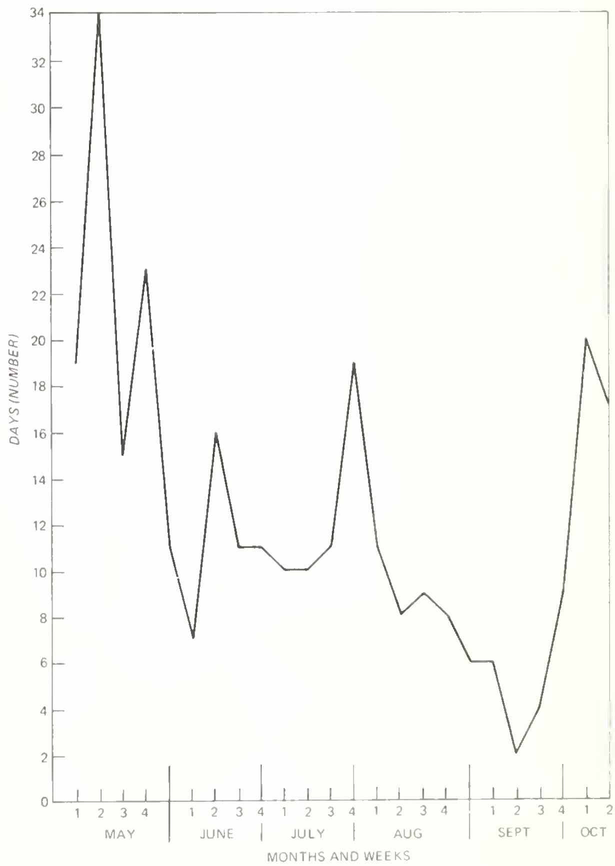


Figure 1.—*Frequency of occurrence of class four, fire-danger (very high) days at Ely, Minnesota, during 1936-70, grouped by weeks.*

Topography

The area burned by the Little Sioux fire is flat to rolling, containing numerous swamps between the low ridges. These ridges are rocky ledges without a uniform pattern. The topography therefore had little influence on the behavior of the fire; however, the boggy areas between the ridges were wet, making vehicular travel difficult — sometimes impossible.

Fuels

About 65 percent of the area burned had been recently logged. Some of the fuel on these logged areas had been partially reduced by prescribed burning. The fire spread rapidly in the open, cutover areas largely because there was little obstruction to winds. Almost all the logged areas are located in the southern portion of the fire region and account for most of the fuel type near the point of ignition. Unburned slash and burned slash areas are rated H-M[1] and M-H, respectively, for springtime conditions (USDA Forest Service 1938).

A small part of the burn area had been planted to red pine and white spruce following the logging operations. All the plantations were no older than 10 years and also rated H-M.

The remainder of the fire area contained several different vegetative and fuel types. The more important types and their ratings are (USDA Forest Service 1938):

Mature aspen stands	L-M
Aspen-birch with coniferous understory	L-M
Mature jack pine stands	L-M
Lowland black spruce stands	L-M
Pure balsam fir stands	L-M
Tall grass marsh	E-M
Balsam fir stands recently killed by spruce budworm	M-H

Throughout the burned area there was dead balsam fir resulting from the spruce budworm outbreak of the early 1960's. The dead material made line construction difficult and provided a convenient bed for the ignition and spread of spot fires (fig. 2). The dead fir may not have greatly influenced the advance

Figure 2. — *Fire behavior in balsam fir that was affected by earlier spruce budworm attack.*

of the main flame front, but it certainly did interfere with suppression efforts.

Much of the fuel in the area was tall grass marsh. This fuel type is conducive to rapid spread and was partly responsible for the large size of the initial fire run, particularly in the southern sectors. Lowland black spruce was the only fuel type that did not burn well, probably because of the wetness of the low areas, the result of spring snowmelt.

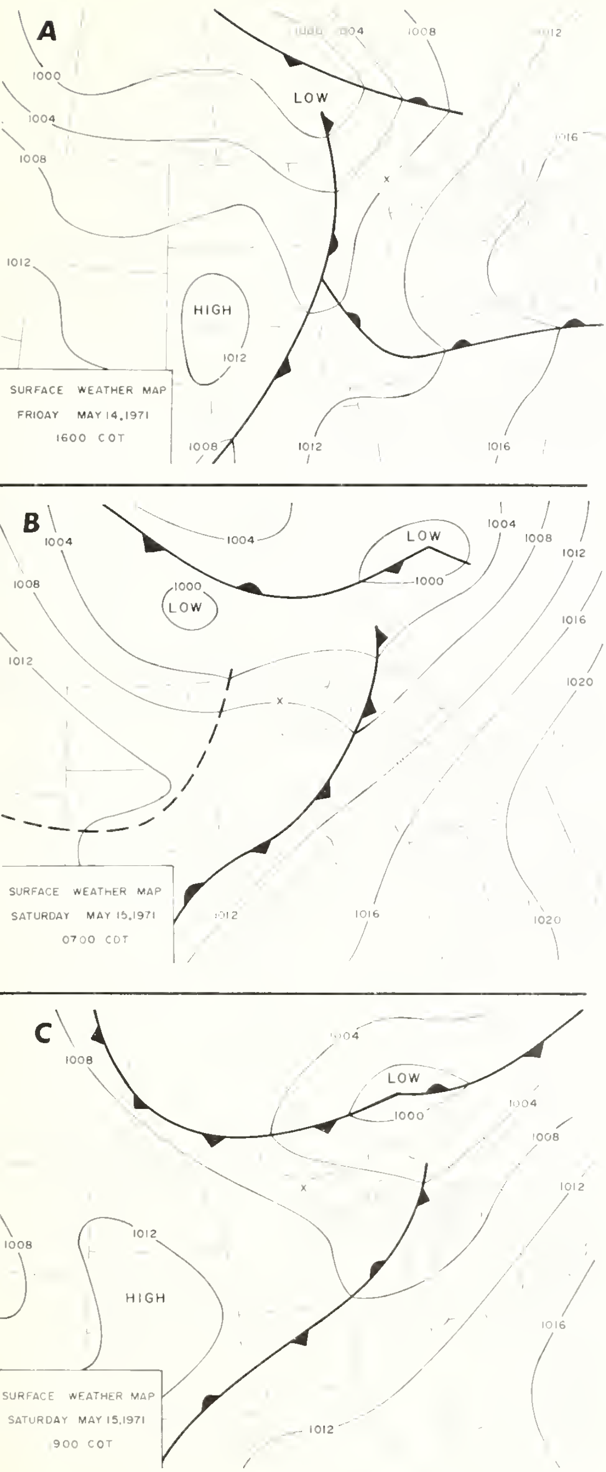
Synoptic Weather

Three periods of weather greatly infuenced the behavior of this fire. All three periods involved frontal movement coincident with major fire runs.

A fast-moving frontal system passed over the Little Sioux area early on the night of May 14 (fig. 3A). Ahead of and with it associated weather spurred the fire's early afternoon start as well as its greatest spread. Dry air prevailed to the east of this system and had covered the region for 2 days previous to the fire. Early afternoon relative humidity readings were in the teens and low 20's at Ely on May 12 and 13, with overnight rises to 55 percent. This low diurnal humidity range, coupled with brisk afternoon winds, intensified fuel drying.

Late afternoon upper-air soundings at nearby International Falls and St. Cloud, Minnesota, on the 14th showed a highly unstable atmospheric layer in the first 350 feet above surface. A conditionally unstable temperature lapse rate prevailed above this to 10,000 feet.

[1] *Letter designations indicate rate of spread and resistance to control. The ratings are L—low, M—moderate, H—high, and E—extreme. As an example, L-M represents a low rate of spread and a moderate resistance to control. Spread rates in chains per hour would average about 10 for a letter designation of L, 20 at M, 40 at H, and 80 at E.*



igure 3. — *Surface weather features occurring (A) during the period of initial attack and the first fire run, (B) before the second major fire run, and (C) during the third major fire run. An "X" designates the fire location.*

Early evening winds were strong southwesterly ahead of the fast-moving frontal system, although a wind shift to the southeast in the fire region occurred 45 minutes before the 2045 c.d.t. frontal passage. It is not clear whether this southeast shift was fire induced or the result of an anomoly in the large-scale, isobaric pressure pattern. Obviously, the fire-fighter's rule-of-thumb that wind shifts clockwise within a frontal system is not infallible. Nature, unfortunately, does not always follow the classical model.

The morning weather map on the 15th (fig. 3B) shows a surface pressure trough well into western Minnesota, following about 300 miles behind the main frontal system. This secondary impulse moved rapidly eastward under upper-level, zonal flow and, associated with high vorticity values, produced general cloudiness and a few scattered showers in northern Minnesota. This trough brought increased windspeeds, causing the second major fire run during the morning of the 15th.

A stationary front stayed well north of the Canadian border during the eastward movement of the described system. However, as the secondary impulse later consolidated with the main system and slowed in eastern Wisconsin, the Canadian front sagged slowly southward (fig. 3C). Sufficient cool air moved in behind it to change its designation to a cold front. This Canadian front moved southward to the U.S. border, causing brisk west to north-northwest winds ahead, with a sharp shift to the northeast behind. These prefrontal winds caused the third major run. This cold front did not move southward over the fire, but its close proximity during late afternoon and early evening on Saturday presented meteorologists with a difficult weather forecast decision. Weather conditions and accompanying fire behavior patterns could have been quite diverse, with only small changes in the movement of the front.

CHRONOLOGY

Friday, May 14

A routine aircraft patrol detected the Little Sioux fire at 1330, approximately 50 miles southeast of International Falls, Minnesota, and 2 miles from an all-weather road. It was a holdover from a prescribed burn of April 26. The weather conditions at the time of detection were: temperature 76° F., relative humidity 15 percent, and winds southwest at 16 m.p.h.

with gusts to 20 m.p.h. Because the fire started in an open area where slash was recently burned it did not spread rapidly until it moved beyond this fuel type.

Escaping initial attack, the fire reached unburned fuel about 1615 and began to spread rapidly with the strong southwesterly winds. Hourly observations taken at International Falls showed the wind increased from 15 m.p.h. at 1300 to 23 m.p.h. at 1600. Rate of spread increased dramatically when the fire reached the previously unburned area. The main fire front reached the Echo Trail road (fig. 4), about 2 miles from the point of origin, at approximately 1745. Crowning became widespread, and a large spot fire was observed approximately half a mile north of the road at that time. Long-range spotting was generally due to the high winds, low fine fuel moisture, and the prevalence of slash and spruce budworm-killed balsam fir that provided fuel for easy ignition and

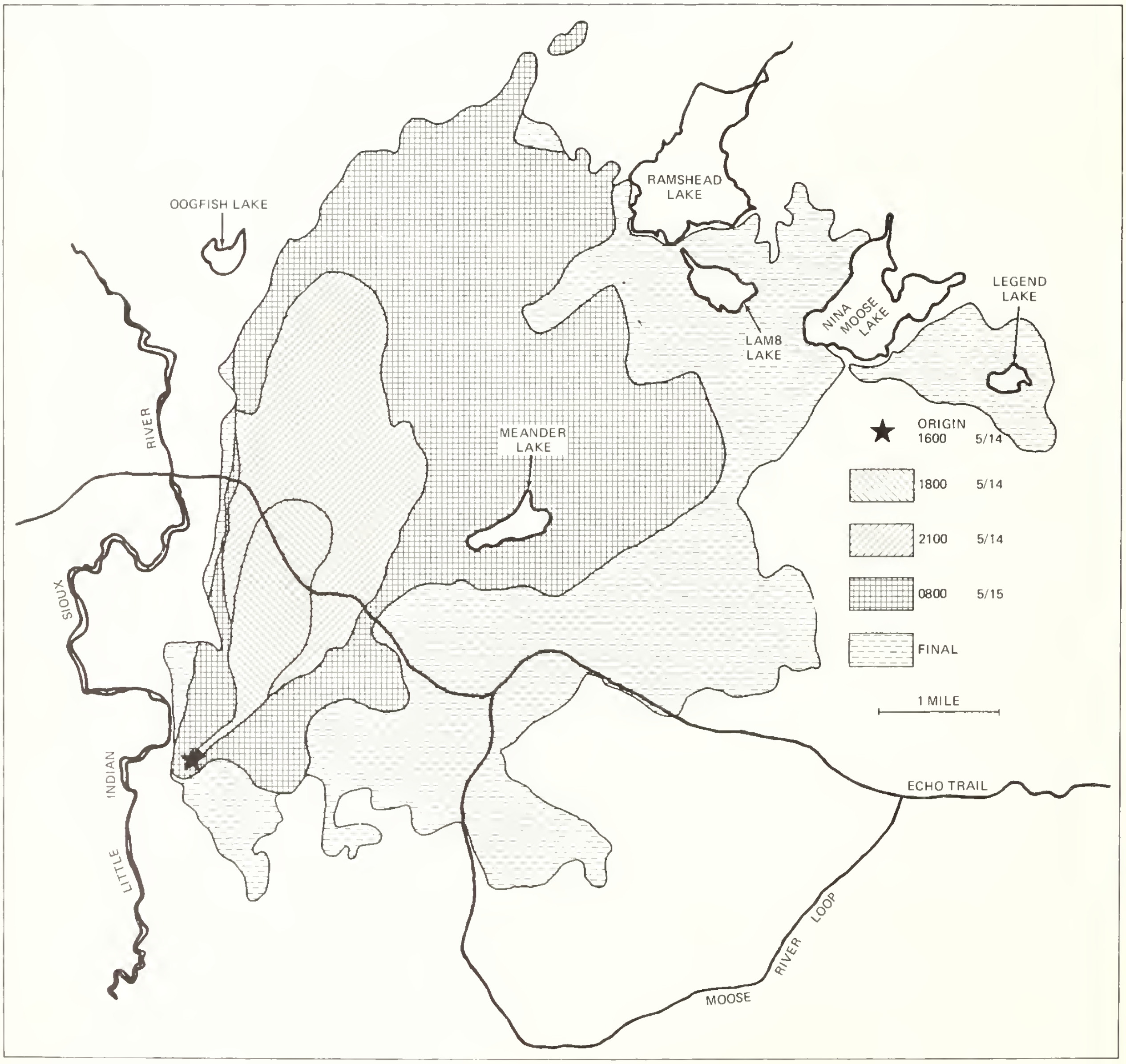


Figure 4. — *Estimated perimeters and gross areas burned at selected times during fire.*

rapid spread. The main flame front moved forward at about 1.2 m.p.h., and the extensive spot fires contributed greatly to the total burning area (fig. 5). Barriers such as roads, trails, and spruce swamps were easily crossed and hence the fire spread was essentially unimpeded.

Figure 5. — *Spotting well in advance of the main flame front.*

The fire moved in a north-northeast direction, and at approximately 1800 aerial observers reported that the burning area had the typical cigar shape of a fast-moving fire in flat topography (fig. 4). The burning area was about 3 miles long and ½ mile wide. The fire was greatly influenced by the presence of the cold front to the west: associated south-southwest winds averaging 20 m.p.h. and gusting to 30 m.p.h. caused the rapid spread during the first 6 hours. About 2000 the wind shifted to the southeast and the fire began to burn in a northwesterly direction along the west flank. This wind direction persisted for approximately 45 minutes before returning to the southwest. A gradual wind shift began toward the northwest as the front passed. The fire then burned toward the east and moved about 2 miles before stopping about 0100 on May 15 (fig. 4). A short, light drizzle at 0200 stopped fire spread for the remainder of the night.

This first major run was the most severe behavior observed on the fire. Long-distance spotting was common up to three-fourths of a mile ahead of the flame front that moved 7 miles in about 6 hours. The fire reached perhaps 60 percent of its final size during this first run.

Saturday, May 15

The second significant run occurred on Saturday morning. With the approach of the secondary pressure trough (fig. 3B), winds began to increase about 0900. At 0930 the temperature was 65°, relative humidity 37 percent, and the winds west-southwest at 10 to 15 m.p.h. with gusts. Responding to these stronger winds, the fire began to spread toward the east. The secondary pressure trough passed over the fire area about 1100 and 0.05 inch of rain fell during the next hour. This light shower wet the fine fuels and stopped the fire spread; consequently, only 5 percent of the total fire area was burned at this time.

A cool, dry, Pacific airmass moved in behind the secondary trough. At 1400 at the fire site temperature was 70°, relative humidity 22 percent, and winds from the north-northwest at 15 to 20 m.p.h., gusting to 25 m.p.h. The morning's light rain had stopped significant forward spread of the fire, but in the afternoon low relative humidity and strong winds caused the fuels to dry quickly, and by 1700 the fire began a third major run. Consequently, at this time the southeastern sector of the fire expanded greatly, although spread was not as rapid as it had been the previous day. The flame front moved forward at about 0.6 m.p.h. compared with about 1.2 m.p.h. on Friday evening.

This third run was caused by strong north-northwest winds generated by the southern movement of the Canadian cold front (fig. 3C). This run continued until about 2100 when the wind velocity decreased and the fine fuel moisture increased, due to lower temperature and higher relative humidity. The fire burned about 25 percent of its final size during this 4-hour period.

Sunday, May 16

Fire behavior on this day was relatively mild compared with that of the previous 2 days. At 1500 temperature was 73°, relative humidity 18 percent, and wind northwest at 5 m.p.h. Fortunately, the winds remained very light throughout the day. The fire did not make a significant run, although isolated areas of unburned fuel within the perimeter burned. About 10 percent of the final fire acreage burned on this day, the last period of significant fire spread.

At 0630 on the morning of May 17, a squall line preceding a front moving in from the west passed over the fire area and by 0800 produced one-fourth of an inch of precipitation. This shower and subsequent precipitation essentially stopped the fire.

SUMMARY

The extreme fire behavior exhibited by the Little Sioux fire was the product of a number of factors. Antecedent, abnormally dry weather caused mild drought across a large portion of northern Minnesota during a time of year when vegetation is still in the cured stage. Friday, May 14, was one of the most severe fire-weather days experienced in the history of the Superior National Forest. The spread of the fire was enhanced by extensive cutover areas and grass marshes conducive to very high or extreme rates of spread. Spot fires were a significant problem; their ignition and spread were greatly assisted by the dead fuels remaining from the spruce budworm outbreak of the early 1960's. Intense crown fires occurred in areas where the forest stands were uncut, chiefly during the first run of the fire. Among the many complicating weather factors that existed during this fire were the wind shifts and high velocities associated with rapid frontal movements through the area.

The light rain shower that occurred the morning of May 15 prevented the fire from burning a much greater acreage. The fire could have been three or four times as large if precipitation had not wet the fine fuels at that time.

Fire control operations were hampered by the inaccessibility of much of the fire perimeter and the extensive spot fires that occurred throughout the area. Springtime conditions made vehicular travel impossible over many of the logging roads within the burn area. It was only after all-terrain vehicles were obtained and more favorable weather conditions slowed the spread of the fire that control operations became effective.

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CANOEIST SUGGESTIONS for STREAM MANAGEMENT In the MANISTEE NATIONAL FOREST of MICHIGAN

HAEL J. SOLOMON
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Manuscript approved for publication March 14, 1972.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

CONTENTS

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CANOEIST SUGGESTIONS FOR STREAM MANAGEMENT IN THE MANISTEE NATIONAL FOREST OF MICHIGAN

Michael J. Solomon and Edward A. Hansen

SUMMARY

Canoeing in northern Lower Michigan has in-
reased greatly during the last decade, resulting in ttering, crowding, and degradation of rivers and verbanks. A survey was undertaken to determine anoeists' opinions concerning their experiences on e Pine River. These opinions permit the listing of anagement priorities from the canoeist's standpoint.

An important part of this survey was to determine e canoeists' attitudes toward eroding streambanks. he Pine River is only one of many streams with evere streambank erosion. In the past, streambanks ave been stabilized in Michigan primarily to improve sh habitat. Now, however, bank stabilization for sh habitat improvement is being contemplated for ome streams, such as the lower portion of the Pine iver, where canoeing is the major use. In such cases, e canoeists' attitudes toward eroding streambanks hould play a large role in deciding whether or not to abilize the banks.

About 50,000 persons canoed the Pine River during 971. Most canoeists enjoyed their trip, particularly e rapids and the wild, natural appearance of the ream and its shoreline. The primary objections con- erned littering and crowding. Comments that involve ream management can be summarized as "leave the ream natural with little or no development" and clean up the litter." Canoeists were unconcerned bout eroding streambanks and about a dam they had portage around.

THE STUDY AREA

The Pine River flows through the Manistee National Forest in the northwest part of the Lower Peninsula of Michigan. It is within a few hours drive of all the large cities in southern Michigan and is less than a day's drive from metropolitan areas such as Chicago, Gary, Columbus, and Toledo. It is readily accessible to about 10 percent of the nation's population for weekend canoeing and camping trips.

The Pine is 60 miles long; the lower 40 miles are canoeable. There are eight primary canoe access points (fig. 1). Five local canoe liveries service the Pine River and additional canoes are occasionally brought from more distant liveries. Maximum float time is 13 hours (Edgetts to Low Bridge); thus, most of the River can be seen in 1 day, though this is seldom done. The Pine River has 204 eroding banks along the lower 26 miles (Hansen 1971), ranging up to 1,000 feet in length and 100 feet in height. Two-thirds of the shoreline is presently owned by either the State of Michigan or by a public utility. Much shoreline is also privately owned along the upper end of the canoeable portion of the stream, but almost none along the lower end. Along the shoreline are one Federal and one State campground.

The Pine is as undeveloped as any river in Michigan's Lower Peninsula. In the canoeable portion (Edgetts to Low Bridge), there are less than 50 cabins, many of which are rustic or not easily seen from the stream. The only other obvious intrusions by man are eight bridges and Stronach Dam, a small abandoned hydroelectric dam.

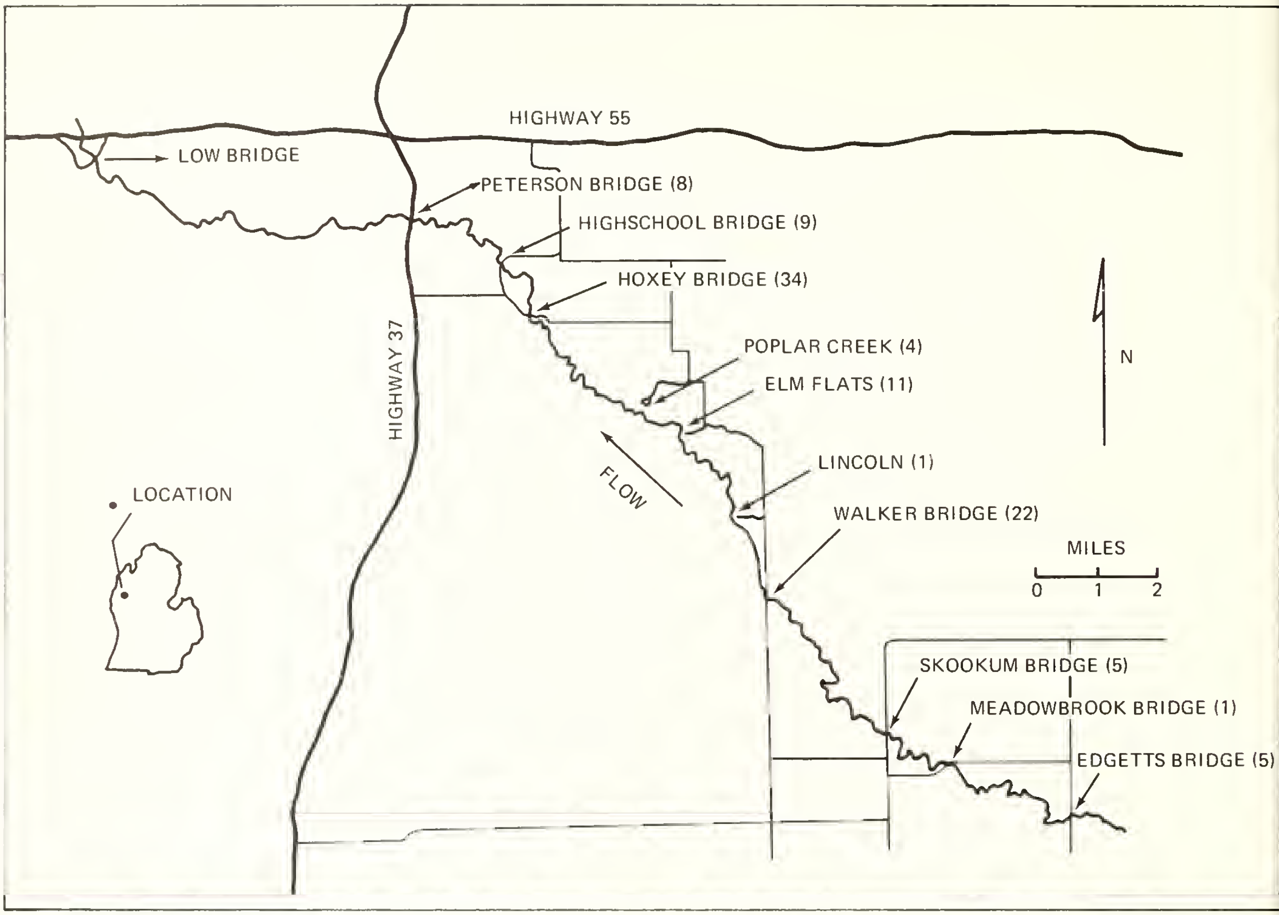

Figure 1.–Pine River Study Area. Arrows pointing toward the river show main access points. Arrows pointing away indicate two main exit points where canoeists were interviewed. (Percent entering at each point in parentheses.)

METHODS

The study was conducted from May 20, 1971, through September 30, 1971. Most of the canoeing on the Pine is done between these dates. Five weekday and 5 weekend days were randomly selected from this period. Two dates that fell on holidays were treated as "weekend" dates, because no consistent difference between weekend and holiday responses was detected.

Peterson Bridge and Low Bridge were selected as the two access sites at which to conduct the interview (fig. 1). All canoeists over 15 years of age exiting between the hours of noon and 8:00 p.m. were interviewed on the selected dates.

Most of the questionnaire was structured so that the respondents could simply check appropriate replies. However, the section dealing with the canoeist's impressions of the canoe trip ("high" and "low" points of the trip, and "suggested improvements") was left "open-ended" so that respondents could write in whatever occurred to them. The responses thus obtained were presumably spontaneous.

The weekday samples provided reliable data on the total number of canoeists exiting from the two access points. Weekend data, however, had population estimate errors that increased as canoeist numbers increased. When large numbers of canoeists exited, some canoeists (particularly "underage" canoeists) were accidently missed, resulting in a low estimate of anoeist numbers. A second attempt to obtain total anoeist numbers at an exit point by grouping the uestionnaires by party size and then summing the arty-size information for all parties resulted in a conistent overestimate of canoeist numbers. An indeendent count on one of the weekend sample dates ndicated that the actual total number of canoeists 'as close to the mean of the estimates obtained by the bove two approaches. Therefore, the average of the wo estimates was used for the other four weekend ample dates.

The annual number of canoeists was estimated by alculating the average number of weekend and weekay rental canoes for the 10 sample dates from data upplied by local outfitters. The averages were exanded to account for private and organization canoes 11 percent weekends and 31 percent weekdays) and canoeist per canoe factor of 2.1; they were then applied to the canoeing season of May 1 to September 30. This procedure overestimates canoe usage during May and September but does not account for canoeists in April and October.

Because the majority of interviews were conducted on weekends (93 percent), "total sample" and "weekend" statistics are nearly the same and are not separated in the text. Weekday statistics are presented separately only when they depart markedly from the weekend data.

RESULTS

Canoeist Characteristics

Twenty percent of the canoeists came from the Detroit area and 28 percent from the Grand Rapids-Muskegon area (fig. 2). About 14 percent were from out-of-State, primarily from bordering metropolitan

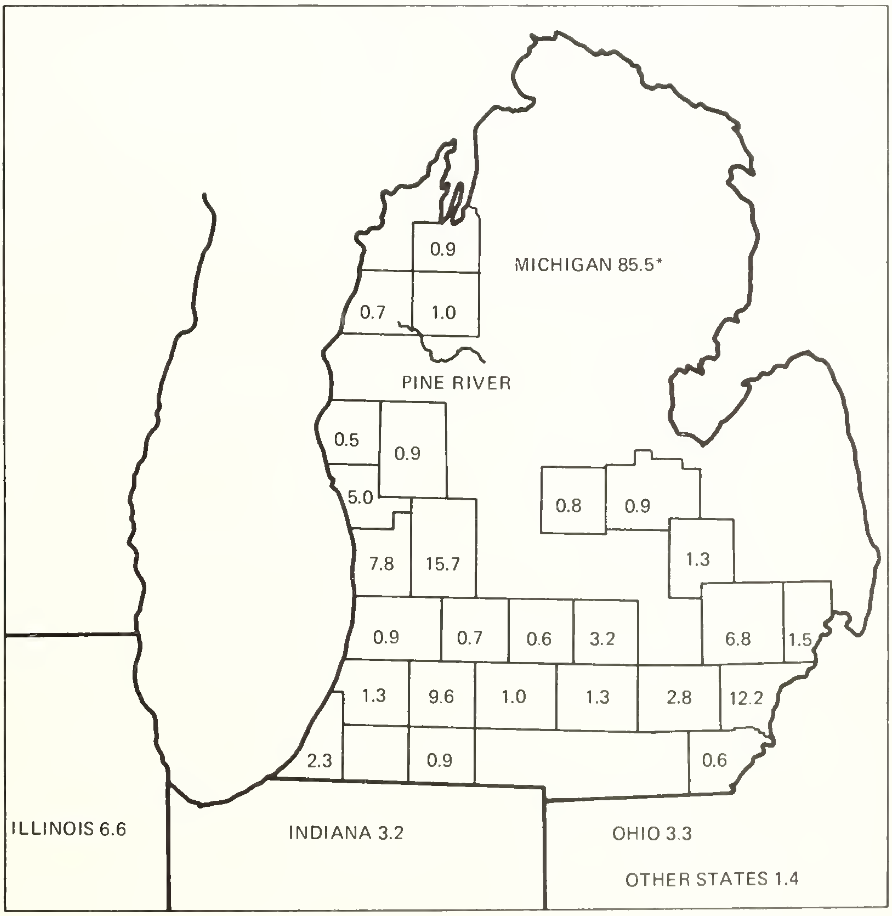

Figure 2.—Origin of canoeists (in percent). The asterisk indicates counties with less than 0.5 percent not shown.

areas in Illinois, Indiana, and Ohio. Almost no visitors came from the north, as was also noted in a study of Manistee National Forest campers (King 1965).

The total number of respondents for the 10 sample days was 2,676. Weekday and weekend respondents numbered 193 and 2,483 respectively (table 1). There was an average of 82 canoeists per day on weekdays and 911 canoeists per day on weekends. Total number of canoeists for the 1971 season was estimated to be 50,000.

Party size varied from 1 to 120. Approximately 40 percent of the canoeists traveled in groups of less than 10, 30 percent in groups of 10 to 19, and 30 percent in groups of 20 to 100. Eighty-eight percent of the users canoed with two people in a canoe and 10 percent were three to a canoe. The average was 2.1 people per canoe.

Two-thirds of the canoeists interviewed left from three of the 10 launch areas (see parenthetical data in figure 1). Hoxey Bridge was the major entry point, with about 50 percent of the weekday use and 34 percent of the weekend use. Walker Bridge was the second most heavily used access point, with 22 percent of the traffic. Use of the upstream launch areas is possibly greater than indicated in figure 1 because some of these canoeists may exit before reaching the two exit points sampled in this survey. The magnitude of this bias is believed to be small.

Approximately 60 percent of the canoe trips were for a single day or less. One-third were 2-day trips and 7 percent were 3-day trips. However, in addition, nearly half of the canoeists were camping either before or after their canoe trip.

Almost two-thirds of those interviewed were making their first trip down the Pine. Only 12 percent had visited it more than 4 years. Eighteen percent of the canoeists made more than one visit to the Pine River during this summer.

Eighty-nine percent of the canoes were rental, 10 percent were private, and 1 percent belonged to camps. Weekdays showed many more canoes from organized camps (22 percent) and fewer private (9 percent) than weekends. Students were the largest user group, comprising 27 percent of the sample, followed by professionals with 23 percent. When only weekdays were considered, 65 percent were students and 12 percent were professionals.

Table 1.—Total sample size

Date (1971)	Canoeists interviewed	Estimated total exiting
Weekdays:		
May 26 (Wed.)	4	4
June 25 (Fri.)	34	57
June 28 (Mon.)	45	62
July 20 (Tues.)	67	110
August 10 (Tues.)	43	103
Total weekday	193	336
Holidays and weekends:		
May 31 (Mon.)	292	1/350 (± 58)
June 5 (Sat.)	438	611 (±173)
July 25 (Sun.)	524	625 (±100)
August 21 (Sat.)	669	851 (±182)
September 5 (Sun.)	560	2/662 (±102)
Total weekend	2,483	3,099
Total all days	2,676	3,435

1/ Upper value based on party-size data and lower value on number of completed questionnaires.

2/ Independent count tallied 657.

Most of the Pine River users were young: half were the 16 to 24 age bracket and on weekdays three-urths were in this category. In addition, many noeists were less than 16 years old and were not terviewed. Only 11 percent were 40 years of age or der. Thirty-nine percent of the population was fe-ale.

Half of those polled had some college education. even percent had 4 years of college education and additional 16 percent had some postgraduate work. nly 4 percent of all canoeists over 19 years of age d less than a high school education.

Canoeist Attitudes

Response was excellent; less than 2 percent of the noeists refused to fill out the questionnaire. Eighty-ght percent made some comment for at least one of e write-in questions about the "high" or "low" ints of the trip, or "suggested improvements." hese responses constituted the most valuable portion the study. Of those that didn't answer the write-in estions, 6 percent did not have any strong im-essions pro or con about their trip and indicated by writing "none," and 6 percent accidently or tentionally did not complete the questionnaire.

ip Purpose

Respondents were requested to check all "pur-ses" that applied to their canoe trip. The results e tabulated below:

	Canoeists interviewed Percent
ings to do:	
Canoe	96
Camp	45
Sight-see	27
Swim	25
Picnic	18
Photography	5
Fish	4
Hike	3
etting away from it all:	
Relaxation	53
Away from civilization	49
Commune with nature	27
Solitude	19

There is an important difference between the above two groups. Whereas many of the items in the first group imply some development — i.e., campgrounds, picnic areas, waste disposal facilities, canoe launching sites, parking areas, etc. — the last three items in the second group imply little or no development. Many people indicated "purposes" from both groups, thus presenting a dilemma to recreation resource managers to try to strike an acceptable compromise between "develop" and "leave natural."

Almost 20 percent of the users indicated solitude as a purpose for their trip. It appears that "solitude" is essentially a state of mind, because on weekends the canoeist shares the river with nearly a thousand other users. Party size did not seem to affect this state of mind either. Sixteen percent of those traveling in groups of 40 or larger were still seeking solitude as a trip purpose.

Trip High Points

Most canoeists were well satisfied with their canoe trip and many listed several high points. Comments under "high points" outnumbered those under "low points" and "suggested improvements" by a ratio of 2 to 1 (table 2). The most commonly stated high points of the trip were factors associated with the stream and its "wilderness" surroundings. Half of the respondents indicated rapids or scenery as the high point of their trip; fewer indicated such associated factors as nature (7 percent) and solitude (5 percent). This high satisfaction with the overall stream environment probably accounts for the lack of such items under "low points," with the minor exception of the 4 percent of the respondents who would like "even more rapids."

Other high points frequently stated concerned the canoe trip itself; i.e., camping (11 percent), tipping over (8 percent), companionship (7 percent), and swimming (5 percent).

Low Points and Suggested Improvements

These two categories are discussed together because the replies are similar for both. Generally, when a respondent listed a "low point" he also suggested ways to improve it. Exceptions are low points such as "insects," "not enough rapids," and "tipping over," which are essentially nonmanageable.

Table 2.—Canoeists' attitudes toward their trip

High point mentioned [1/]	Canoeists interviewed	Low point mentioned [1/]	Canoeists interviewed	Improvement suggested [1/]	Canoeists interviewed
	Percent		Percent		Percent
Rapids	34	Litter	16	Clean up litter	24
Scenery	24	Too many people	9	Leave natural	21
Camping	11	Obstructions to canoeing	7	Remove canoeing obstructions	11
Tipping over	8	Rowdy or drunk canoeists	5	More intermediate facilities	5
Companionship	7	Not enough rapids	4	More campsites	2
Nature	7	Insects	3	Limit private development	2
Solitude	5	Too few or poor campgrounds	3	Control erosion	1
Swimming	5	Intermediate facilities	3	More sand beaches	1
Clean, cold water	5	Tipping over	2	Limit canoes	1
Narrowed stream	[2/] 5	Stronach Dam	[2/] 1	Remove Stronach Dam	[2/] 1
Eroding banks	4	No reply	47	No reply	35
Obstructions	4				
Watching other canoeists	2				
Stronach Dam	[2/] 2				
No reply	26				
Total comments [3/]	118		53		68

[1/] All items mentioned by 2 percent or more of the canoeists are shown. Only selected items are shown that had less than 2 percent response.

[2/] Based only on responses from canoeists who passed these features.

[3/] Some respondents listed several items under "high points," "low points," or "improvements."

The satisfaction of canoeists showed up again in the answers given to the question "How do you feel the Pine River and its shoreline could be improved?" (table 2). Twenty-one percent of the canoeists stated "leave it natural" or "perfect as is." an additional 35 percent gave no reply, and it seems reasonable to assume that many of these were also satisfied with the stream in its present condition.

The most frequent complaint was about litter. Sixteen percent of the respondents listed it as a low point and 24 percent stated that it should be cleaned up. A total of 31 percent of the respondents made some comment about litter.

The second most frequently stated low point was "too many people" (fig. 3). A 1962 study that was made before the rapid increase in canoeing on the Pine River found few complaints about "too many people" canoeing (Lucas 1970). However, that study was based on campers in general and was not restricted to canoeists.

It is significant that almost all of the complaints made during this study were on weekends or holidays when crowding was most evident. Almost no complaints were made on weekdays. On weekends when 300 or more people exited at the two sample points, about 9 percent objected to crowding. It seems valid to hypothesize that as total numbers increase, the proportion objecting to "crowding" would increase also. However, there was no increased dissatisfaction expressed as canoeist numbers increased from 300 to 700. Nor was the percent of canoeists that complained about crowding related to exit point. Either total number of canoeists exiting from a stream is not a sensitive indicator of crowding at high-use intensities, or possibly people who dislike crowding tend to stay away as crowding increases.

Canoeists in small parties objected most to crowding. In parties of 20 or more (10+ canoes), the major contact is with other members of the same party, which apparently is not objectionable; or possibly, people in large parties are more tolerant of or even desire large numbers of people.

Figure 3.—"Too many people" was the second most frequently expressed objection.

Party size	*Objecting to too many people Percent*
1- 5	11.7
6- 9	7.9
10-19	10.8
20-29	5.2
30-39	5.5
40-49	1.5
50+	3.7

Another complaint related to crowding concerned owdy and/or drunk" canoeists. Complaints of wdyism increased disproportionately as use in-eased. No solutions to the crowding problem were ggested under improvements except for a small mber of respondents (1 percent) who suggested gulating the number of canoes.

The third most frequently stated "low point" was "obstructions to canoeing" (table 2). Although a few canoeists wanted a general cleanup of logs and debris in the stream, a larger number specifically stated removal of only a few log jams and trees that completely blocked the stream. For example, one large log jam 2 miles above the downstream exit point is the largest on the stream, and 70 percent of the complaints about obstructions were made at that exit. Selective removal of obstructions at only a few points in the stream would probably eliminate most of the complaints about such items. Any substantial removal of obstructions might begin to detract from the enjoyment of the group who list "obstructions" as a high point of their trip.

About 6 percent of the respondents expressed disappointment at the lack or poor quality of campgrounds and other facilities along the stream (table 2). About the same number requested under "suggested improvements" that more facilities (toilets, picnic sites, drinking water, signs, campsites, etc.) be constructed (table 2). There were slightly more requests for more facilities from campers (5 percent) than noncampers (3 percent), a trait noted by Lucas (1970). Also, 97 percent of the requests for more facilities came on weekends.

The response "leave natural" does not necessarily mean "no development." Two percent of those stating "leave natural" advocated more facilities, as opposed to 7 percent for all canoeists. On the other hand, only 1 percent of the "leave natural" group desired removal of obstructions, compared with 14 percent of all canoeists. Both groups held the same attitudes toward litter.

Stronach Dam, which requires a portage, is situated three-fourths of a mile above the lower exit point. Only 1 percent of the canoeists listed removal of Stronach Dam as a suggested improvement whereas 2 percent of the canoeists listed the dam as a "high point." In addition, a larger group (5 percent) listed as a "high point" a narrowed abraided section on reservoir fill above Stronach Dam that would be destroyed by dam removal. Thus, it appears that canoeist opinion does not presently call for removal of Stronach Dam.

Only 1 percent of the respondents requested stabilization of eroding banks (fig. 4). In contrast, about 4 percent of the respondents listed eroding banks as a high point of their trip (table 2). The typical response was that they "liked to run and slide down the steep sand banks" or the "cliffs looked impressive." However, in general there was little comment pro or con on the esthetics of the banks. Less than 1 percent ob-

Figure 4.—As many canoeists liked the dramatic "cliffs" as objected to streambank erosion.

ected to "muddy water," a condition to which bank erosion contributes, whereas 5 percent were impressed by the "clean, cold water."

The lack of comment on eroding streambanks, together with the high satisfaction expressed for the "scenery" and the emphasis on "leave natural," leads to the conclusion that the eroding banks are accepted as part of the natural environment by canoeists.

MANAGEMENT IMPLICATIONS

A wide range of attitudes were evidenced by canoeist responses in this study. Often what is liked by part of the group is disliked by others in the same group. This constitutes a management dilemma; i.e., how much management should be undertaken, whose desires should be met, and how should priorities be established? This study cannot give final answers to these questions. Other important factors need to be considered also, such as the maximum number of canoeists that can use the stream without serious environmental degradation, the attitudes of other users who do not canoe, and the way in which the recreation resource of the stream fits in with that of nearby streams.

Management alternatives will be discussed within a "complementary-antagonistic" framework. Items in the complementary category can be managed without much conflict between canoeists. However, the items categorized as "antagonistic" present varying degrees of difficulty for management planning. Canoeists expressed opinions about these items that were mutually exclusive. Some can probably be resolved through judicious compromise but others will require an either/or decision.

Complementary Management Options

Canoeists strongly indicated their desire to maintain the natural environment through such comments as "perfect as is," "halt private development," and "you can't improve on nature." No one complained about lack of commercialization. Consequently, a management plan to keep the stream environment "natural" would meet with general approval.

Many, if not most, canoeists would be in favor of a litter reduction program of some type. Several things could be done to reduce the litter problem. For example, more refuse containers with better spacing and more frequent servicing could be provided. It could be required that all material carried in the canoe be either secured or in a floatable container, thus preventing loss when the canoe tips. Cans, bottles, and other nonburnable containers could be banned.

Antagonistic Management Options

The comment "too many people" was given within the context of "too many other canoeists." However, from a management standpoint "too many people" must also be considered in relation to the maximum number the environment can tolerate before serious degradation occurs, and to the seriousness of conflicts between different user groups (fishermen versus canoeists, or canoeists out for a group outing versus canoeists seeking solitude).

Regulation of canoe numbers presents a dilemma. Although no canoeists liked the crowding and many complained about it, presumably no one would willingly stay away to reduce the crowding problem. thus, any regulation of canoeist numbers is antagonistic because it will benefit some canoeists to the detriment of others (those eliminated). On the other hand, lack of regulation would probably result in a continued increase of canoeist numbers to the detriment of those who object to "crowding" and those who are seeking "solitude." Increased canoeist numbers would also tend to compound problems such as "not enough campgrounds and other facilities," "litter," and "degradation of the shoreline," while reduced canoeist numbers would tend to lessen the severity of these problems.

This study does not define the optimum level of use. However, it does provide a clue in that although canoeists were generally satisfied with their trip, a substantial portion of weekend canoeists already object to crowding, and another fraction wants more facilities of all types, which would in turn detract from the widely heralded "naturalness" of the area. Thus, it seems reasonable to say that weekend canoeist numbers (an estimated 900+ people per day) are somewhere near the level the Pine River can handle and still satisfy the diversified desires of the canoeists. Any management efforts to reduce canoeist impact on the shoreline (e.g., prohibiting landing at ecologically unstable areas of the shore), reduce litter, construct off-stream facilities effectively screened from the canoeist view, or reduce canoeist numbers during peak hours by more even distribution during the day would tend to permit greater numbers of canoeists to use the stream. Or, given a fixed number of canoeists, the quality of the canoeing experience would be increased.

Although many canoeists requested more facilities (such as campgrounds, picnic sites, and toilets), construction of such facilities without some type of ceiling on user numbers might encourage even more crowding. This added crowding might result in even lower quality facilities or fewer facilities when expressed on a per-canoeist basis. Also, additional canoeist numbers would be antagonistic to other desirable assets such as "solitude" and the "naturalness of the stream." Thus, the following recommendation for added facilities is within the context of more facilities per canoeist together with the assumption that other desirable attributes of the canoeing experience would not suffer.

Better distributed and more intimate camping facilities are needed. Campgrounds could be developed to provide facilities only for canoeists. Better intermediate facilities are also needed. These could be developed at camping areas, entrance points, and selected intermediate points along the stream to provide adequate sanitary facilities, drinking water, and refuse containers. Disturbance to the natural shoreline should be minimized. Better access facilities could also be provided at selected points.

A few key obstructions could probably be removed with little detriment to the "challenge of obstructions" noted under "high points." Wide-scale removal of obstructions should be avoided, however. Also, there appears to be little justification for dam removal.

Streambank erosion was viewed as a problem by only a few canoeists, and the banks were not considered to be esthetically detracting. In fact, more canoeists liked the eroding banks than disliked them. Therefore, streambank stabilization on the Pine River should be done only if clearly dictated by factors other than canoeing.

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GARY R. LINDELL

the changing market for hardwood plywood stock panels

NORTH CENTRAL FOREST EXPERIMENT STATION
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Manuscript approved for publication May 16, 1972

THE CHANGING MARKET FOR HARDWOOD PLYWOOD STOCK PANELS

Gary R. Lindell

"Stock panel" is a trade name for a hardwood plywood panel commonly destined for remanufacture into such items as furniture and cabinets. Occasionally it is used for partitions but seldom for wall covering or paneling. It is characterized by its standard size and an unfinished hardwood veneer face and back and a veneer core. Most of these panels have a birch face and back and are ¾ inch by 4 feet by 8 feet in size. The bulk of this product is now produced by a small number of mills in the Pacific Northwest.

The market for hardwood plywood stock panels is declining. Production for 1969 and 1970 was more than 20 percent below that for 1968 according to the Western Hardwood Plywood Producers, an association representing stock panel producers in the Pacific Northwest. Meanwhile, the wholesale price index for birch plywood fell nearly 5 percent from August of 1969 through December 1970.[1] Although some of this drop was due to the general downturn in the economy, production of hardwood plywood stock panels declined to a far lower level than most end markets. For example, the 1970 indexes of millwork and furniture output were down 14 percent and 5 percent, respectively, from 1968. Housing starts in 1970 were about 5 percent below the 1968 figure whereas total construction expenditures were about 8 percent higher. Mobile home shipments in 1970 were 26 percent above the volume recorded for 1968.[2] Our study involved identifying and ranking the major end markets for stock panels and gathering supplemental information on recent and prospective trends in sales to these markets.

[1] *U. S. Department of Labor, Bureau of Labor Statistics. Wholesale prices and price indexes (monthly).*

[2] *U. S. Department of Commerce, Office of Business Economics, Survey of current business (monthly), and U. S. Department of Commerce, Bureau of Domestic Commerce, Construction review (monthly).*

PROCEDURE

In 1970 there were 11 major producers of stock panels, all located in the Pacific Northwest. Six of these firms supplied the names and addresses of their 1970 customers from which a composite list of 504 wholesalers and distributors of stock panels was compiled. These firms were mailed a questionnaire to obtain information on the types of markets to which they sold stock panels in 1970 and recent and expected trends in stock panel sales to these markets. From this canvass 296 usable questionnaires were returned, a response rate of nearly 60 percent. Replies were received from firms in 42 States and all 9 Census geographic regions (fig 1).

RESULTS

The 296 wholesalers and distributors who responded to the survey handled nearly 249 million square feet (surface measure) of hardwood plywood stock panels in 1970. On the basis of preliminary Census data we estimate this to be something less than half the total stock panel market.[3]

Producers and sellers of stock panels indicated that reshipment to markets out of the region was minimal so we will assume that stock panels shipped to wholesalers or distributors in a particular region were eventually resold to end markets within that region (fig.2).

Thirteen major end markets were identified by the responding wholesalers and distributors; four of those markets accounted for four-fifths of the stock panel sales (fig. 3). Let us examine them in order of importance.

[3] *U. S. Department of Commerce, Bureau of the Census. Hardwood plywood: 1970. Ser. MA-24F(70)-1, Nov. 1971: p. 3.*

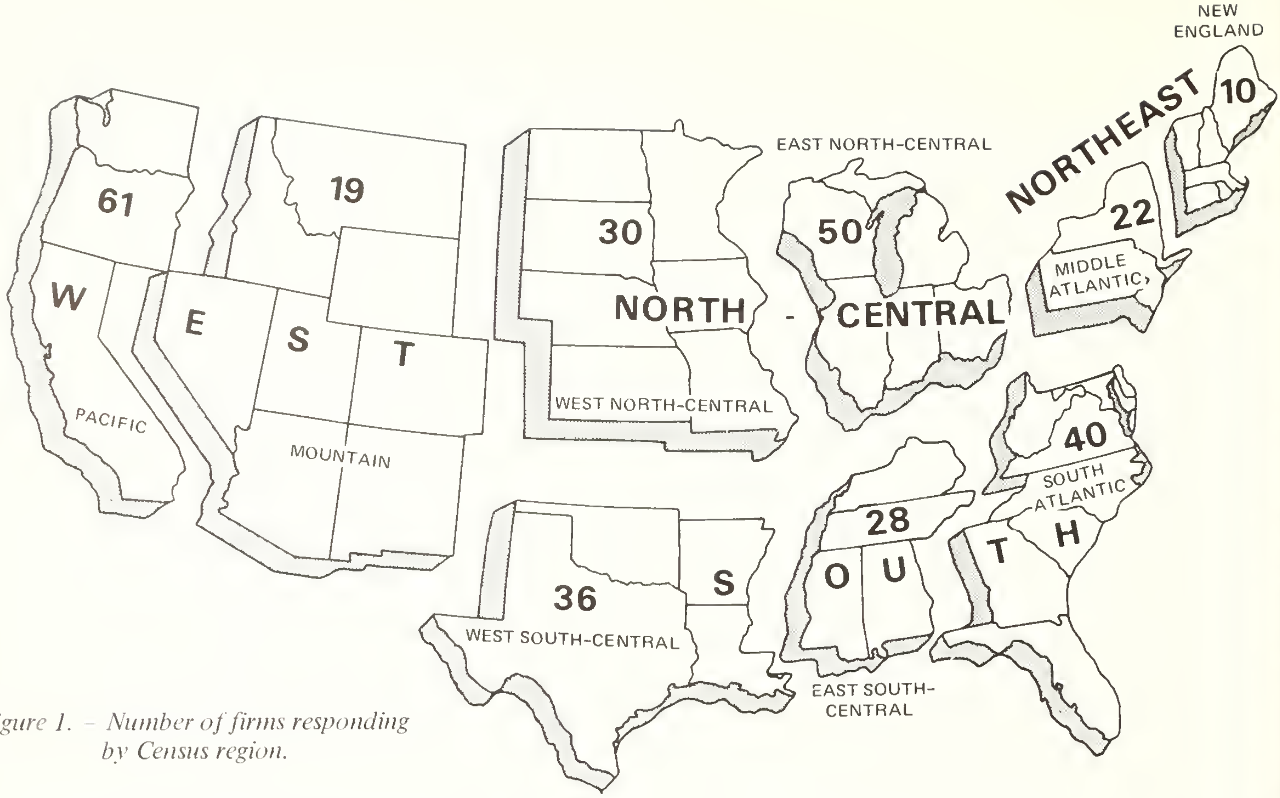

Figure 1. – Number of firms responding by Census region.

Millwork and Custom Cabinet Shops

Millwork and custom cabinet shops purchased about 60 million square feet or 24 percent of the 249 million square feet handled by wholesalers and distributors. Shops in the Pacific States received nearly half the total sales to this end market (table 1). The other half was fairly evenly distributed among the remaining regions.

Of the 200 wholesalers and distributors responding, about one-third indicated that sales to the millwork and custom cabinet markets had decreased since 1967 (table 2). However, these firms accounted for 69 percent of the volume of sales to this market. Another one-fourth (representing 20 percent of the sales) indicated that sales had increased while the remainder indicated that sales were unchanged.

Table 1. – Regional distribution of wholesaler and distributor sales of hardwood plywood stock panels by end market, 1970

(In percent by volume)

Market	Pacific	West south-central	South Atlantic	New England	West north-central	East north-central	Middle Atlantic	East south-central	Mountain	Total all regions
Millwork and custom cabinet shops	49	4	11	9	7	5	8	5	2	100
Other wholesalers & distributors	52	23	4	2	12	5	1	1	1/	.100
Retail building material dealers	21	17	15	6	12	11	7	8	3	100
Kitchen cabinet mfrs.	32	5	12	12	6	16	10	5	2	100
Building contractors	18	60	15	1/	3	1	2	1	1/	100
Furniture mfrs.	13	5	4	23	1	2	19	33	1/	100
Partitions or fixtures mfrs.	23	6	6	24	8	8	20	4	1	100
Radio, TV, or phono mfrs.	17	15	1/	49	1/	1	17	1	1/	100
Mobile home mfrs.	14	9	31	5	23	13	1	4	1/	100
Others	31	1	8	37	3	5	14	1/	1	100
Total for region	36	13	11	10	8	8	8	5	1	100

1/ Negligible

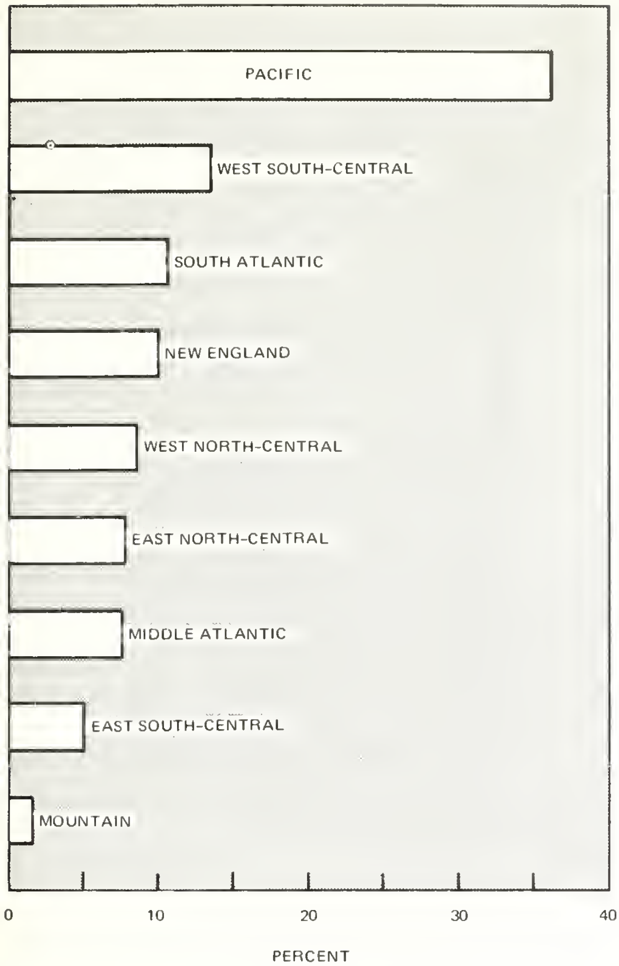

Figure 2. – Regional destination of hardwood plywood stock panel shipments, 1970 (in percent by volume).

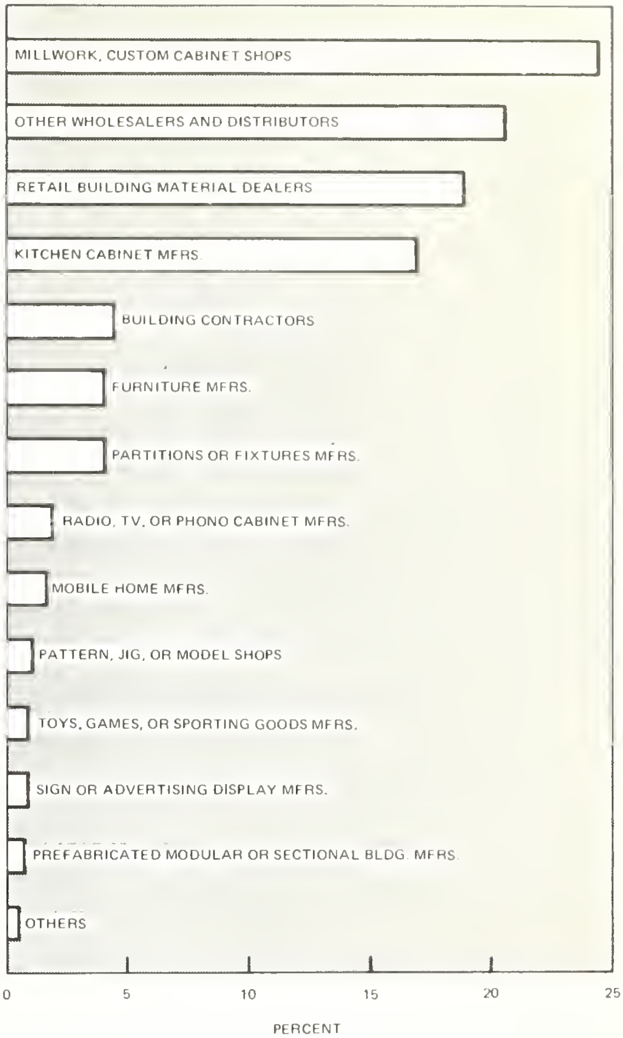

Figure 3. – Wholesaler and distributor sales of hardwood plywood stock panels by end market (in percent by volume).

Other Wholesalers-Distributors

Another 51 million square feet or 20 percent of the total volume was sold to other wholesalers or distributors; again chiefly to wholesalers-distributors in the Pacific region. No effort was made to trace the product through subsequent market transactions to final markets. We are assuming that the patterns of usage and reasons for increase or decrease in sales were similar to those for other markets.

Retail Building Material Dealers

Retail yards were the next most important market for stock panels in 1970, accounting for more than 46 million square feet or approximately 19 percent of total sales. Undoubtedly some of this is used for do-it-yourself projects. Also in many areas, building contractors obtain the bulk of their materials from retail yards instead of from wholesalers or distribution centers. Sales were fairly evenly distributed across the country, but the Pacific region again received the largest share.

Of the 221 respondents in this field, two-fifths (representing 48 percent of the volume of sales to this market) noted a decrease in sales. Only one-fifth (representing 27 percent of the volume) noted an increase.

Kitchen Cabinet Manufacturers

Kitchen cabinet manufacturers (who also produce bathroom vanities) purchased 42 million square feet of stock panels in 1970 or 17 percent of the total. Nearly one-third of the amount destined for this market was

Table 2. – Number of respondents noting an increase, decrease, or no change in hardwood plywood stock panel sales to various markets since 1967

Market	Number of respondents noting an: Increase	Decrease	No change	Total number of respondents
Millwork and custom cabinet shops	55	75	70	200
Other wholesalers and distributors	15	31	66	112
Retail building material dealers	49	89	83	221
Kitchen cabinet mfrs.	39	61	27	127
Building contractors	22	24	46	92
Furniture mfrs.	10	32	28	70
Partitions and fixtures mfrs.	22	47	21	90
Radio, TV, or phonograph cabinet mfrs.	8	17	20	45
Mobile home mfrs.	18	18	16	52
Others	22	54	97	173
Total responses	260	448	474	1,182

sold to cabinet manufacturers in the Pacific States.

Half of the 127 respondents on this market indicated that sales had decreased. They accounted for 49 percent of the sales to this market. One-third of the respondents (representing 36 percent of the sales) noted an increase in sales.

Building Contractors

Sales to building contractors accounted for nearly 11 million square feet or 4 percent of the total volume in 1970. The bulk of the sales to this market were to builders in the west south-central region.

This does not present a true picture of the relative importance of building contractors as a market for stock panels in various regions because of the different market channels used. For example, in some sections, such as the west north-central region, builders commonly purchase the bulk of their materials from retail yards, seldom from a wholesaler or distribution center. In other sections, such as the west south-central region, direct sales from wholesaler to builder are common.

Respondents noting a change in sales to this market were nearly evenly split. However, those noting an increase accounted for 69 percent of the sales to building contractors while those noting a decrease accounted for only 11 percent of the sales.

Furniture

Sales to furniture manufacturers totaled approximately 10 million square feet or about 4 percent of the total. About three-fourths of the volume was destined for the east south-central and northeast regions.

Nearly half the respondents (accounting for 46 percent of the sales to this market) noted a decrease in sales. Only 10 of the 70 respondents noted an increase and the remaining 28 indicated that sales were unchanged.

Partitions and Fixtures

Manufacturers of partitions and/or office and store fixtures absorbed about 10 million square feet or 4 percent of the total stock panel volume. Sales were primarily to the northeast region.

Over half the respondents (representing 58 percent of the sales) noted that sales to this market had decreased since 1967 while one-fourth (accounting for 38 percent of the sales) noted an increase. The remaining one-fourth indicated that sales were unchanged but they accounted for less than 5 percent of the sales to this market.

Radio, TV, or Phonograph Cabinets

Manufacturers of cabinets for radios, television sets, or phonographs absorbed about 5 million square feet or nearly 2 percent of the total volume in 1970. Nearly half the sales were to manufacturers in the New England region.

Slightly over one-third of the respondents noted a decrease in sales to this market while 18 percent noted an increase. However, these respondents respectively accounted for only 20 percent and 16 percent of the sales to this end market.

Mobile Homes

Manufacturers of mobile homes absorbed approximately 5 million square feet or 2 percent of total stock panel sales in 1970. About four-fifths of the volume was destined for mobile home manufacturers in the South Atlantic, north-central, and Pacific regions. This pattern corroborated the 1967 *Census of Manufacturers* which showed three-fourths of the value of industry shipments originating in these three regions.[4]

[4] *U. S. Department of Commerce, Bureau of the Census. 1967 Census of manufacturers. 1971.*

Respondents noting a change in sales to mobile home ıanufacturers were evenly split: one-third indicated hat sales had decreased and one-third noted an increase; hese respondents respectively accounted for 36 percent nd 18 percent of the volume to this market.

Others

Sales were recorded to several other markets including attern shops and manufacturers of prefabricated or ıodular buildings, toys and sporting goods, and signs nd advertising displays.

Sales to this composite group totaled approximately ' million square feet or 4 percent of the total. Most ıgns were to firms in the New England region with the 'acific region next.

One-third of the respondents (accounting for 50 ercent of the sales to these markets) indicated that ales had decreased since 1967. Over half the respondents oted steady sales but they accounted for only 40 perent of the sales to these markets.

Summary and Reasons for Sales Trend

Of the 1,182 responses to the question of trends in tock panel sales since 1967, 448 (38 percent) indicated hat sales had decreased while only 260 (22 percent) ndicated an increase in sales. On the average, the firms hat indicated a decrease in sales accounted for 47 ercent of the volume sold to the various end markets vhile those firms that noted an increase accounted for n average of 33 percent of the sales. The remaining 474 – 40 percent of the responses – indicated that sales ad remained steady.

Many reasons were given for the decrease in sales ince 1967 but by far the most common was the inreased use of plastic overlaid particleboard panels table 3).

The increased use of other substitute panel products ıch as hardboard was the next most important reason ontributing to declining sales. This also included plastic verlaid hardboard or plywood.

About 10 percent of the reasons given for declining ales involved the trend towards factory-built cabinets nd a decrease in the construction of custom or siteuilt cabinets. This change does not necessarily imply a ›ss in markets to substitute materials, but a shift in the elative importance of the various end markets. In this ase, construction of kitchen cabinets is shifting from he local cabinet shop to the large factory that markets egionally or nationally.

Table 3. – Reasons for decrease in hardwood plywood stock panel sales since 1967

Reason	Number of responses	Percent of total
Increased use of particleboard core panels with plastic overlays	216	54
Increased use of substitute panel products including printed or overlaid hardboard and plywood	69	17
Increased use of factory built cabinets and decreased use of custom or site-built cabinets	40	10
General slowdown in business and construction	29	7
Increased use of imported stock panels	26	7
More customers buying directly from manufacturers	7	2
Others	13	3
Total	400	100

A general slowdown in business and construction was the next most often mentioned factor contributing to declining sales. Several other factors were mentioned as contributing to declining sales including the increased use of imported plywood, more direct sales from panel manufacturer to user and an increase in the use of cut-to-size and opposed to stock-size panels.

Most of the reasons given for an increase in stock panel sales since 1967 involved a general increase in the level of the economy and construction (table 4). Also, several firms noted expanded sales to fast-growing industries such as the mobile home industry.

Table 4. – Reasons for increase in hardwood plywood stock panel sales since 1967

Reason	Number of responses	Percent of total
General increase in business and construction	61	56
Increased promotion and selling of stock panels	11	10
Change from softwood plywood to hardwood plywood for cabinets	8	7
Hardwood plywood stock panels help speed up production	6	6
Increased recognition of quality of hardwood plywood relative to plastic covered particleboard panels	5	5
Others	17	16
Total	108	100

Regional fluctuations reflected locally prevailing trends. For example, all of the firms that noted an increase in sales because of an increase in construction were located in the south and west. Conversely, nearly all the firms that noted a decrease because of construction slowdown were located in the northeast and northcentral regions. This says nothing about changes in the competitive position of hardwood plywood stock panels relative to substitute panels; presumably a general increase in the economy and construction also would result in expanded sales for other types of panels. Most of the other responses, however, indicated that hardwood plywood had improved its market position relative to other types of panels.

The Outlook

Three-fourths of the respondents who expect stock panel markets to change feel that stock panel sales will decrease over the next 3 years; only one-fourth expect an increase. Most of those expecting a decrease cited further inroads of plastic overlaid panels in the market (table 5).

Table 5. – Expected changes in hardwood plywood stock panel sales by 1974 and reasons for these changes

Change and reason	Number of responses	Percent of total
Decrease:		
Increased use of plastic-overlaid particleboard	70	40
Increased use of prefinished, manufactured cabinets and decreased use of custom or site-built cabinets	18	11
Increased use of other substitute materials	12	7
Increased use of imported hardwood plywood	6	3
Other reasons	26	14
Total decrease	132	75
Increase:		
Increase in housing construction	10	6
Expected increase in manufacture of mobile homes and kitchen cabinets	6	3
Other reasons	29	16
Total increase	45	25
Total all responses	177	100

SUMMARY AND CONCLUSIONS

The top three end markets for stock panels in 1970 in order of declining sales were millwork and custom cabinet shops, retail building material dealers, and kitchen cabinet manufacturers. Apparently the major end product for stock panels is kitchen cabinets (fig. 4). Both millwork-cabinet shops and kitchen cabinet manufacturers – which were major markets for stock panels in 1970 – produce kitchen cabinets. In addition, many stock panels are sold to builders, either directly from the wholesaler or through retail building material dealers for the construction of cabinets onsite.

Important changes are occurring in the production and marketing of kitchen cabinets. More and more kitchen cabinets are being produced in large kitchen cabinet plants, primarily at the expense of the local custom cabinet shop and the producer of semicustom, unfinished cabinets for local builders. With the growing importance of the large kitchen cabinet plant, stock panel producers can expect changes in the type and form of raw material sold to this market. Because of the large initial investment in equipment required to apply plastic overlays or fabricate plastic components, large kitchen cabinet manufacturers are more likely than smaller firms to produce plastic or plastic overlaid cabinets. Consequently, the trend toward large plants favors the use of plastics. The respondents felt increased use of plastic overlaid particleboard was the major cause of declining sales to the kitchen cabinet industry over the 3 years preceding the survey and poses a major obstacle to stock panel sales in the near future.

Moreover, kitchen cabinet manufacturers are progressing towards assembly-type operations. As a result, there has been a marked shift away from the purchase of stock hardwood plywood panels to panels that have been sized to fit specific needs.[5] Apparently stock panel producers should be prepared to offer more cut-to-size items to maintain their share of this important market.

The major change in stock panel markets is the substantial inroads being made by substitute panels with a particleboard core and a flexible or rigid plastic overlay. Apparently plastic covered panels are also eroding several traditional stock panel markets such as furniture, television cabinets, and partitions. Lower cost was the reason most often given for using these other types of panels, although voids in the core were often mentioned as a problem with stock panels.

Several firms foresaw a disenchantment with plastic covered panels by industrial users and consumers and a return to hardwood plywood for such items as kitchen cabinets. However, most respondents felt that present trends would continue over the next 2 to 3 years, at least. In the absence of a more effective effort on the part of stock panel producers to offer a more competitive product, this means that stock panels will be increasingly relegated to a high value but low volume item.

[5] *Lindell, Gary R., and Gustav C. Klippel. The kitchen cabinet market: big business for panel industries. Plywood & Panel 12(8): 14-15. 1972.*

Figure 4. – Several types of firms produce kitchen cabinets, the major end product for stock panels in 1970.

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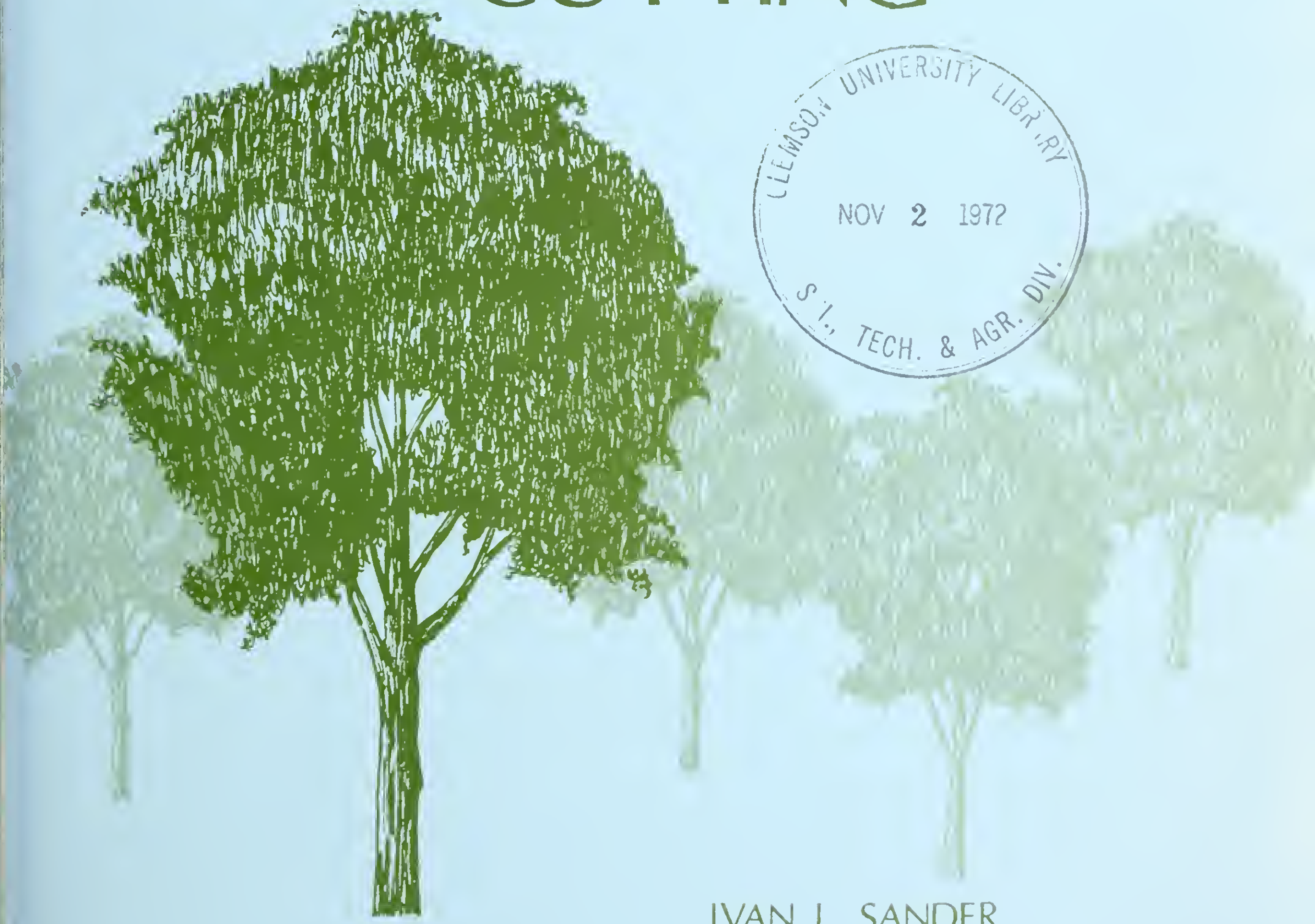
Size of Oak Advance Reproduction: KEY to GROWTH FOLLOWING HARVEST CUTTING



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Manuscript approved for publication May 23, 1972

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Size of Oak Advance Reproduction: Key to Growth Following Harvest Cutting

Ivan L. Sander

When a mature upland oak stand is harvested, the oaks in the new stand come from advance reproduction already present on the area. Some oak reproduction is present under most mature stands over the commercial range of oak species. However, the amount varies greatly from stand to stand, and ranges from almost nothing to thousands of stems per acre (Minckler and Jensen 1959, Trimble and Hart 1961, Arend and Scholz 1969). The oak component of newly regenerated stands is sometimes inadequate even when oak advance reproduction is abundant, because it fails to grow fast enough to compete successfully. Thus, numbers alone do not indicate how many oaks will become dominant in the new stand.

An Ohio study showed the size of the advance reproduction to be an important determinant of new oak sprout growth following clearcutting (Sander 1971). In this study the old stems were cut off near the ground to force them to sprout. Growth of the new sprouts was related to the diameter of the old stem at the ground line; the larger the old stem cut off, the faster the sprout that originated from its stump grew.

These results have been confirmed by a study in southern Illinois reported here. This study shows that oak reproduction growth following overstory treatment depends on size of the reproduction before cutting, whether or not an advance reproduction stem was cut or broken off during logging, and the amount of overstory left after cutting.

THE STUDY

The study consisted of two blocks, each containing three overstory treatments (complete cutting, partial cutting, and uncut) of 0.4 acres each. It was installed in a 60- to 80-year-old sawtimber stand (site index 65) on the Kaskaskia Experimental Forest in southern Illinois.

Basal area before cutting ranged from 56 to 67 square feet per acre in trees larger than 3.5 inches d.b.h. (table 1). White, black, northern red, and scarlet oaks constituted about 80 percent of the basal area, hickory about 15 percent, and scattered black gum, sassafras, and dogwood made up the balance.

All plots were treated during the dormant season. In the complete cutting treatment, all merchantable trees were removed, then all remaining stems taller than 4.5 feet were cut. In the partial cutting treatment, some trees in nearly all diameter classes were removed, leaving about one-half of the stand basal area. No trees were removed from the uncut plots (table 1).

Table 1. — Stand Characteristics before and after treatment
(Per acre)

Treatment	Original stand: Number of trees	Original stand: Basal area	Original stand: Stocking	Original stand: Aver.1/ d.b.h.	Residual stand: Number of trees	Residual stand: Basal area	Residual stand: Stocking	Residual stand: Aver.1/ d.b.h.
		Sq. ft.	Percent	Inches		Sq. ft.	Percent	Inches
Uncut	107	56	48	9.8	107	56	48	9.8
Partial cut	112	67	56	10.4	65	34	29	9.8
Complete cut	159	67	60	8.8	0	0	0	0

1/ Diameter of the tree of average basal area.

Reproduction was sampled on 16 4.35-milacre subplots in each plot. Before treatment, all oak stems less than 4.5 feet tall on each subplot were classified according to their origin (fig. 1). The following classification was used throughout the study.

Reproduction Type	*Description*
A	New seedlings. – True seedlings established after treatment.
B	Seedling advance reproduction. – Individuals less than 4.5 feet tall in which the roots and stems are the same age and present before treatment.
C	Seedling sprout advance reproduction. – Individuals less than 4.5 feet tall in which the roots are older than the stems and present before treatment.
D	New sprouts from seedling advance reproduction. – New stems originating after treatment from dormant buds at the root collar. These were type B before treatment.
E	New sprouts from seedling sprout advance reproduction less than 4.5 feet tall. – New stems originating after treatment from dormant buds at the root collar. These were type C before treatment.
F	New sprouts from seedling sprout advance reproduction over 4.5 feet tall and less than 2 inches in diameter at the ground. – New stems originating after treatment from dormant buds at the root collar. These were not measured before treatment.

Their heights were then measured, and they were permanently marked. At the end of the first growing season after treatment, all stems were remeasured and those that had new sprouts were reclassified. In addition, new seedlings that had become established were permanently marked and measured. Advance reproduction stems taller than 4.5 feet were not measured before treatment, but 1 year later it became apparent that new sprouts from these stems would be an important element in the reproduction. So, at this time they were measured and permanently marked. Remeasurements were made on the completely cut and partially cut plots 1, 2, 6, and 12 years after treatment, and on the uncut plots 1, 2, and 12 years after treatment.

During early spring following treatment, an incendiary fire burned over the study plots. The fire was set in the early evening and apparently did not burn extremely hot or uniformly over the plot areas. The major effect of the fire was the top-killing of some advance reproduction stems. This resulted in more new sprouts at the end of the first growing season than would ordinarily be present after logging alone. All of the new sprouts on the uncut plots resulted from this fire.

RESULTS

Mortality

Mortality was variable and not consistent for all reproduction types within and between treatments, and analysis of variance showed no significant differences. However, some general trends were apparent. At the start of the study there were 2,376 stems of oak reproduction per acre on the completely cut plots, 3,032 on the partially cut plots, and 2,046 on the uncut plots (table 2). Twelve years later, the proportion of stems that had died was greatest on the uncut plots (60 percent), least on the completely cut plots (42 percent), and intermediate on the partially cut plots (53 percent) (table 3).

Table 2. – Oak reproduction prior to, and 1 and 12 years following overstory treatment (Number of stems per acre)

Treatment	Reproduction type						All
	A	B	C	D	E	F	types
Prior to:							
Complete cut	0	684	928	0	0	--	1,612
Partial cut	0	742	828	0	0	--	1,570
Uncut	0	944	562	0	0	--	1,506
One year after:							
Complete cut	382	266	317	252	590	382	2,189
Partial cut	1,109	338	360	245	432	353	2,837
Uncut	288	266	187	418	353	252	1,764
Twelve years after:							
Complete cut	130	93	187	173	454	338	1,375
Partial cut	317	180	211	70	303	301	1,382
Uncut	43	137	115	209	173	152	829

Mortality of reproduction types A and B was generally greater than that of types C and D; the lowest mortality occurred in types E and F regardless of overstory treatment. Mortality of the relatively small reproduction types A, B, and D was highest from 2 to 6 years after treatment, while most of mortality in the larger types C, E, and F occurred later.

These trends suggest that mortality is related to the size and relative vigor of the various reproduction types as well as to the amount of overstory left on the plots. The smaller stems had more restricted root systems, were less vigorous, and thus more likely to succumb to competition and other forces than the larger stems.

Figure 1. – Oak reproduction types: (A) new oak seedling; (B) seedling advance reproduction; (C) seedling sprout advance reproduction; (D) new sprout from seedling advance reproduction; (E) new sprout from seedling sprout advance reproduction less than 4.5 feet tall; (F) new sprout from seedling sprout advance reproduction more than 4.5 feet tall.

HEIGHT GROWTH

Treatment Comparisons

The effects of overstory density on height growth of oak reproduction began to show up the first year after treatment. The first-year differences were small, but by the end of the second year all reproduction types were generally tallest on the completely cut plots and shortest on the uncut plots (fig. 2). After 6 years, all reproduction types were significantly taller on the completely cut plots than on the partially cut plots. Furthermore, the differences increased, until at age 12 the reproduction on the completely cut plots averaged about twice as tall as on the uncut plots.

These results confirm those from earlier studies showing that even a relatively light residual overstory reduces growth of reproduction and that complete overstory removal provides the conditions necessary for best reproduction growth (Tryon and Carvell 1958, Sander and Clark 1971).

Regardless of residual overstory, 12 years after treatment reproduction type F was the tallest, type A was the shortest, type C was taller than type B, and type E was taller than type D (fig. 2). Thus, total height of reproduction at this age is dependent upon height before cutting as well as amount of overstory left, and in the case of new sprouts, probably upon size of the root system as well.

Table 3. – Mortality of oak reproduction following overstory treatment (In percent)

Time since treatment (years)	A[1/]	B	C	D	E	F	All types
COMPLETE CUT							
2	6	53	6	3	1	0	12
3-6	41	15	15	14	9	2	15
7-12	19	10	23	14	13	9	15
Total	66	78	44	31	23	11	42
PARTIAL CUT							
2	9	33	11	15	2	0	12
3-6	42	22	11	41	7	2	25
7-12	21	9	15	15	22	12	17
Total	72	64	37	71	31	14	53
UNCUT							
2	50	59	21	21	8	0	30
3-12	35	15	24	29	43	40	30
Total	85	74	45	50	51	40	60

1/ Includes only new seedlings established the first year after treatment.

Completely Cut Plots

Early height growth determines whether or not stems will attain and maintain dominance after complete cutting. Type F reproduction grew almost 3 feet per year the first 2 years after complete cutting, much faster than any other reproduction type (fig. 2). From then until age 12, type F stems grew at a uniform rate of about 2 feet per year. Reproduction type E grew at a uniform rate of about 1.7 feet per year for the first 6 years following cutting. Then growth declined and averaged about 0.9 feet per year between age 6 and 12. Type C growth followed a pattern similar to that of type E, but at a lower average rate. Reproduction types B and D grew at similar rates throughout the 12 years, but always grew at a lower rate than types C, E, and F. Type A stems grew slowest of all, and at age 12 averaged only about 2.5 feet tall.

It is obvious that no stems of reproduction types A, B, and D will ever grow into the dominant stand on the completely cut plots. At age 12, all stems of these types were either intermediate or suppressed, with over 90 percent in the suppressed crown class (table 4). Most type C and E stems were also intermediate or suppressed, but a few grew fast enough to become codominant.

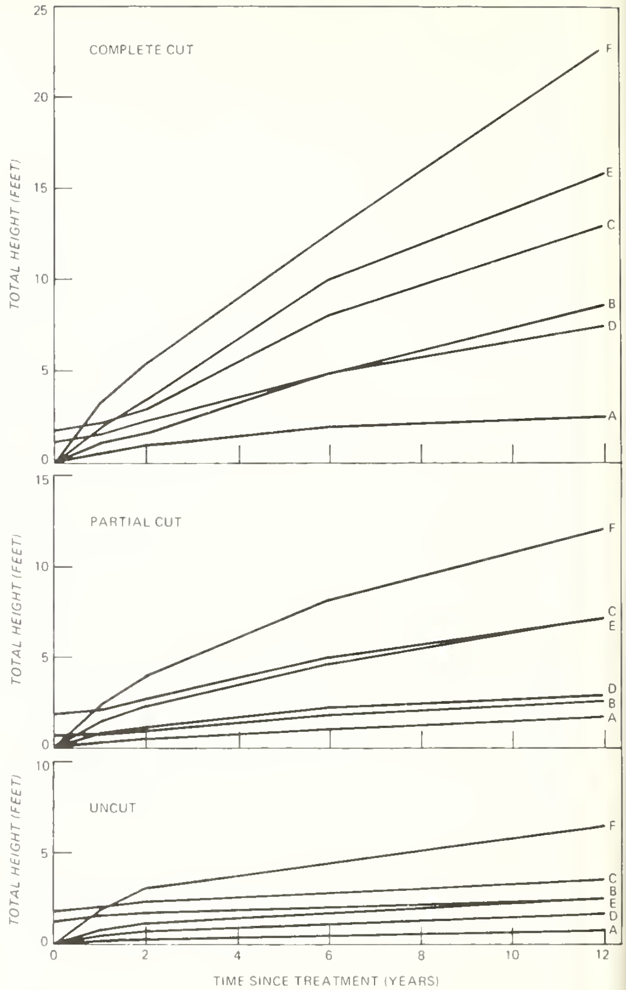

Figure 2. – Height of oak reproduction following different intensities of overstory treatment.

Type F stems were the only ones to grow fast enough so that most of them (63 percent) were either dominant or codominant at 12 years of age.

Partially Cut Plots

The relative height growth and position in the stand of the various reproduction types 12 years after partial cutting were much the same as after complete cutting (fig. 2). Reproduction type F stems grew fastest, followed by types C and E, which grew at about the same rate. Types A, B, and D grew slowest, and although their heights differed slightly after 12 years, their growth rates were similar (fig. 2). None of the reproduction

Table 4. – Distribution of oak reproduction types by crown or height class 12 years after overstory treatment

(In percent)

COMPLETE CUT

Crown or height class	Reproduction type A	B	C	D	E	F	All types
Dominant	0	0	0	0	0	23	6
Codominant	0	0	7	0	5	40	13
Intermediate	0	8	12	4	19	26	15
Suppressed	100	92	81	96	76	11	66[1]
PARTIAL CUT							
15+	0	0	3	0	2	14	4
10-15	0	0	0	0	7	41	10
6-10	0	4	24	0	19	28	15
<6	100	96	73	100	72	17	71
UNCUT							
10-15	0	0	0	0	0	19	3
6-10	0	0	0	0	4	19	4
4-6	0	5	12	3	13	14	9
<4	100	95	88	97	83	48	84

ypes on the partially cut plots grew at a uniform rate. Rather, all grew slower during each succeeding period.

The small reproduction types A, B, and D grew owly following the partial cut and are of doubtful alue for replacing the part of the stand that was removed. Twelve years after cutting, few stems of these types vere taller than 6 feet (table 4). Furthermore, as the verhead canopy and the large reproduction continue to xpand, many of the reproduction type A, B, and D ems will become more suppressed than they were at ge 12, and many may die.

Although a few Type C and E stems were among the allest reproduction, nearly three-fourths of them were ss than 6 feet tall at age 12 (table 4). Some have own fast enough to become part of the stand that is lling the openings created by cutting, but most have t. However, if they persist they should be large nough to grow well and comprise the principal oak mponent in the reproduction after future cuts.

The tallest reproduction on the partially cut plots nsisted mostly of Type F stems, which comprise the minant oak component in the reproduction that is lling the openings. These results suggest that the large dvance reproduction should be depended upon to egenerate partially cut stands.

Uncut Plots

All reproduction types grew slowly on the uncut plots. Type F grew fastest but averaged only 6.5 feet tall after 12 years. All other reproduction types averaged less than 4 feet tall, and grew only about 0.1 foot per year from age 2 to 12 years (fig. 2). Eighty percent or more of the stems of all reproduction types except type F were less than 4 feet tall, whereas about one-half of the type F stems were taller than 4 feet (table 4).

Reproduction will continue to grow slowly on the uncut plots. Much of it will probably die back, and mortality is likely to be high, especially in the smaller reproduction types. The larger types with well-established root systems are most likely to persist and be available to regenerate the area when a harvest cutting is made.

MANAGEMENT IMPLICATIONS

The results of this study suggest that careful consideration should be given to the size as well as the amount and distribution of oak advance reproduction when planning harvest cuttings to regenerate oak stands. Although some stems resulting from advance reproduction less than 4.5 feet tall grew satisfactorily, the bulk of the reproduction that made acceptable growth came from advance reproduction over 4.5 feet tall. Thus, an average height of at least 5 feet, preferably 6 to 8 feet, should be a useful guide for determining whether oak advance reproduction on a harvest area is likely to compete successfully and become dominant in the new stand.

If a planned harvest area contains enough of these large oak advance reproduction stems to satisfy reproduction objectives, the harvest cutting can be made immediately. Complete overstory removal will provide the conditions for most rapid growth of the new stand and should be used unless esthetics or multiple-use coordination dictate otherwise.

If oak advance reproduction is plentiful, but predominantly small, harvest cutting should be delayed. In such situations a period of 20 years or longer may be necessary to allow the advance reproduction to become large enough so that it will grow satisfactorily following a harvest cut. If overstory stands are heavily stocked, oak reproduction beneath them will grow slowly and may even die. Even overstories that are at the lowest limit of stocking that fully utilizes the site, such as on the uncut plots in this study, greatly suppress oak reproduction growth.

Some type of partial cut should be helpful in enhancing reproduction growth, and possibly shortening the development period. But just how partial cutting can be applied to best advantage is still not clear. Several light cuts that gradually open the overstory may work better than one or two heavy cuts. An important factor to consider is the density, composition, and size of the understory species other than oak. Any cutting designed to enhance oak advance reproduction growth would also benefit other species, possibly to the detriment of the oaks. So, some understory treatment in combination with cutting in the overstory may be necessary.

Hardwood reproduction following all types of harvest cutting has generally been adequate to form acceptable new stands, especially in the eastern and central parts of the upland oak range (Minckler and Jensen 1959, Trimble and Hart 1961, Sander and Clark 1971). However, the oak component has not always been as large as desired, and in some areas along the western edge of the oak range it has been inadequate (Arend and Scholz 1969). If both size and numbers of advance reproduction are considered when planning harvest cuts, better predictions of how many oaks are likely to compete successfully in new stands will be possible.

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☆U.S. Government Printing office: 1972 – 760-884

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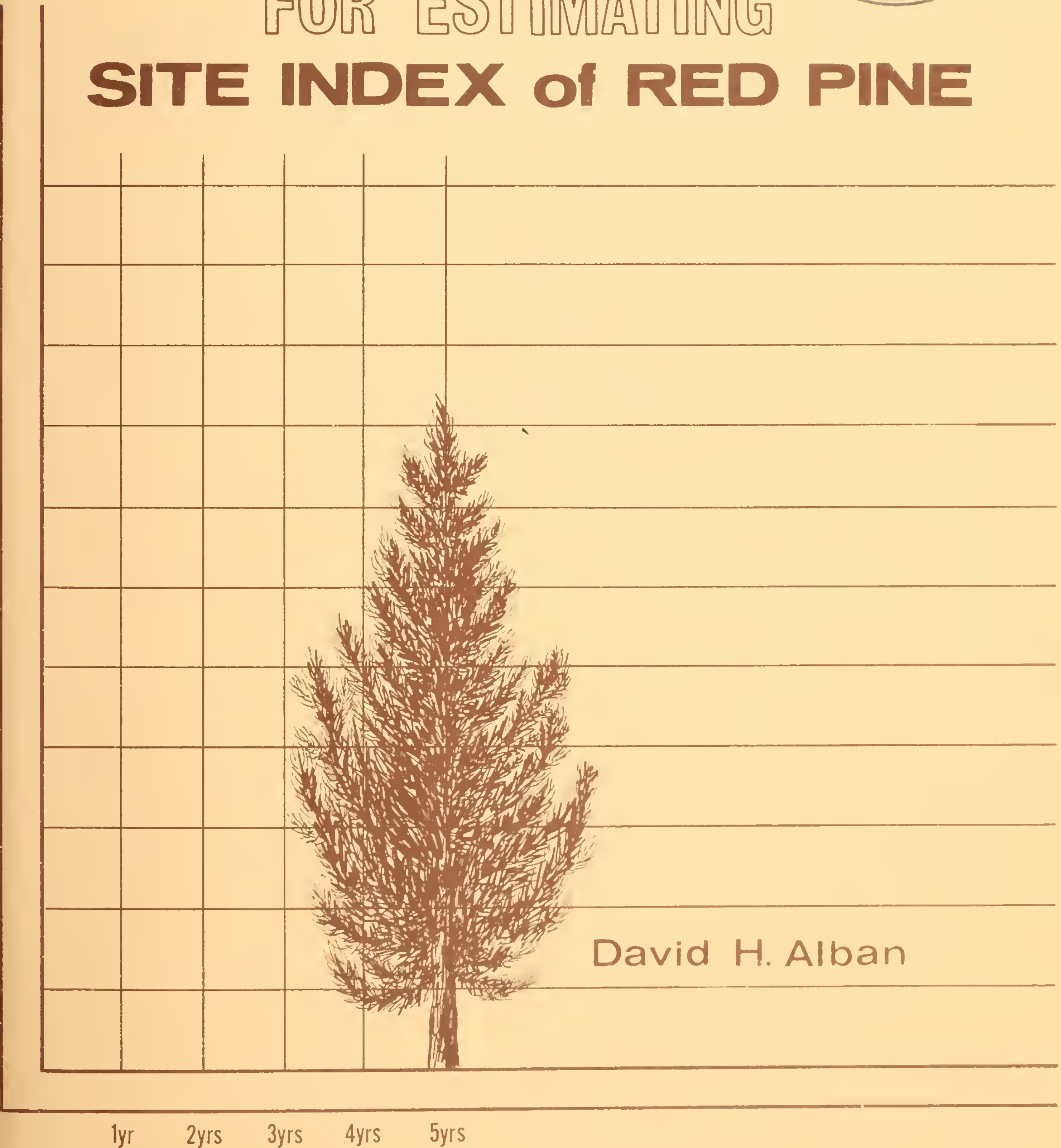
1972

AN IMPROVED GROWTH INTERCEPT METHOD FOR ESTIMATING SITE INDEX of RED PINE



David H. Alban

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FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

THE AUTHOR is a Soil Scientist at the Station's Northern Conifers Laboratory in Grand Rapids, Minnesota. The Laboratory is maintained in cooperation with the University of Minnesota.

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Manuscript approved for publication May 24, 1972

An Improved Growth Intercept Method For Estimating Site Index of Red Pine

David H. Alban

For tree species that have limbs showing distinct annual whorls the cumulative length of three to five internodes beginning at breast height has been suggested as a measure of site quality, particularly for young stands (Ferree *et al.* 1958, Wakely and Marrero 1958, Warrack and Fraser 1955).

The advantages of such a method are: (1) it can be used in stands too young to be evaluated with standard site index curves; (2) it eliminates the need to measure total tree age or height, either of which can be a major source of error; (3) it can be measured easily and rapidly; and (4) by measuring internode lengths above breast height (BH) many of the variabilities associated with the establishment period can be reduced or eliminated. Disadvantages of the method include the effects of short-term climatic fluctuations, and the fact that sometimes early growth of a stand does not accurately reflect later growth (Wilde 1964).

Growth intercept (GI) has most commonly been defined as the total length of the first five internodes above BH, and this 5-year growth intercept has usually been a reliable predictor of height growth for the next 5 to 20 years. However, because most studies have been conducted using juvenile stands no direct comparison has been possible between growth intercept and dominant tree height at the site index reference age. In several studies the measured 5-year growth intercept in young stands has been correlated with site index estimated from standard site index curves using total height and age. But this approach must be used with caution because height growth curves may vary in shape from one site condition to another (Bull 1931, Carmean 1956, Husch 1956, Spurr 1955).

In the study reported here, older stands (with two exceptions noted under Methods) were used and the growth intercept was related to the actual height attained by dominant trees at age 50 (Ht_{50}). Particular attention was paid to selecting suitable starting heights from which to measure the growth intercept. Plantations were also sampled and the application of the growth intercept information (obtained from natural stands) to plantations is evaluated and discussed.

METHODS

As part of a study of the relationship between soil properties and the growth of red pine (*Pinus resinosa* Ait.), 69 plots were established in natural stands throughout the commercial range of red pine in northern Minnesota. Most stands occurred on well-drained upland soils of sand to sandy loam texture, but a few were on soils with silt loam to loam surface texture. Red pine growing on organic soils or on rock outcrops were not included.

The stands were selected carefully to ensure that fire or other severe environmental disturbances had not injured either the trees or the site. No stand was used if major insect or animal damage was apparent, or if the dominant trees took longer than 12 years to reach BH. One stand was 47 and another was 49 years old, the rest ranged in age from 50 to 95 years. The basal areas were from 75 to 175 square feet per acre (of which at least 75 percent was red pine). On each plot three to seven dominant trees were felled, the position of each whorl on the stem recorded, and the stems were sectioned as follows: 1-foot sections from the 6-inch stump to 6.5 feet; 2-foot sections from 6.5 to 20.5 feet; and 3-foot sections from 20.5 feet to the top of the tree. Total age was estimated by adding 2 years to the ring count at the 6-inch stump. On each section the annual rings were counted and from this data a single average height growth curve was constructed for each plot. From this curve, total height at 50 and 25 years, and growth intercepts measured from numerous positions along the stem were determined.

Normally growth intercept is measured from actual internode lengths. In the present study growth intercept was estimated from the stem analysis data because the lower limbs were no longer visible in many of the older stands. Forty-nine of the plots used in this study had at least three sample trees with whorls extending lower than 8 feet from the ground. From these a comparison was made between the 5-year growth intercept determined from actual internode lengths above 8 feet and one estimated from the stem analysis data, which showed that the stem analysis method gave a good approximation of the growth intercept as measured from actual internode lengths. The average difference between the growth intercept measured by the two methods was only 0.27 feet.

RESULTS AND DISCUSSION

Natural Stands

The correlation between Ht_{50} and height growth during 5-year periods showed a rapid rise with increasing height above the ground (fig. 1). Thus a much better estimation of Ht_{50} will result from measuring a growth intercept starting at least several feet above BH.

Most studies in red pine plantations have found only a very weak relationship between the time required to reach BH and later tree growth (Day *et al.* 1960, Ferree *et al.* 1958, Husch 1956). The present study in natural red pine stands likewise showed a weak relationship between height at age 50 and the number of years to reach BH ($r = -0.29$). Seedling establishment and early growth are strongly affected by special factors such as seedling vigor, competition, animal and insect damage, etc., which have much less effect on later growth. Growth intercept, to be most reliable, must be measured above the height where the influence of these special factors becomes small, at about 8 feet in the present study.

The correlation coefficient between Ht_{50} and total height at age 25 (Ht_{25}) is 0.76. This is nearly the same value as obtained for the relationship between Ht_{50} and

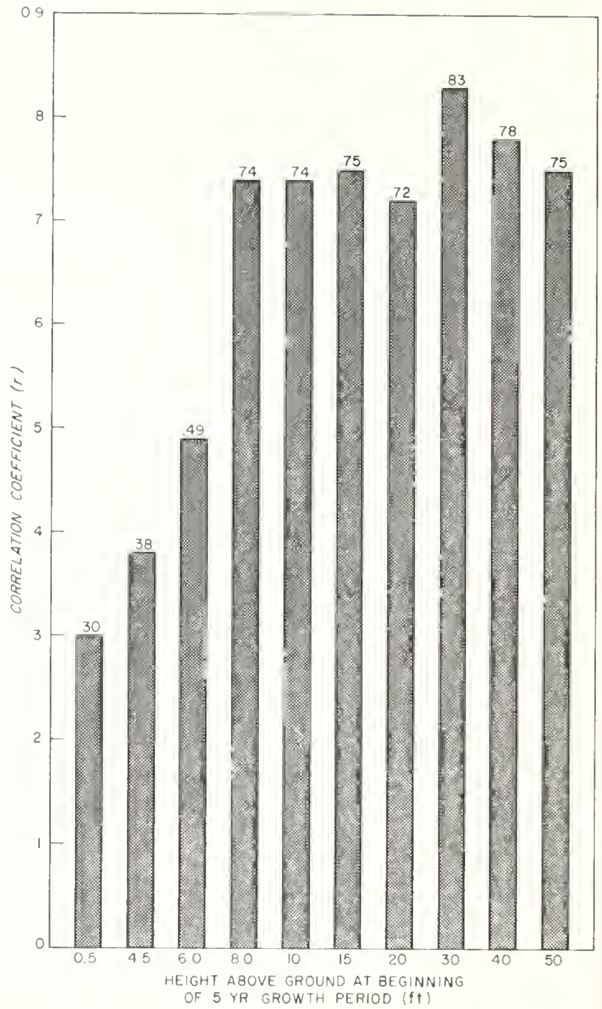

Figure 1. – Correlations between height at age 50 and 5-year growth intercepts.

5 years height growth beginning anywhere from 8 to 50 feet along the stem (fig. 1). Thus it is possible to predict Ht_{50} just as accurately using a carefully selected 5-year growth period as it is using the first 25 years height growth.

In order to decide on a suitable number of internodes to measure for growth intercept, the length of 3, 5, 10, and 15 internodes above 10 feet was correlated with Ht_{50}. The correlation coefficients were 0.56, 0.74, 0.81, and 0.86 respectively. Five internodes result in a reasonable compromise between ease of measurement and precision.

Measuring the 5-year growth intercept beginning 8, 10, or 15 feet above ground results in considerably better prediction of Ht_{50} than starting at 4.5 feet (BH) (table 1). In particular the number of plots estimated within 2.5 feet of the actual Ht_{50} is increased by about 50 percent, and the number of plots having an error greater than 7.5 feet is reduced to just a few percent. The fact that the equations derived for 5-year growth periods starting at 8, 10, or 15 feet are virtually identical means that any 5-year growth period beginning within these limits will result in nearly identical predictions of site index. Consequently, it is recommended that the growth intercept for red pine be measured as the five internodes starting from the first whorl above 8 feet. Site index can then be predicted by substitution of the 5-year growth intercept above 8 feet into the equation $Ht_{50} = 32.54 + 3.434\ GI_8$.

The substitution of growth intercept values from 3 to 12 into the above equation resulted in a range of values that covers nearly the entire spread of site index values for red pine in Minnesota.

Five-year growth intercept above 8 feet	*Predicted height at age 50*
Feet	*Feet*
3	42.8
4	46.3
5	49.7
6	53.1
7	56.6
8	60.0
9	63.4
10	66.9
11	70.3
12	73.7

During the course of this study several hundred red pine stands were examined and the highest site index for natural stands was about 70 feet. No stands except those with severe early suppression had site index values less than 42 feet.

The slope of the recommended equation (3.434) means that a 1-foot error in the estimation of stand growth intercept will contribute an error of 3.4 feet to the prediction of site index. In this study using three to seven trees per plot the maximum standard error of the mean for the measurement of growth intercept was 0.80 feet. This error corresponds to an error of about

Table 1. – Precision of predicting height at age 50 using 5-year growth intercept beginning at four different heights above ground[1] (cumulative percentage of plots within specified error limits).

Ht_{50} error limits (feet)	Height above ground from which 5-year growth intercept measured: 4.5 feet	8 feet	10 feet	15 feet
0 - 2.5	33	51	48	48
0 - 5.0	62	81	81	77
0 - 7.5	88	97	97	96
0 - 10.0	94	99	99	100
0 - 12.5	97	100	100	100
0 - 15.0	100	100	100	100

1/ The prediction equations and correlation coefficients are as follows:

4.5 feet	$Ht_{50} = 45.35 + 1.913\ GI_{BH}$	r = .38
8 feet	$Ht_{50} = 32.54 + 3.434\ GI_8$	r = .74
10 feet	$Ht_{50} = 33.54 + 3.264\ GI_{10}$	r = .74
15 feet	$Ht_{50} = 32.03 + 3.342\ GI_{15}$	r = .75

2.7 feet in the estimation of site index. By increasing the sample size the error could be reduced, but the number of trees which should be sampled in a given case will depend on both the variability within the stand and the precision desired.

An average of 8.3 years was required for the trees in this study to reach BH. In applying the recommended growth intercept equation to stands taking greater or fewer years to reach BH, a certain amount of error is introduced into the estimation of Ht_{50}. However, by working with stands taking 6.3 to 10.3 years to reach BH (which includes 91 percent of the stands in this study) the maximum error in estimating Ht_{50} will be about 2 feet.

A comparison was made of actual Ht_{50} with Ht_{50} estimated by three methods: (1) the equation $Ht_{50} = 32.54 + 3.434\ GI_8$ and the 5-year growth intercept above 8 feet, (2) the equation $Ht_{50} = 45.35 + 1.913\ GI_{BH}$ and the 5-year growth intercept above breast height, and (3) total height at age 25 in conjunction with Gevorkiantz' site index curves (Gevorkiantz 1957). Of the three methods, the GI_8 method of estimating Ht_{50} deviated least from the actual in all measurements but one (table 2). The negative average deviation of the site index curve method indicates that it does not predict as rapid a height growth from ages 25 to 50 as found in this study. This underestimation is about twice as large for plots with site index over 55 as for plots with site index under 55.

Table 2. — Comparison of three methods of estimating height at age 50

Method of estimating site index	Deviations of estimated from actual Ht_{50}: Average absolute difference	Deviations of estimated from actual Ht_{50}: Average difference	Percent of plots[1] in which the estimated Ht_{50} deviates from actual Ht_{50}: > 5 feet in error	Percent of plots[1] in which the estimated Ht_{50} deviates from actual Ht_{50}: > 10 feet in error
	Feet	Feet		
5 years growth above 8 ft. (GI_8)	± 2.9	0.0	19	1
5 years growth above BH (GI_{BH})	± 4.2	+ 0.1	38	6
Site index curve total height age 25	± 3.5	- 1.2	17	1

1/ Total number of plots was 69.

Application

For estimating red pine site index in our natural stands, the growth intercept method starting at 8 feet is clearly superior to growth intercept starting at breast height. Growth intercept above 8 feet is also somewhat better than measuring total height and age in stands 25 years or younger and estimating site index from the standard site index curves.

Best results in estimating Ht_{50} from GI_8 will be obtained in even-aged fully stocked red pine stands not affected by severe environmental disturbance (e.g., by fire or erosion). Only dominant trees without obvious insect, disease, or fire damage should be used, which are the same criteria to be applied when estimating site index by use of standard site index curves. It is also important that site index trees were not severely suppressed as seedlings. Trees requiring more than 11 years to reach BH are suspect and have probably been suppressed to some degree.

Using these criteria of stand and tree selection, Ht_{50} of red pine can be satisfactorily estimated by the following growth intercept method: the length of five internodes beginning at the first whorl above 8 feet is measured on individual trees, the number of which will depend on the variation between trees and the desired precision. Using only three to seven trees on a uniform one-tenth-acre plot resulted in an estimate of GI_8 with an average standard error of 0.45 feet. Measurement of more trees entails little additional work and it is anticipated that a minimum of 10 to 20 trees may be needed in most situations. However, in practice enough trees should be measured to reduce the error to an acceptable level. After GI_8 is estimated to a suitable level of precision, Ht_{50} is read from the above tabulation or by substitution in the equation: $Ht_{50} = 32.54 + 3.434\ GI_8$.

Using a 13-foot, two-piece, collapsible pole in young red pine stands, two workers can measure the 5-year growth intercept from either BH or 8 feet with nearly equal ease. Either can be measured at a rate of about 10 trees per 5 minutes. The average growth intercept of 10 trees measured with a pole will differ from taped measurements on the same 10 trees after felling by less than 0.1 foot.

Extension to Plantations

It is of considerable interest and importance to evaluate this method in plantations. Twenty 25- to 70-year-old plantations (average age 32 years) established primarily on abandoned agricultural land were sampled in the same manner as the natural stands.

Both plantations and natural stands were stratified into the "good sites" (those with $GI_8 \geq 8.5$ feet), and "poor sites" (with $GI_8 < 8.5$ feet). For both the good and poor sites the average height growth of plantations was slightly greater than for natural stands. Therefore, in order to facilitate comparison between height growth

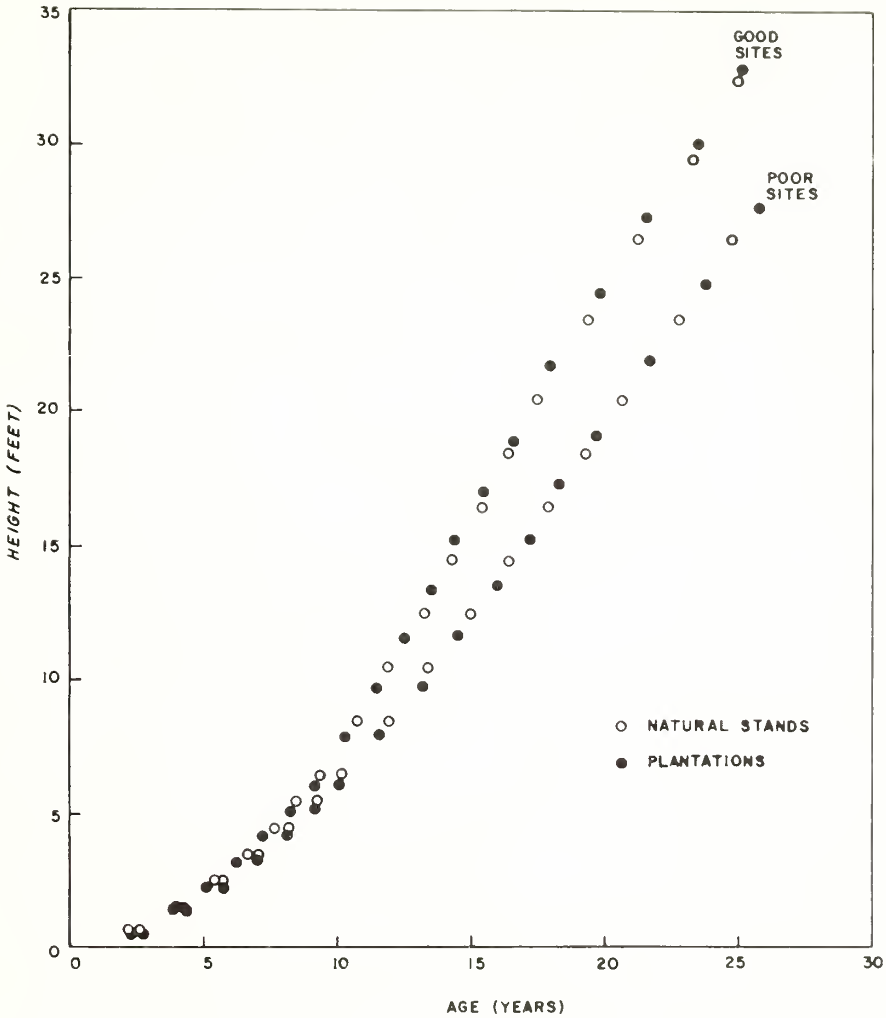

Figure 2. – Comparison of height growth patterns of plantations and natural red pine stands. (See text for details.)

tterns of natural stands and plantations, the planta-ns' height growth curves were adjusted downward to incide with those of the natural stands at age 25:

$$\text{djusted Plantation eight at age X} = \left(\begin{array}{l}\text{plantation height}\\ \text{at age X}\end{array}\right)\left(\frac{\text{natural stand } Ht_{25}}{\text{plantation } Ht_{25}}\right)$$

After this plantation adjustment it is clear that the eight growth patterns of natural stands and plantations e nearly identical (fig. 2). Most natural stands were obably established after fire and the trees were free of verhead competition, as were trees in the plantations. Therefore dominant trees in natural stands and plantations required about the same number of years to reach BH (8.3 and 7.7 respectively).

Very few red pine plantations in Minnesota are older than 35 years, hence few direct measurements of Ht_{50} are possible. Consequently two measures of site quality were tested: (1) total height at age 25 and (2) total height growth for 20 years after attainment of BH (Ferree *et al.* 1958). These two measures of site quality were closely related to each other (r = 0.90 for natural stands and 0.97 for plantations), and each was closely related to GI_8. In the present study Ht_{25} was used as a measure of site quality for plantations. As with natural stands

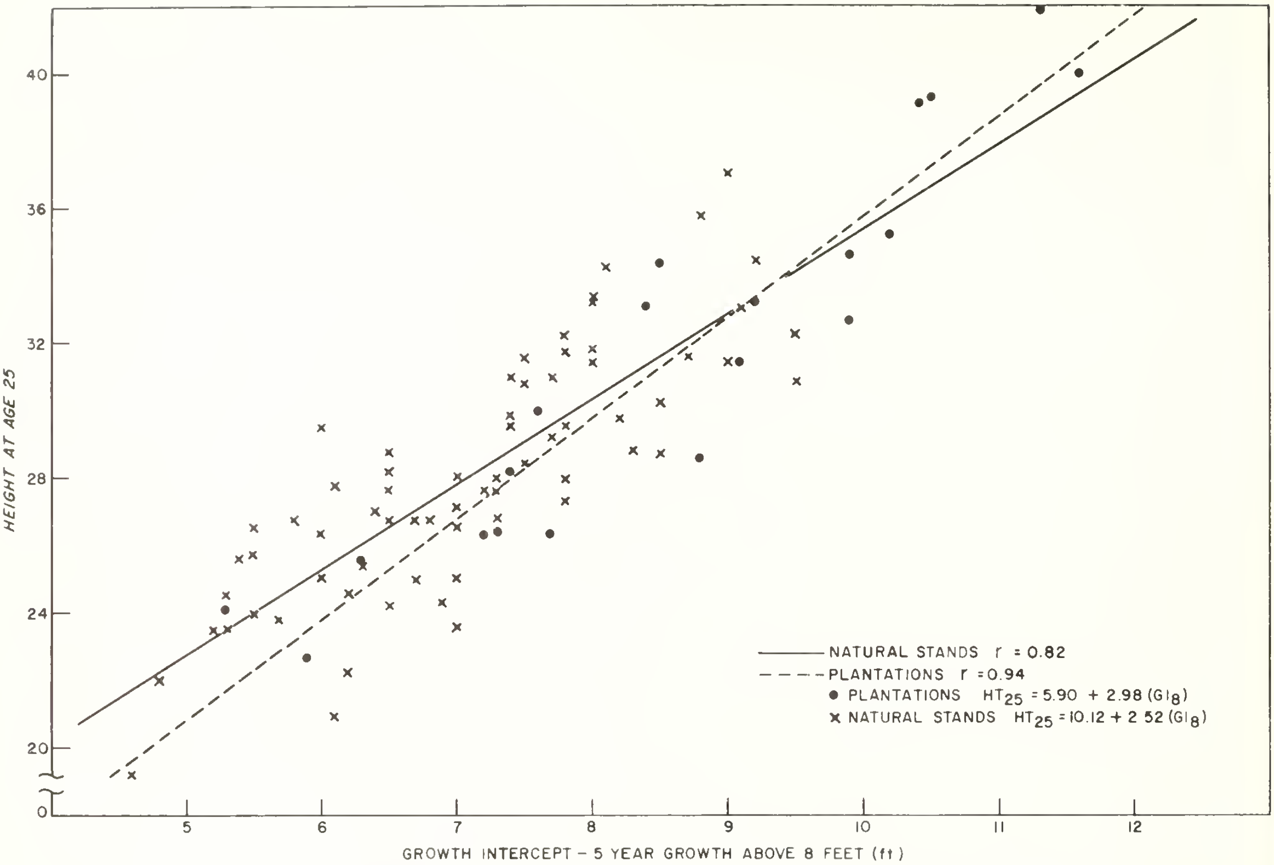

Figure 3. – Relationship between height at age 25 and 5-year growth intercept measured above 8 feet.

site quality was estimated more closely by using 5-years growth above 8 feet rather than above BH ($r = 0.94$ for GI_8, and 0.78 for GI_{BH}).

The relationship between GI_8 and the total height at age 25 for both plantation and natural stands shows that the plantations fit in with the general relationship quite well, although they were established on better sites than most of the natural stands (fig. 3). The equations for predicting Ht_{25} for plantations, and for natural stands are not significantly different at the 5 percent level in either slope or intercept. Within the limits of the GI_8 values commonly found in this study (5 to 11.5 feet) these two equations result in a maximum difference in estimated Ht_{25} of less than 2 feet. Hence the growth intercept equation developed for natural stands is also applicable to plantations in Minnesota.

A further check of the applicability of the equation was made utilizing red pine plantation height growth curves from Connecticut (Bull 1931) and New York (Richards *et al.* 1962). Three height growth curves corresponding to the best, poorest, and average sites were constructed from Bull's data. Three of Richards' height growth curves corresponding to site index values of approximately 46, 58, and 70 feet at 50 years were used. In each case the growth intercept (GI_8) and the Ht_{25} were read from the height growth curves. The Ht_{25} as read from the curves was then compared with and found to be slightly less than Ht_{25} estimated from the growth intercept and the equation developed for natural stands in Minnesota [$Ht_{25} = 10.12 + 2.52 (GI_8)$] (table 3).

These small differences are a reflection of the fact that the height growth patterns of red pine are quite similar over a wide geographic range (Spurr 1955). In spite of the similarity of red pine height growth curves

Table 3. — Application of recommended growth intercept method to plantation data from Connecticut and New York

Source of data	5 year growth intercept above 8 ft. Col. A	Ht_{25} estimated from growth intercept (Ht_{25} = 10.12+ 2.52 (GI_8)) Col. B	Ht_{25} from Bull's or Richards' height growth curves Col. C	Difference Col. B-Col. C
	Feet	Feet	Feet	Feet
Bull (1931):				
Best sites	12.3	41.1	39.5	+ 1.6
Average sites	9.4	33.8	32.3	+ 1.5
Poorest sites	6.2	25.7	22.7	+ 3.0
Richards et al. (1962):				
Best sites (Ht_{50} ca. 70 feet)	10.8	37.3	36.9	+ .4
Average sites (Ht_{50} ca. 58 feet)	7.9	29.9	29.0	+ .9
Poorest sites (Ht_{50} ca. 46 feet)	4.5	21.4	20.4	+ 1.0

over a wide geographic range, individual stands may deviate considerably from the standard curves. In particular the time required to reach BH may be variable. For natural stands or plantations which have taken 8 ± 2 years to reach BH the equation reported in this paper will enable the prediction of Ht_{25} within reasonable limits. For stands falling outside of this range sizeable errors in the estimation of Ht_{25} may result. In Minnesota no stands were found in which red pine reached BH in less than 6 years. And most stands requiring more than 10 to 11 years to reach BH have probably experienced severe early suppression and so are not suitable for estimation of site index.

The evidence presented in table 3 and figure 3 strongly suggests that the recommended growth intercept method (GI_8) can be used to predict Ht_{25} in plantations as well as natural stands over a wide geographical range. Certainly if there are errors involved in extending the results to plantations they are not great. If plantations follow different growth patterns than natural stands the differences should be most pronounced at young ages and there is no reason to believe that plantations and natural stands on similar sites grow differently after 25 years. It follows, therefore, that the recommended growth intercept method which can be used to predict Ht_{25} in plantations and natural stands, and Ht_{50} in natural stands, can also be used to predict Ht_{50} in plantations.

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PROJECTING THE ASPEN RESOURCE IN THE LAKE STATES

WILLIAM A. LEUSCHNER

ORTH CENTRAL FOREST EXPERIMENT STATION • FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE

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ACKNOWLEDGMENTS

The help and advice of colleagues in private industry, the North Central Forest Experiment Station, and the Eastern Region, USDA Forest Service, are gratefully acknowledged. The members of the Station's Forest Survey project deserve particular credit for their assistance in discussing and compiling the data for this report. Special thanks are due Jerold T. Hahn for updating the survey data to a common base year.

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Manuscript approved for publication June 26, 1972.

PROJECTING THE ASPEN RESOURCE IN THE LAKE STATES

William A. Leuschner

Aspens (*Populus tremuloides* and *P. grandidenta-a*) are dominant forest species in the Lake States of Michigan, Minnesota, and Wisconsin. Often looked own upon in the past as little more than a weed, spen now makes up more than 45 percent of the nnual production of pulpwood in the Lake States. Aspen pulpwood harvest increased from 3,000 cords n 1920 (Zasada 1947) to nearly 2 million cords in 970. And a goodly amount is cut each year for other ses.

Aspen is also important in deer and grouse man-gement. Young aspen and its associated species pro-ide browse and forage for deer. The young sucker tands serve as protective cover against predators or the young and drumming male grouse and the uds of mature male aspen are food for the older irds.

Aspen has several biological characteristics that end to enhance its appeal and usefulness. First, it s short lived and fast growing so it can be grown in hort rotations.

Second, aspen will reproduce itself well by sucker-ng if the old stand is thoroughly clearcut. This means vell stocked stands can be established by fairly simple nanagement practices and at a low initial investment.

Finally, the necessity for even-aged management nd the moderate size of the trees at the end of the otation facilitate mechanized harvesting.

These and other characteristics have stimulated esearch on short-rotation aspen management (Ein-spahr and Benson 1968). If this research bears fruit, we could see aspen playing an even more important ole in the Lake States forest economy.

The future physical supply of aspen will, of course, nfluence long-term plans for industrial expansion and forest management. In the past, making such projections has been time consuming and expensive because inventory data were gathered State by State, whereas many management decisions, particularly in the industrial sector, required consideration of an entire region. In addition, each State's data were gathered in a different year making an overall comparison of the resource at one point in time even more difficult.

The first objective of this report is to provide a common base of inventory data for aspen in the Lake States. This is done by describing the current status of the growing stock in a base year for all survey units in the region (fig. 1).

The second objective is to give managers and landowners a better idea of what the future will hold by projecting levels of aspen growing stock and cut under several sets of likely conditions. These projections are not intended to predict the exact inventory or cut on a specific future date nor are they intended to cover all possible management alternatives or technological changes. Rather, they seek to define the range of the future physical supply of aspen if certain general policies are followed today. The projections provide an overview of the resource on a regional basis, by survey unit, and should help answer broader questions rather than provide answers for specific forests or sections of land.

The data used in this study are from the forest surveys of Michigan, Minnesota, and Wisconsin made in 1966, 1962, and 1968, respectively. These data were updated to the common base year 1968 using a standard Forest Service technique called TRAS (Larson and Goforth 1970). Thus no new fieldwork was performed for this study. Technical terms, including definitions of cover types, conform with those used by Forest Survey.

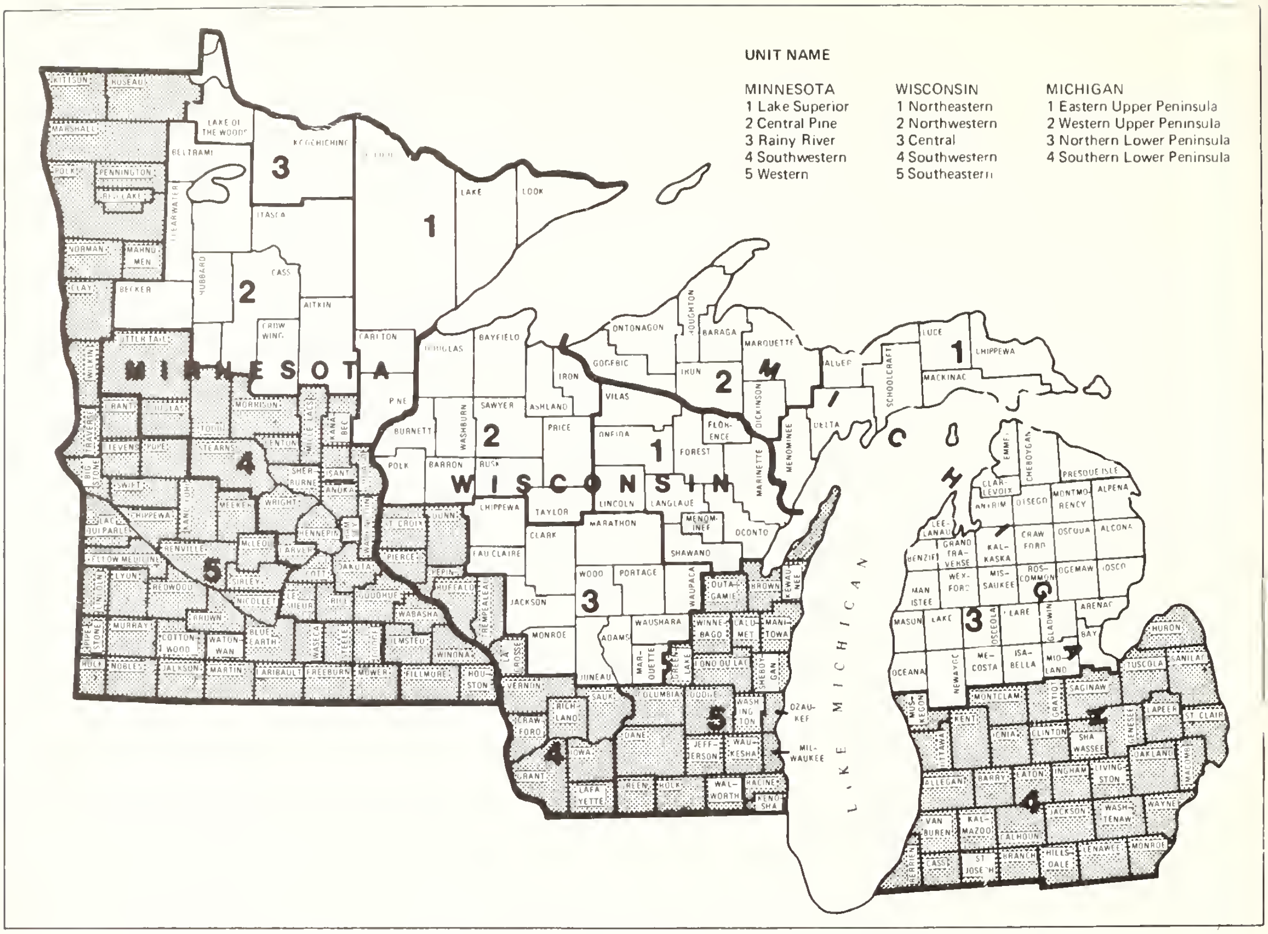

Figure 1.—Forest survey units in the Lake States. Unshaded units are study area.

CURRENT STATUS OF THE RESOURCE

There were an estimated 7.5 billion cubic feet of aspen growing stock in the region in 1968. Most of the aspen volume is in Minnesota, northwestern Wisconsin, and the northern part of Michigan's Lower Peninsula. Most of the volume is in the aspen type and in the smaller diameter classes, regardless of type. Wisconsin, followed by north-central Minnesota and Michigan's northern Lower Peninsula have the better aspen sites.

Further details may be obtained from tables 1-5 which are subdivided by survey unit.[1] Tables 1-4 contain aspen growing stock volumes for aspen in *all cover types* updated to 1968. Tables 1 and 2 show volumes by d.b.h. class and cover type and d.b.h. class and ownership class; tables 3 and 4 contain volume by density (volume of aspen growing stock per acre) and cover type and density and ownership class. Table 5 contains growing stock volumes for the *aspen cover type only* by site index and age classes in the year the survey was made.

THE MODEL AND FUTURE CONDITIONS

It should be understood that these are projections and not predictions. Although they give an exact amount of inventory or cut at a precise point in time, they really indicate only the general level and approximate timing, within the bounds of the assumptions.

[1] *Time and financing restrictions made calculation of the current status and projections on a county basis impossible.*

Different inventory and timing are projected depending on the assumptions used. So anyone using the projections must understand the assumptions.

Sharp changes of direction occurred in the model that would not occur in real life. The model may show an abrupt drop in cut in 1 year whereas in real life cut would drop more slowly and be accompanied by such signs as increased difficulty in finding stumpage and higher prices. The projections, then, must not be interpreted literally. The results are presented as 5-year moving averages to smooth these fluctuations and to remind the user they are not precise predictions.

Although the projections give the resource's response to likely sets of condtions, many of these conditions are under the control of the land manager. He may react to these projections, change the conditions under his control, and thereby cause different results. Indeed, this is desirable and one test of the usefulness of projections.

Finally the projections do not give a final answer. They should be revised every few years to allow for changes in the underlying structure. They should also be revised when new and better data become available or if a major change in technology, such as short rotation management, becomes widely adopted.

Considering all these qualifications, one may well question the value of the projections. They *are* useful, however, because they define the general situation that will prevail in the future and allow us to assess the options we will have. They facilitate judging whether or how an organization can continue to operate. And if a course of action is recommended to modify the inventory, the projections can be used to indicate the effectiveness of that course of action. Indeed, the results of some possible management practices are projected and their results presented.

The specification of assumptions allows others to judge if all relevant variables have been considered and properly evaluated. Any corrections required can be incorporated and better projections made. Also, although projections must be revised as we progress into the future, the fact that we stop things at one point in time allows us to see ahead more clearly, particularly in the near years. This is analogous to stopping a speeding car to look down the road. You can see the closer terrain in more detail and more clearly than when the car was moving and you can take the time to study more closely that farther down the road. However, you must drive farther down the road and stop again before you can see the distant terrain more clearly.

The Projection Model

The theoretical basis for the projection model is presented in detail elsewhere (Leuschner 1972). Essentially, the model takes the growing stock inventory at the beginning of the year, subtracts cut, adds or subtracts growing stock to account for changes in commercial forest acreage, and adds growth on the cut, on acreage change, and on residual volume. The result is the growing sotck volume at the beginning of the next year. This process is repeated for each succeeding year.

This basic framework is simple. The determination of the variable values and the way they are handled in the actual calculations are what gives the model its uniqueness and validity. These are discussed at greater length in the appendix. The reader who plans to use these projections for major decisions or in-depth work is urged to review them thoroughly.

The program can analyze any number of survey units at one time. In any particular year the program first calculates the new commercial forest acreage for each cover type in each survey unit (fig. 2). The first survey unit then has its cut projected for each 2-inch d.b.h. class and this in turn is allocated by forest type. The total cut is our best estimate of what forest industry will actually buy adjusted for the amount of aspen available. Cut is distributed to survey units and d.b.h. classes according to historical trends.

After cut is allocated, the growing stock volume at the beginning of the next year is calculated for each type and d.b.h. class by means of a growth percent based on historical trends of net annual growth. Thus, mortality is included. Then the cut is checked to see if the resource can support it under the availability assumption. If it can, the program moves on to the next survey unit; if it cannot, the amount of cut that can't be supported is allocated to the remaining survey units.

Table. 1—Aspen growing stock volume, all cover types, by survey unit, d.b.h., and cover type, 1968
(Million cubic feet)

D.b.h. class (inches)	Red, white, and jack pine	Balsam fir–white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Nonstocked and other	Total
REGIONAL TOTAL									
6	55.7	88.7	20.1	119.2	61.2	1,862.1	52.1	0.4	2,259.5
8	44.8	74.6	18.7	169.3	78.1	1,889.5	51.2	.3	2,326.5
10	33.4	48.3	20.3	181.2	63.5	1,217.2	51.6	--	1,615.5
12	13.7	33.6	11.3	132.8	33.2	515.9	25.4	.2	766.1
14	11.5	15.5	19.2	81.6	12.9	215.9	7.9	--	364.5
16	1.8	7.5	4.1	27.7	2.7	76.9	4.1	--	124.8
18	.4	1.2	4.6	8.8	1.5	11.4	.6	--	28.5
20	.2	1.9	--	2.6	.2	8.7	--	--	13.6
22+	--	--	--	1.8	--	2.6	--	--	4.4
Total	161.5	271.3	98.3	725.0	253.3	5,800.2	192.9	.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
6	5.5	12.1	3.8	8.7	--	59.3	1.6	--	91.0
8	1.0	16.4	3.3	13.6	0.5	72.0	.5	--	107.3
10	3.0	2.8	2.3	11.1	--	39.6	2.7	--	61.5
12	.8	6.0	2.0	7.9	--	20.1	.4	--	37.2
14	--	.6	3.2	6.0	--	12.3	--	--	22.1
16	--	.5	.6	2.7	--	4.2	.6	--	8.6
18	--	--	1.2	1.8	--	--	--	--	3.0
20	--	--	--	1.2	--	.4	--	--	1.6
22+	--	--	--	--	--	--	--	--	--
Total	10.3	38.4	16.4	53.0	.5	207.9	5.8	--	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
6	2.7	15.0	2.1	22.2	3.1	107.4	4.6	--	157.1
8	3.5	17.0	1.2	36.4	3.2	123.3	2.0	--	186.6
10	3.5	11.1	--	35.5	.6	86.1	5.4	--	142.2
12	2.5	13.5	.7	22.2	.6	34.6	3.9	--	78.0
14	.6	6.0	2.7	13.9	.7	26.0	1.1	--	51.0
16	--	1.6	1.0	4.8	--	8.1	--	--	15.5
18	--	.5	--	1.2	--	2.0	--	--	3.7
20	--	--	--	--	--	1.2	--	--	1.2
22+	--	--	--	.7	--	.7	--	--	1.4
Total	12.8	64.7	7.7	136.9	8.2	389.4	17.0	--	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
6	5.9	11.4	2.6	23.4	25.1	193.5	7.6	--	269.5
8	3.3	6.7	5.4	34.7	26.6	253.2	10.5	--	340.4
10	2.7	4.5	3.8	31.3	24.9	183.0	4.8	--	255.0
12	2.2	3.9	3.7	32.0	9.6	91.9	2.1	--	145.4
14	.3	1.7	3.4	14.7	3.8	42.9	.9	--	67.7
16	.6	1.6	2.5	5.5	.4	12.4	.7	--	23.7
18	--	--	--	1.2	--	3.5	--	--	4.7
20	--	--	--	.4	--	3.1	--	--	3.5
22+	--	--	--	.4	--	1.5	--	--	1.9
Total	15.0	29.8	21.4	143.6	90.4	785.0	26.6	--	1,111.8
MINNESOTA - LAKE SUPERIOR									
6	9.5	14.0	0.4	6.9	--	483.6	19.4	--	533.8
8	12.8	13.3	1.3	8.9	1.6	375.1	12.1	--	425.1
10	2.0	5.2	2.8	6.1	--	237.9	12.8	--	266.8
12	.9	2.3	2.2	2.3	.1	123.6	4.4	--	135.8
14	5.1	.7	--	1.0	--	41.3	.7	--	48.8
16	--	2.3	--	--	--	20.1	.7	--	23.1
18	--	--	--	--	--	2.1	--	--	2.1
20	--	--	--	.4	--	--	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	30.3	37.8	6.7	25.6	1.7	1,283.7	50.1	--	1,435.9

(Continued on next page)

After all survey units are completed, the process is repeated for as many years as the analyst cares to project.

Future Resource Conditions

Because the future is always uncertain, there are many possible directions the resource can take and consequently many sets of assumptions. To avoid confusing the results with too many answers, projections were limited to three sets of conditions that were judged generally indicative of what could happen to the resource. The sets of conditions, or assumptions, were called *recent trends*, *breakup*, and *positive practices* and were used to project cut and growing stock in each survey unit.

D.b.h. class (inches)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Nonstocked and other	Total
MINNESOTA - CENTRAL PINE									
6	18.6	9.0	0.8	9.9	6.5	473.5	7.4	--	525.7
8	10.9	3.5	.9	7.9	11.0	502.1	9.4	--	545.7
10	7.3	3.5	7.8	11.6	9.2	281.8	11.0	--	332.2
12	1.4	.3	--	8.7	2.1	91.5	3.4	--	107.4
14	1.7	.5	9.2	15.8	.5	39.5	1.4	--	68.6
16	--	--	--	.7	.2	10.4	1.2	--	12.5
18	--	.2	3.4	.4	--	1.4	--	--	5.4
20	--	1.0	--	--	--	.3	--	--	1.3
22+	--	--	--	--	--	--	--	--	--
Total	39.9	18.0	22.1	55.0	29.5	1,400.5	33.8	--	1,598.8
MINNESOTA - RAINY RIVER									
6	2.1	14.3	5.9	4.7	0.1	138.5	0.3	--	165.9
8	.8	4.9	2.0	2.1	.1	100.1	.7	--	110.7
10	--	6.9	1.1	10.4	.1	75.0	.6	--	94.1
12	--	1.1	.4	9.2	--	11.0	.4	--	22.1
14	--	2.6	.3	4.0	--	6.8	.2	--	13.9
16	--	--	--	.7	--	8.1	.2	--	9.0
18	--	.3	--	--	.1	--	--	--	.4
20	--	.9	--	--	--	2.5	--	--	3.4
22+	--	--	--	--	--	--	--	--	--
Total	2.9	31.0	9.7	31.1	.4	342.0	2.4	--	419.5
WISCONSIN - NORTHEASTERN									
6	4.1	7.5	3.3	16.8	4.2	131.4	4.8	--	172.1
8	5.3	7.5	2.8	26.6	6.7	165.7	6.9	--	221.5
10	7.1	7.4	1.5	29.1	3.7	111.7	5.4	--	165.9
12	3.1	3.2	.8	16.1	2.9	47.6	4.1	--	77.8
14	2.4	1.4	.4	6.5	2.1	15.9	2.2	--	30.9
16	.5	.4	--	4.2	.5	4.2	.3	--	10.1
18	.2	--	--	2.1	.4	1.5	.4	--	4.6
20	--	--	--	.3	--	.7	--	--	1.0
22+	--	--	--	.6	--	.4	--	--	1.0
Total	22.7	27.4	8.8	102.3	20.5	479.1	24.1	--	684.9
WISCONSIN - NORTHWESTERN									
6	5.0	5.3	0.8	19.0	8.8	190.3	5.9	--	235.1
8	5.6	4.9	1.1	32.6	15.1	230.2	7.9	0.3	297.7
10	7.7	6.5	.9	35.3	15.3	164.5	8.0	--	238.2
12	2.2	3.4	.6	30.1	10.7	79.3	5.9	.2	132.4
14	1.2	2.1	--	16.5	3.2	28.0	1.2	--	52.2
16	.7	1.1	--	8.3	.8	7.8	.5	--	19.2
18	.2	.2	--	2.1	.4	.5	.2	--	3.6
20	.2	--	--	.4	--	.3	--	--	.9
22+	--	--	--	.2	--	--	--	--	.2
Total	22.8	23.5	3.4	144.5	54.3	700.9	29.6	.5	979.5
WISCONSIN - CENTRAL									
6	2.3	0.1	0.4	7.5	13.3	84.7	0.7	0.3	109.3
8	1.7	.3	.6	6.6	13.3	67.8	1.1	--	91.4
10	.2	.3	.3	10.9	9.6	37.6	.7	--	59.6
12	.5	--	.9	4.3	7.2	16.3	.8	--	30.0
14	.2	--	--	3.0	2.8	3.0	.1	--	9.1
16	--	--	--	.7	.7	1.7	--	--	3.1
18	--	--	--	--	.7	.4	--	--	1.1
20	--	--	--	--	.2	.2	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	4.9	.7	2.2	33.0	47.8	211.7	3.4	.3	304.0

Recent Trends

The assumptions for these conditions are derived from the difference between the last two forest surveys for a particular survey unit and, for variables that are not included in forest survey data, from the recent historical trends. The *recent trends* projections show what the cut and growing stock would be if the trends that prevailed in the last decade or so continued into

Table 2.—Aspen growing stock volume, all cover types, by survey unit, d.b.h., and ownership class, 1968
(Million cubic feet)

D.b.h. class (inches)	National Forest	Indian	Other federal	State	County & municipal	Forest industry 2/	Farmer	Misc. private	Total
REGIONAL TOTAL									
6	351.1	54.0	19.1	256.2	490.1	143.5	206.3	739.2	2,259.5
8	338.7	68.0	19.2	205.0	429.9	176.7	271.3	817.7	2,326.5
10	191.5	39.9	13.9	167.4	281.6	146.3	213.4	561.5	1,615.5
12	91.2	19.3	2.5	62.1	106.2	88.2	141.4	255.2	766.1
14	44.5	5.0	.9	38.3	56.4	41.8	56.0	121.6	364.5
16	15.6	1.6	.7	10.0	13.8	15.9	27.0	40.2	124.8
18	4.4	--	--	3.0	3.7	3.7	4.7	9.1	28.5
20	2.5	--	.1	.4	1.2	3.2	1.1	5.0	13.6
22+	.7	--	--	.1	--	.7	.5	2.4	4.4
Total	1,040.2	187.8	56.4	742.5	1,382.9	620.0	921.7	2,551.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
6	18.0	--	2.9	3.9	--	25.6	9.7	30.9	91.0
8	13.0	--	.8	9.5	--	28.4	15.8	39.8	107.3
10	9.6	--	2.3	5.9	0.3	12.2	9.4	21.8	61.5
12	7.4	--	--	2.9	--	5.1	8.7	13.1	37.2
14	4.0	--	--	3.5	--	5.1	1.5	8.0	22.1
16	.6	--	--	.6	--	1.6	3.0	2.8	8.6
18	1.1	--	--	.8	--	--	.1	1.0	3.0
20	.7	--	--	--	--	--	--	.9	1.6
22+	--	--	--	--	--	--	--	--	--
Total	54.2	--	6.0	27.1	.3	78.0	48.4	118.3	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
6	25.7	--	--	20.6	5.0	27.2	17.4	61.2	157.1
8	30.5	--	0.4	22.2	4.6	34.8	23.4	70.7	186.6
10	23.4	--	.9	18.4	3.7	31.7	11.9	52.2	142.2
12	12.8	--	--	9.7	1.9	25.4	6.1	22.1	78.0
14	8.4	--	--	6.6	.4	13.1	4.1	18.4	51.0
16	2.6	--	--	1.9	--	5.3	.8	4.9	15.5
18	.6	--	--	.5	--	1.7	--	.9	3.7
20	.2	--	--	.1	--	--	--	.9	1.2
22+	.3	--	--	.1	--	.5	--	.5	1.4
Total	104.5 1/	--	1.3	80.1 1/	15.6	139.7	63.7	231.8	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
6	6.4	--	1.1	9.1	3.9	3.9	37.6	207.5	269.5
8	15.5	--	1.6	7.7	4.7	3.2	45.5	262.2	340.4
10	9.8	--	--	10.1	3.7	2.7	30.8	197.9	255.0
12	6.2	--	.4	8.5	1.7	2.0	26.6	100.0	145.4
14	1.8	--	--	2.8	1.1	.7	17.0	44.3	67.7
16	.7	--	--	--	.4	--	6.9	15.7	23.7
18	.3	--	--	--	--	--	1.1	3.3	4.7
20	1.2	--	--	--	--	--	--	2.3	3.5
22+	--	--	--	--	--	--	--	1.9	1.9
Total	41.9	--	3.1	38.2	15.5	12.5	165.5	835.1	1,111.8
MINNESOTA - LAKE SUPERIOR									
6	162.4	26.7	--	64.7	121.7	9.8	18.5	130.0	533.8
8	135.7	12.7	--	47.3	88.8	20.7	25.2	94.7	425.1
10	84.6	.7	--	32.2	61.4	22.3	15.5	50.1	266.8
12	42.0	.6	--	13.9	28.3	23.9	4.7	22.4	135.8
14	15.8	--	--	4.9	9.2	6.9	1.6	10.4	48.8
16	8.5	--	--	2.1	3.9	.9	2.5	5.2	23.1
18	.2	--	--	.7	1.2	--	--	--	2.1
20	--	--	--	.1	.3	--	--	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	449.2	40.7	--	165.9	314.8	84.5	68.0	312.8	1,435.9

(Continued on next page)

the future. These projections can serve as a standard for comparison and may indicate whether or not we should change our current practices.

The specific assumptions are discussed in detail in the appendix. The major ones will be discussed in general here under three categories: growth, cut, and acreage.

It is assumed that the growth variables remain constant throughout the projection period: specifically, the growth percent calculated by d.b.h. class and survey unit remains constant, the ingrowth into the 6-inch d.b.h. class (the first d.b.h. class in the computer program) by survey unit remains constant, and the outgrowth from one d.b.h. class into the next d.b.h. class remains constant.

D.b.h. class (inches)	National Forest	Indian	Other federal	State	County & municipal	Forest industry 2/	Farmer	Misc. private	Total
				MINNESOTA - CENTRAL PINE					
6	89.4	10.3	4.3	83.5	161.7	25.5	36.6	114.4	525.7
8	90.6	35.7	9.2	57.9	156.4	24.5	43.8	127.6	545.7
10	16.4	17.2	5.7	50.7	95.8	13.8	54.1	78.5	332.2
12	1.7	5.5	1.0	10.8	18.6	4.5	47.9	17.4	107.4
14	6.5	--	--	12.1	25.7	1.4	12.9	10.0	68.6
16	.1	--	.5	.9	.9	.2	6.0	3.9	12.5
18	2.2	--	--	.5	1.1	--	1.3	.3	5.4
20	.5	--	--	.1	.3	--	--	.4	1.3
22+	--	--	--	--	--	--	--	--	--
Total	207.4	68.7	20.7	216.5	460.5	69.9	202.6	352.5	1,598.8
				MINNESOTA - RAINY RIVER					
6	0.2	4.9	6.4	55.0	56.0	11.6	1.7	30.1	165.9
8	.2	2.3	4.4	35.2	30.6	17.4	2.4	18.2	110.7
10	.1	2.7	3.6	31.7	19.9	23.3	5.2	7.6	94.1
12	--	.4	.9	5.6	3.9	6.8	1.6	2.9	22.1
14	--	--	.5	4.6	.8	4.9	.5	2.6	13.9
16	--	--	.2	2.9	.5	4.7	--	.7	9.0
18	--	--	--	.1	.1	.2	--	--	.4
20	--	--	.1	.1	.1	3.1	--	--	3.4
22+	--	--	--	--	--	--	--	--	--
Total	.5	10.3	16.1	135.2	111.9	72.0	11.4	62.1	419.5
				WISCONSIN - NORTHEASTERN					
6	17.5	0.7	0.5	6.8	42.0	22.2	10.9	71.5	172.1
8	28.2	3.3	.5	9.9	44.8	23.2	18.5	93.1	221.5
10	31.4	2.9	.2	8.6	22.1	23.5	12.7	64.5	165.9
12	11.3	2.8	--	6.2	10.1	11.3	5.0	31.1	77.8
14	5.1	.6	.4	2.5	4.2	5.7	2.6	9.8	30.9
16	.7	.1	--	.5	1.7	1.8	1.7	3.6	10.1
18	--	--	--	--	.2	1.2	1.0	2.2	4.6
20	--	--	--	--	.1	.2	.5	.2	1.0
22+	.5	--	--	--	--	--	.5	--	1.0
Total	94.7	10.4	1.6	34.5	125.2	89.1	53.4	276.0	684.9
				WISCONSIN - NORTHWESTERN					
6	31.5	10.4	--	5.9	59.7	16.7	47.9	63.0	235.1
8	25.0	13.6	--	10.1	73.8	21.5	71.0	82.7	297.7
10	16.0	16.4	0.2	8.4	63.9	14.9	47.4	71.0	238.2
12	9.7	9.9	.1	4.3	36.9	8.9	26.8	35.6	132.4
14	3.0	4.4	--	1.2	13.8	3.4	11.1	15.3	52.2
16	2.5	1.4	--	1.1	6.5	1.4	3.3	3.0	19.2
18	--	--	--	.4	1.1	.6	.4	1.1	3.6
20	--	--	--	--	.3	--	.2	.4	.9
22+	--	--	--	--	--	.2	--	--	.2
Total	87.9	56.2	.3	31.4	255.9	67.6	208.1	272.1	979.5
				WISCONSIN - CENTRAL					
6	--	1.0	3.9	6.6	40.0	1.2	25.9	30.7	109.3
8	--	.5	2.3	5.2	26.2	2.9	25.7	28.6	91.4
10	--	--	1.1	1.4	10.8	1.9	26.5	17.9	59.6
12	--	--	.1	.1	4.9	.4	13.9	10.6	30.0
14	--	--	--	--	1.3	.4	4.6	2.8	9.1
16	--	--	--	--	--	--	2.7	.4	3.1
18	--	--	--	--	--	--	.9	.2	1.1
20	--	--	--	--	--	--	.4	--	.4
22+	--	--	--	--	--	--	--	--	--
Total	--	1.5	7.4	13.3	83.2	6.8	100.6	91.2	304.0

1/ Due to Forest Survey data collection procedures direct estimates of National Forest and State volumes were unavailable by d.b.h. but the sum of the total row of the two was known. This volume was allocated to National Forest and State in the same proportion as it was present in 1966. These totals were then allocated to d.b.h. in the same proportion as volume was present in other d.b.h. classes.

2/ Includes leased land.

Cut is determined as a function of mill pulping capacity.[2] It is assumed that pulping capacity continues to increase at its historical rate during the projection period and that pulpwood remains a constant percent of total aspen cut. Further, it is assumed that cut is at least initially distributed to survey unit and d.b.h. class in its historical proportion and to cover

[2] *Lenschner, William A. An econometric model of the Wisconsin aspen pulpwood market. (Unpublished manuscript.)*

Table 3.— Aspen growing stock volume, all cover types, by survey unit, volume per acre, and cover type, 1968
(Million cubic feet)

REGIONAL TOTAL

Volume per acre (cubic feet)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Other	Total
0 - 199	62.9	61.9	35.9	181.8	75.7	487.8	48.4	0.9	955.3
200 - 399	47.1	81.4	34.9	226.9	86.0	703.9	70.1	--	1,250.3
400 - 599	29.7	61.8	6.3	140.7	48.5	879.8	41.6	--	1,208.4
600 - 799	10.3	61.5	9.7	100.0	30.1	878.5	20.0	--	1,110.1
800 - 999	5.3	3.7	1.8	45.2	10.2	860.9	6.5	--	933.6
1,000 - 1,199	1.7	--	4.9	10.8	2.8	652.9	--	--	673.1
1,200 - 1,599	4.5	1.0	4.8	6.3	--	938.8	6.3	--	961.7
1,600 - 1,999	--	--	--	1.3	--	234.1	--	--	235.4
2,000+	--	--	--	12.0	--	163.5	--	--	175.5
Total	161.5	271.3	98.3	725.0	253.3	5,800.2	192.9	.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
0 - 199	8.0	11.5	6.1	16.3	0.5	24.4	0.8	--	67.6
200 - 399	2.3	3.1	7.8	18.0	--	31.1	5.0	--	67.3
400 - 599	--	4.2	2.5	9.4	--	49.7	--	--	65.8
600 - 799	--	19.6	--	9.3	--	43.6	--	--	72.5
800 - 999	--	--	--	--	--	25.4	--	--	25.4
1,000 - 1,199	--	--	--	--	--	24.8	--	--	24.8
1,200 - 1,599	--	--	--	--	--	8.9	--	--	8.9
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	10.3	38.4	16.4	53.0	.5	207.9	5.8	--	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
0 - 199	7.3	12.3	4.8	28.9	1.9	30.1	5.7	--	91.0
200 - 399	2.0	24.1	2.9	35.9	1.9	55.8	7.3	--	129.9
400 - 599	3.5	24.1	--	28.2	4.4	80.9	4.0	--	145.1
600 - 799	--	4.2	--	16.2	--	50.0	--	--	70.4
800 - 999	--	--	--	27.7	--	62.2	--	--	89.9
1,000 - 1,199	--	--	--	--	--	69.8	--	--	69.8
1,200 - 1,599	--	--	--	--	--	40.6	--	--	40.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	12.8	64.7	7.7	136.9	8.2	389.4	17.0	--	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
0 - 199	8.9	7.8	6.7	42.5	24.8	42.7	3.5	--	136.9
200 - 399	1.0	15.0	2.1	54.5	34.0	107.2	13.6	--	227.4
400 - 599	5.1	7.0	2.9	17.1	16.0	141.2	9.5	--	198.8
600 - 799	--	--	9.7	24.0	11.3	159.6	--	--	204.6
800 - 999	--	--	--	--	4.3	108.2	--	--	112.5
1,000 - 1,199	--	--	--	5.5	--	49.7	--	--	55.2
1,200 - 1,599	--	--	--	--	--	98.8	--	--	98.8
1,600 - 1,999	--	--	--	--	--	48.9	--	--	48.9
2,000+	--	--	--	--	--	28.7	--	--	28.7
Total	15.0	29.8	21.4	143.6	90.4	785.0	26.6	--	1,111.8
MINNESOTA - LAKE SUPERIOR									
0 - 199	9.6	8.3	3.2	4.1	0.6	43.8	15.0	--	84.6
200 - 399	12.6	10.8	3.5	8.6	1.1	124.1	13.3	--	174.0
400 - 599	8.0	13.6	--	6.5	--	228.9	4.1	--	261.1
600 - 799	--	1.4	--	2.4	--	172.2	11.5	--	187.5
800 - 999	--	3.7	--	2.1	--	217.8	2.3	--	225.9
1,000 - 1,199	--	--	--	--	--	171.3	--	--	171.3
1,200 - 1,599	--	--	--	2.0		288.3	3.9	--	294.2
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	37.3	--	--	37.3
Total	30.2	37.8	6.7	25.6	1.7	1,283.7	50.1	--	1,435.9

(Continued on next page)

type in proportion to the aspen growing stock in that type.

Commercial forest acreage in all types is changed at the same rate as the aspen type acreage changed between forest surveys. This has two effects. First, the trend of the breakup (see below) occurring between surveys is automatically included in the projection, and second, the absolute amount of acreage change levels off as we proceed through time. It is also assumed, throughout the projection period, that 1 acre is added for every 2 acres subtracted when there is a net decrease in commercial forest area. The opposite is assumed for net additions. Finally, it was assumed that the volume lost from the system due to acreage losses is the average volume per acre in that cover type and that acreage coming into the system has no measurable aspen volume on it for 25 years.

Volume per acre (cubic feet)	Red, white, and jack pine	Balsam fir-white spruce	Black spruce, tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch	Other	Total
				MINNESOTA - CENTRAL PINE					
0 - 199	8.9	3.4	7.9	13.8	9.9	259.3	9.8	--	312.5
200 - 399	12.3	6.7	14.7	15.3	9.0	175.2	9.0	--	242.2
400 - 599	1.5	2.0	--	11.3	3.0	124.1	5.2	--	147.1
600 - 799	7.1	5.9	--	11.7	5.9	148.5	5.6	--	184.7
800 - 999	5.3	--	--	--	1.7	157.4	4.2	--	168.6
1,000 - 1,199	1.7	--	--	2.9	--	138.7	--	--	143.3
1,200 - 1,599	3.1	--	--	--	--	235.5	--	--	238.6
1,600 - 1,999	--	--	--	--	--	95.4	--	--	95.4
2,000+	--	--	--	--	--	66.4	--	--	66.4
Total	39.9	18.0	22.1	55.0	29.5	1,400.5	33.8	--	1,598.8
				MINNESOTA - RAINY RIVER					
0 - 199	1.5	3.7	--	2.9	0.2	7.4	--	--	15.7
200 - 399	--	3.8	--	3.9	.2	28.8	--	--	36.7
400 - 599	--	1.3	--	3.8	--	14.8	--	--	19.9
600 - 799	--	21.2	--	2.9	--	60.4	--	--	84.5
800 - 999	--	--	--	--	--	39.3	--	--	39.3
1,000 - 1,199	--	--	4.9	--	--	49.3	--	--	54.2
1,200 - 1,599	1.4	1.0	4.8	4.3	--	108.0	2.4	--	121.9
1,600 - 1,999	--	--	--	1.3	--	33.6	--	--	34.9
2,000+	--	--	--	12.0	--	.4	--	--	12.4
Total	2.9	31.0	9.7	31.1	.4	342.0	2.4	--	419.5
				WISCONSIN - NORTHEASTERN					
0 - 199	9.1	7.0	5.0	26.9	6.4	25.4	5.0	--	84.8
200 - 399	8.2	9.1	2.9	38.1	7.5	62.8	10.6	--	139.2
400 - 599	5.4	3.4	.9	22.3	5.0	79.7	5.6	--	122.3
600 - 799	--	7.9	--	12.8	1.6	78.7	2.9	--	103.9
800 - 999	--	--	--	2.2	--	82.8	--	--	85.0
1,000 - 1,199	--	--	--	--	--	62.9	--	--	62.9
1,200 - 1,599	--	--	--	--	--	70.2	--	--	70.2
1,600 - 1,999	--	--	--	--	--	11.0	--	--	11.0
2,000+	--	--	--	--	--	5.6	--	--	5.6
Total	22.7	27.4	8.8	102.3	20.5	479.1	24.1	--	684.9
				WISCONSIN - NORTHWESTERN					
0 - 199	6.1	7.2	2.4	37.3	12.7	36.8	6.5	0.5	109.5
200 - 399	7.3	8.8	1.0	39.9	18.5	78.7	9.9	--	164.1
400 - 599	6.2	6.2	--	33.8	11.2	109.2	13.2	--	179.8
600 - 799	3.2	1.3	--	17.9	4.9	133.1	--	--	160.4
800 - 999	--	--	--	13.2	4.2	131.8	--	--	149.2
1,000 - 1,199	--	--	--	2.4	2.8	67.0	--	--	72.2
1,200 - 1,599	--	--	--	--	--	73.9	--	--	73.9
1,600 - 1,999	--	--	--	--	--	45.2	--	--	45.2
2,000+	--	--	--	--	--	25.2	--	--	25.2
Total	22.8	23.5	3.4	144.5	54.3	700.9	29.6	.5	979.5
				WISCONSIN - CENTRAL					
0 - 199	3.5	0.7	0.4	9.2	18.6	17.6	2.0	0.3	52.3
200 - 399	1.4	--	--	12.7	13.9	40.2	1.4	--	69.6
400 - 599	--	--	--	8.3	8.9	51.4	41.6	--	68.6
600 - 799	--	--	--	2.8	6.4	32.5	--	--	41.7
800 - 999	--	--	1.8	--	--	35.9	--	--	37.7
1,000 - 1,199	--	--	--	--	--	19.5	--	--	19.5
1,200 - 1,599	--	--	--	--	--	14.6	--	--	14.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	4.9	.7	2.2	33.0	47.8	211.7	3.4	.3	304.0

Breakup

Aspen stands begin to deteriorate rapidly after the trees pass maturity, a process commonly called "breakup." Overmature trees are increasingly susceptible to their traditional disease and insect enemies; Graham reports a stand can be reduced to a worthless condition in 5 to 10 years (Graham *et al.* 1963, p. 44). As the aspens die they are replaced by more tolerant tree and brush species that usually are present as an understory. The weak aspen suckers cannot compete with this vegetation and most of them die unless a fire or other major disturbance occurs. The two predominant features of stand breakup are

Table 4.—Aspen growing stock volume, all cover types, by survey unit, ownership class, and volume per acre, 1968
(Million cubic feet)

Volume per acre (cubic feet)	National Forest	Indian	Other federal	State	County & municipal	Forest industry	Farmer	Misc. private	Total
REGIONAL TOTAL									
0 - 199	146.2	74.6	11.7	89.4	95.1	74.4	171.7	292.2	955.3
200 - 399	169.7	13.6	9.5	100.7	194.9	97.4	233.5	431.0	1,250.3
400 - 599	161.0	17.8	7.7	94.2	221.1	125.3	133.6	447.7	1,208.4
600 - 799	139.0	19.1	6.1	106.7	239.6	69.7	128.8	401.1	1,110.1
800 - 999	143.9	17.5	4.7	85.2	219.1	63.0	92.4	307.8	933.6
1,000 - 1,199	107.2	12.6	2.1	75.5	154.4	60.4	38.0	222.9	673.1
1,200 - 1,599	146.9	19.1	12.8	133.6	221.8	96.3	49.7	281.5	961.7
1,600 - 1,999	13.2	4.4	1.3	32.8	22.8	2.4	47.0	111.5	235.4
2,000+	13.1	9.1	.5	24.4	14.1	31.1	27.0	56.2	175.5
Total	1,040.2	187.8	56.4	742.5	1,382.9	620.0	921.7	2,551.9	7,503.4
MICHIGAN - EASTERN UPPER PENINSULA									
0 - 199	19.0	--	2.0	3.2	0.3	6.2	15.9	21.0	67.6
200 - 399	15.0	--	4.0	2.6	--	10.3	9.3	26.1	67.3
400 - 599	9.9	--	--	3.8	--	22.1	14.9	15.1	65.8
600 - 799	4.3	--	--	--	--	20.5	8.3	39.4	72.5
800 - 999	6.0	--	--	--	--	12.5	--	6.9	25.4
1,000 - 1,199	--	--	--	8.6	--	6.4	--	9.8	24.8
1,200 - 1,599	--	--	--	8.9	--	--	--	--	8.9
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	54.2	--	6.0	27.1	.3	78.0	48.4	118.3	332.3
MICHIGAN - WESTERN UPPER PENINSULA									
0 - 199	14.8	--	--	11.3	2.6	18.7	10.0	33.6	91.0
200 - 399	21.4	--	1.3	16.8	2.6	28.1	12.8	46.9	129.9
400 - 599	23.8	--	--	19.9	2.3	36.0	9.7	53.4	145.1
600 - 799	11.5	--	--	8.4	--	20.1	7.5	22.9	70.4
800 - 999	14.8	--	--	10.6	--	14.0	10.4	40.1	89.9
1,000 - 1,199	11.5	--	--	8.3	8.1	15.6	6.0	20.3	69.8
1,200 - 1,599	6.7	--	--	4.8	--	7.2	7.3	14.6	40.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	104.5[1/]	--	1.3	80.1[1/]	15.6	139.7	63.7	231.8	636.7
MICHIGAN - NORTHERN LOWER PENINSULA									
0 - 199	12.4	--	--	3.6	1.8	0.6	23.7	94.8	136.9
200 - 399	16.5	--	--	9.1	1.2	2.9	52.1	145.6	227.4
400 - 599	3.8	--	3.1	8.5	--	9.0	24.2	150.2	198.8
600 - 799	9.2	--	--	2.8	4.1	--	34.2	154.3	204.6
800 - 999	--	--	--	--	--	--	31.3	81.2	112.5
1,000 - 1,199	--	--	--	--	--	--	--	55.2	55.2
1,200 - 1,599	--	--	--	--	8.4	--	--	90.4	98.8
1,600 - 1,999	--	--	--	--	--	--	--	48.9	48.9
2,000+	--	--	--	14.2	--	--	--	14.5	28.7
Total	41.9	--	3.1	38.2	15.5	12.5	165.5	835.1	1,111.8
MINNESOTA - LAKE SUPERIOR									
0 - 199	27.6	2.2	--	9.2	17.3	3.1	5.8	19.4	84.6
200 - 399	54.7	5.1	--	20.7	38.8	7.4	14.5	32.8	174.0
400 - 599	90.6	6.3	--	25.6	48.2	9.0	15.8	65.6	261.1
600 - 799	52.7	6.6	--	26.7	50.2	2.2	10.8	38.3	187.5
800 - 999	72.5	7.0	--	28.8	57.2	9.6	4.1	46.7	225.9
1,000 - 1,199	59.5	4.4	--	17.9	33.7	--	7.9	47.9	171.3
1,200 - 1,599	84.4	9.1	--	37.0	69.4	23.1	9.1	62.1	294.2
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	7.2	--	--	--	--	30.1	--	--	37.3
Total	449.2	40.7	--	165.9	314.8	84.5	68.0	312.8	1,435.9

(Continued on next page)

that the mortality increases rapidly and that the stands do not reproduce to aspen.

Another cause of incomplete aspen reproduction is the partial harvesting of pure aspen stands. Here the residual stand prevents the reproduction of aspen but not the reproduction of more tolerant species and so the site is converted to some nonaspen type. Although this is not strictly breakup (because part of the stand has been harvested) the net effect, on reproduction at least, is the same.

Foresters are also concerned about the loss of aspen volume in mixed stands where aspen is not the predominant species. Here the existing aspen trees may be cut or die and the remaining species success-

Volume per acre (cubic feet)	National Forest	Indian	Other federal	State	County & municipal	Forest industry	Farmer	Misc. private	Total
				MINNESOTA - CENTRAL PINE					
0 - 199	42.3	68.7	7.1	44.1	18.6	16.7	61.3	53.7	312.5
200 - 399	27.4	--	--	28.6	51.6	12.7	70.0	51.9	242.2
400 - 599	14.8	--	--	15.5	67.6	9.6	4.1	35.5	147.1
600 - 799	24.4	--	2.8	25.4	67.8	8.2	16.4	39.7	184.7
800 - 999	20.5	--	3.2	21.3	74.3	7.7	--	41.6	168.6
1,000 - 1,199	18.3	--	--	19.1	62.6	5.4	--	37.9	143.3
1,200 - 1,599	40.4	--	7.6	42.2	97.2	6.3	--	44.9	238.6
1,600 - 1,999	13.2	--	--	13.8	11.4	2.4	32.4	22.2	95.4
2,000+	6.1	--	--	6.5	9.4	.9	18.4	25.1	66.4
Total	207.4	68.7	20.7	216.5	460.5	69.9	202.6	352.5	1,598.8
				MINNESOTA - RAINY RIVER					
0 - 199	--	0.9	0.5	5.4	2.0	3.5	--	3.4	15.7
200 - 399	--	1.7	1.2	12.0	10.0	2.1	1.1	8.6	36.7
400 - 599	--	1.1	.5	7.4	4.8	1.2	1.7	3.2	19.9
600 - 799	0.1	1.7	3.3	29.8	27.0	1.0	1.7	19.9	84.5
800 - 999	.1	1.1	1.5	12.6	14.7	5.5	--	3.8	39.3
1,000 - 1,199	.1	1.5	2.1	17.0	12.6	16.3	3.6	1.0	54.2
1,200 - 1,599	.2	1.7	5.2	35.6	28.6	42.4	--	8.2	121.9
1,600 - 1,999	--	.4	1.3	11.7	7.5	--	--	14.0	34.9
2,000+	--	.2	.5	3.7	4.7	--	3.3	--	12.4
Total	.5	10.3	16.1	135.2	111.9	72.0	11.4	62.1	419.5
				WISCONSIN - NORTHEASTERN					
0 - 199	10.1	0.7	0.1	4.7	17.0	13.8	11.2	27.2	84.8
200 - 399	16.1	1.3	.6	5.0	29.0	19.6	12.3	55.3	139.2
400 - 599	11.7	1.9	.9	4.8	24.8	16.3	8.1	53.8	122.3
600 - 799	12.9	1.5	--	4.7	25.3	8.5	10.1	40.9	103.9
800 - 999	11.0	--	--	7.9	18.7	6.0	9.4	32.0	85.0
1,000 - 1,199	17.7	2.2	--	4.6	7.5	7.6	2.3	21.0	62.9
1,200 - 1,599	15.2	2.8	--	2.8	2.9	17.3	--	29.2	70.2
1,600 - 1,999	--	--	--	--	--	--	--	11.0	11.0
2,000+	--	--	--	--	--	--	--	5.6	5.6
Total	94.7	10.4	1.6	34.5	125.2	89.1	53.4	276.0	684.9
				WISCONSIN - NORTHWESTERN					
0 - 199	19.9	2.0	0.3	3.5	24.7	10.7	22.2	26.2	109.5
200 - 399	18.8	5.5	--	3.1	42.2	12.5	35.1	46.9	164.1
400 - 599	6.3	8.6	--	6.6	48.2	22.2	33.3	54.6	179.8
600 - 799	23.9	7.9	--	4.5	52.5	7.6	28.7	35.3	160.4
800 - 999	19.0	9.4	--	4.0	46.9	5.5	27.9	36.5	149.2
1,000 - 1,199	--	4.5	--	--	25.2	9.1	13.5	19.9	72.2
1,200 - 1,599	--	5.4	--	2.4	12.2	--	27.6	26.3	73.9
1,600 - 1,999	--	4.0	--	7.3	4.0	--	14.5	15.4	45.2
2,000+	--	8.9	--	--	--	--	5.3	11.0	25.2
Total	87.9	56.2	.3	31.4	255.9	67.6	208.1	272.1	979.5
				WISCONSIN - CENTRAL					
0 - 199	--	--	1.6	4.3	10.8	1.2	21.6	12.8	52.3
200 - 399	--	--	2.4	2.8	19.4	1.8	26.3	16.9	69.6
400 - 599	--	--	3.4	1.9	25.1	--	21.9	16.3	68.6
600 - 799	--	1.5	--	4.3	12.7	1.6	11.1	10.5	41.7
800 - 999	--	--	--	--	7.3	2.2	9.2	19.0	37.7
1,000 - 1,199	--	--	--	--	4.8	--	4.8	9.9	19.5
1,200 - 1,599	--	--	--	--	3.1	--	5.7	5.8	14.6
1,600 - 1,999	--	--	--	--	--	--	--	--	--
2,000+	--	--	--	--	--	--	--	--	--
Total	--	1.5	7.4	13.3	83.2	6.8	100.6	91.2	304.0

1/ Due to Forest Survey data collection procedures direct estimates of National Forest and State volumes were unavailable by volume per acre but the sum of the total row of the two was known. This volume was allocated to National Forest and State in the same proportion as it was presented in 1966. These totals were then allocated to volume per acre in the same proportion as volume was present in other volume per acre classes.

fully compete and stop aspen reproduction. Again we have the same two predominant features, rapid decrease in aspen volume and no aspen reproduction.

Most foresters agree these processes are occurring, although there is a difference of opinion about the actual amount and the rate of spread. Unfortun-

Table 5.—Aspen growing stock volume, aspen type only, by survey unit, age class, and site index, 1966
(Million cubic feet)[1]

Age (years)	Site 0 - 39	40 - 49	50 - 59	60 - 69	70 - 79	80 - 89	90+	Total
MICHIGAN - EASTERN UPPER PENINSULA								
0 - 9	--	2.3	2.0	--	0.6	--	--	4.9
10 - 19	--	4.7	.6	0.4	--	--	--	5.7
20 - 29	6.7	1.4	15.6	4.7	--	--	--	28.4
30 - 39	3.3	12.9	40.1	4.4	--	--	--	60.7
40 - 49	6.4	14.0	33.2	4.3	--	--	--	57.9
50+	5.4	28.4	16.7	6.7	--	--	--	57.2
Total	21.8	63.7	108.2	20.5	.6	--	--	214.8
MICHIGAN - WESTERN UPPER PENINSULA								
0 - 9	--	2.8	4.0	4.1	--	--	--	10.9
10 - 19	--	2.0	7.7	8.6	--	--	--	18.3
20 - 29	2.6	15.9	12.8	15.3	2.9	--	--	49.5
30 - 39	20.6	31.9	43.6	51.8	20.5	--	--	168.4
40 - 49	1.8	28.5	30.1	5.2	11.4	--	--	77.0
50+	1.0	25.7	34.2	5.2	1.7	--	--	67.8
Total	26.0	106.8	132.4	90.2	36.5	--	--	391.9
MICHIGAN - NORTHERN LOWER PENINSULA								
0 - 9	6.5	8.3	16.7	6.5	0.6	--	--	38.6
10 - 19	.2	3.5	4.5	.9	4.2	--	--	13.3
20 - 29	1.8	5.3	15.5	44.4	36.2	2.7	--	105.9
30 - 39	4.5	30.5	72.1	125.5	52.5	10.2	--	295.3
40 - 49	5.2	30.2	48.4	69.9	40.9	--	--	194.6
50+	--	47.4	43.8	48.7	6.1	1.6	--	147.6
Total	18.2	125.2	201.0	295.9	140.5	14.5	--	795.3
MINNESOTA - LAKE SUPERIOR								
0 - 9	0.1	1.7	0.2	2.5	--	--	--	4.5
10 - 19	2.0	8.2	21.7	21.5	14.5	--	--	67.9
20 - 29	6.5	82.6	114.6	78.5	36.2	--	--	318.4
30 - 39	12.8	71.1	168.9	66.1	1.0	--	--	319.9
40 - 49	8.3	19.2	85.1	18.0	20.6	--	--	151.2
50+	1.4	19.7	47.3	3.7	--	--	--	72.1
Total	31.1	202.5	437.8	190.3	72.3	--	--	934.0
MINNESOTA - CENTRAL PINE								
0 - 9	0.5	2.6	3.4	1.3	--	1.2	--	9.0
10 - 19	3.5	10.8	14.7	40.7	17.2	.2	--	87.1
20 - 29	4.0	50.3	165.3	189.1	82.1	4.3	--	495.1
30 - 39	3.3	47.8	170.7	111.8	36.1	--	--	369.7
40 - 49	--	24.3	33.4	84.7	4.3	--	--	146.7
50+	1.0	2.5	1.5	15.7	--	--	--	20.7
Total	12.3	138.3	389.0	443.3	139.7	5.7	--	1,128.3
MINNESOTA - RAINY RIVER								
0 - 9	--	3.6	2.4	2.6	--	1.5	--	10.1
10 - 19	2.5	1.5	2.7	12.5	2.1	.3	--	21.6
20 - 29	.5	3.9	41.0	22.6	34.9	--	--	102.9
30 - 39	--	2.5	57.5	19.8	--	31.5	--	111.3
40 - 49	.2	--	2.2	--	--	--	--	2.4
50+	--	--	14.4	7.2	--	--	--	21.6
Total	3.2	11.5	120.2	64.7	37.0	33.3	--	269.9

(Continued on next page)

ately, field data to answer these questions are not readily available. The *breakup* assumption simulates widespread breakup occurring immediately and projects a minimum or worst likely condition.

The *breakup* computer program is exactly the same as the *recent trends* program with two exceptions. First, all uncut volume in the 12-inch and larger d.b.h. classes is moved into the next larger d.b.h. class at each repetition of the program. Because each repetition of the program represents 1 year in this analysis and because there are six d.b.h. classes 12 inches and larger, the volume in the 12-inch class in a particular year that is not cut in the next 6 years will be removed from ("grown" out of) the growing stock projections. Similarly, in a particular year the volume in the 14-inch class has 5 years to be cut before it is grown through the remaining d.b.h. classes and removed, that in the 16-inch class has 4 years, and so on.

The second exception is that the ingrowth into the 6-inch d.b.h. class is set at zero beginning in the 25th year of the projections. This is done to account for the

Age (years)	Site: 0 - 39	40 - 49	50 - 59	60 - 69	70 - 79	80 - 89	90+	Total
				WISCONSIN - NORTHEASTERN				
0 - 9	3.5	0.3	3.9	5.4	2.8	0.9	--	16.8
10 - 19	.3	2.0	4.1	6.1	10.1	2.8	--	25.4
20 - 29	7.9	1.7	4.6	11.8	10.8	10.8	--	47.6
30 - 39	44.8	2.5	18.9	45.6	49.2	15.8	3.4	180.2
40 - 49	7.0	10.2	26.6	59.8	53.0	7.1	--	163.7
50+	.3	2.2	8.2	16.0	18.7	--	--	45.4
Total	63.8	18.9	66.3	144.7	144.6	37.4	3.4	479.1
				WISCONSIN - NORTHWESTERN				
0 - 9	0.2	3.2	8.2	10.2	5.6	2.0	0.3	29.7
10 - 19	.8	3.6	5.9	9.3	11.3	2.9	1.3	35.1
20 - 29	--	1.3	1.7	14.3	29.6	12.4	9.5	68.8
30 - 39	--	6.0	33.8	101.6	118.8	44.9	4.6	309.7
40 - 49	--	2.0	29.7	79.4	74.9	10.2	--	196.2
50+	--	1.6	14.0	32.5	11.7	--	--	59.8
Total	1.0	17.7	93.3	247.3	251.9	72.4	15.7	699.3
				WISCONSIN - CENTRAL				
0 - 9	--	0.7	1.9	1.6	2.1	1.2	--	7.5
10 - 19	--	1.4	3.4	7.5	4.3	2.1	0.3	19.0
20 - 29	0.2	1.0	6.0	9.8	5.6	4.0	5.3	31.9
30 - 39	--	4.8	23.7	30.8	30.7	15.3	--	105.3
40 - 49	--	1.4	6.4	14.5	15.6	4.4	--	42.3
50+	--	3.6	1.3	.8	--	--	—	5.7
Total	.2	12.9	42.7	65.0	58.3	27.0	5.6	211.7

1/ Volume by age and site could not be updated because of the manner in which the data was stored. The volumes in this table are as of the survey year in each state and it is impossible to add them to a regional total.

lack of aspen reproduction. The 25th year was chosen because it seemed a fair average of the length of time it takes aspen reproduction to reach 6 inches d.b.h. Reproduction was not set equal to zero immediately because the conditions in force 25 years ago determine it and these are reflected, in part, in the *recent trends* projection.

Positive Practices

It was mentioned earlier that land managers can affect future inventory and cut. Actions we can take today can positively affect the aspen growing stock of tomorrow. The *positive practices* assumptions indicate what these practices could accomplish if they were instituted today—they are NOT a prescription for what should be done to increase the volume of the aspen resource in the Lake States.

Two problems in current practices are readily identifiable. First, some areas are being heavily cut for aspen, chiefly because of their proximity to pulpmills, which means low transportation costs. If the positive effects were thought worthwhile, cut could be shifted to other areas where greater volumes of aspen growing stock exist.

The second problem is that many stands do not reproduce to aspen. This may be due to breakup, partial cut of pure aspen stands, or the reduction of aspen volume in nonaspen cover types. One cultural practice to increase reproduction might be to remove all trees when cutting.

The *positive practices* assumptions simulate what would happen if such practices were begun immediately. The assumptions are the same as for the *recent trends* with two exceptions. First, cut is now allocated to a particular type, d.b.h. class, and survey unit in proportion to the amount of *aspen* growing stock in that category. For example, if the 6-inch d.b.h. class of the white, red, and jack pine types in the Northeast Survey Unit has 0.15 percent of the total aspen growing stock in the five survey units, it is allocated 0.15 percent of the total cut.

The second assumption is that ingrowth into the 6-inch d.b.h. class will be double that in *recent trends* beginning in the 25th year of the projection. The logic

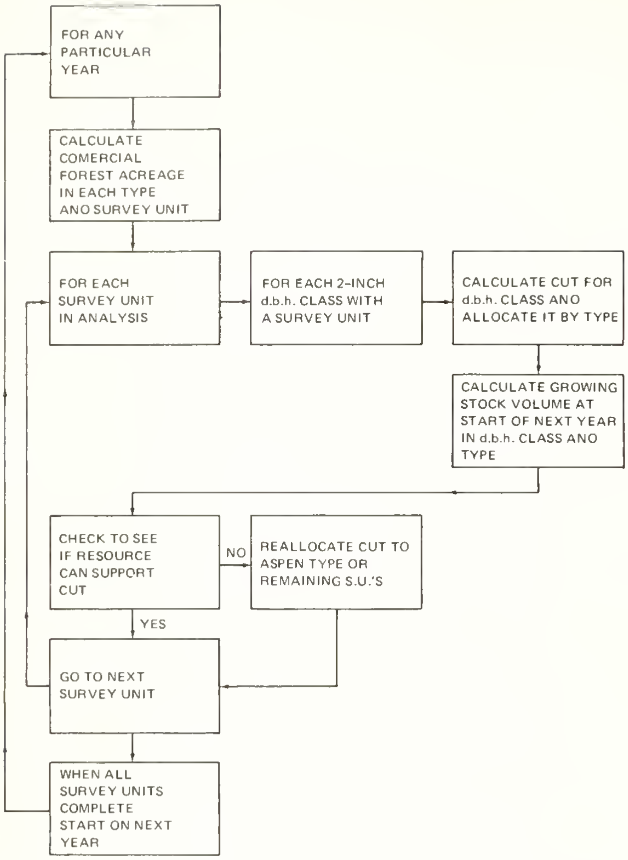

Figure 2.—Outline of computer program for projecting aspen cut and inventory.

for choosing the 25th year is the same as in the *breakup* conditions. The actual amount of reproduction would depend in part on how large a cost we were willing to incur. Although there is no way to predict this, doubling ingrowth did not seem unreasonable.

REGIONAL PROJECTIONS

Goods and services, including harvested aspen, flow within and sometimes between economic regions. These regions are not precisely defined nor are there firm rules for doing so. In the case of harvested aspen, past history and the existing transportation network help define regions. Data availability and the range within which the species grow give a further, pragmatic, definition to the regions.

The Wisconsin-Upper Peninsula region includes the northern three survey units in Wisconsin and the two units in Michigan's Upper Peninsula (U.P.) (fig. 1). Only a small amount of the aspen pulpwood cut in Wisconsin is exported but a large proportion of the aspen cut in the U.P. is shipped into Wisconsin. Further, the large proportion of the U.P. aspen cut in the Eastern Survey Unit makes it likely that the supply in that Unit affects demand in the Western Unit.

The second region includes only one survey unit, Michigan's Northern Lower Peninsula. Roughly half of the aspen pulpwood cut in Michigan is cut on the Lower Peninsula and virtually all of that in the Northern Unit. Bridge tolls have kept significant amounts of aspen from crossing the Straits of Mackinac in the past and make it unlikely that much will in the future under present conditions.

The Minnesota region is made up of the three northernmost survey units. Over 90 percent of the aspen pulpwood harvested in Minnesota the last several years has been used within the State. Further, the aspen stands are distant—usually a multiline rail haul—from the nearest mills in Wisconsin. There were also data considerations, discussed below, that made it logical to analyze Minnesota separately.

These three regions were projected separately. This meant that the survey units within any one region could have unsupported cut allocated to each other but not to survey units in other regions (see discussion of the Projection Model). The results of the projections will be discussed by these regions (tables 6 and 7).

Wisconsin-Upper Peninsula

Five survey units were allowed to *interact* for this set of projections (fig. 3).

Recent Trends

The *recent trends* projections show that in about 15 to 20 years the Northeast Survey Unit will not be able to support its historical trend of cut and that 8 to 10 years after that the two U.P. units will not be able to support the cut allocated to them. This cut consists of their historical trends plus the additional cut allo-

Table 6.— Projected aspen cut and growing stock, all cover types, by survey unit, year, and assumption, 5-year average

Survey unit and year	Recent Trends: Cut	Recent Trends: Growing stock	Breakup: Cut	Breakup: Growing stock	Positive Practices: Cut	Positive Practices: Growing stock
	Million cubic feet	Billion cubic feet	Million cubic feet	Billion cubic feet	Million cubic feet	Billion cubic feet
MICHIGAN:						
Eastern Upper Peninsula						
1970	15.2	0.35	15.2	0.34	12.8	0.35
1975	17.4	.37	17.4	.33	15.3	.38
1980	19.5	.38	19.5	.33	17.4	.39
1985	21.6	.37	22.6	.33	19.0	.38
1990	26.9	.34	31.7	.28	20.1	.35
1995	29.5	.27	28.1	.22	20.7	.32
2000	24.6	.24	28.6	.19	20.5	.30
Western Upper Peninsula						
1970	22.9	.63	22.9	.62	22.7	.62
1975	26.1	.59	26.1	.46	23.6	.59
1980	29.3	.53	29.3	.38	24.3	.55
1985	32.5	.46	33.8	.29	24.6	.49
1990	40.3	.35	35.9	.16	24.7	.43
1995	41.5	.26	23.5	.11	24.3	.37
2000	27.7	.14	16.8	.10	23.4	.34
Northern Lower Peninsula						
1970	38.1	1.08	38.1	1.08	38.1	1.08
1975	43.4	1.00	43.4	.80	43.4	.99
1980	48.8	.88	48.8	.65	48.8	.86
1985	54.1	.73	54.1	.49	54.1	.69
1990	59.5	.55	59.5	.29	59.5	.49
1995	64.8	.33	26.6	.14	64.8	.27
2000	57.3	.20	17.7	.12	26.5	.09
MINNESOTA:						
Lake Superior						
1970	23.8	1.52	23.8	1.51	28.3	1.51
1975	28.5	1.74	28.5	1.51	34.0	1.70
1980	33.1	1.97	33.1	1.59	39.7	1.88
1985	37.7	2.22	37.7	1.67	45.4	2.05
1990	42.3	2.47	42.3	1.72	51.1	2.21
1995	47.0	2.74	47.0	1.73	56.6	2.35
2000	51.6	3.00	51.6	1.68	60.9	2.51
Central Pine						
1970	30.6	1.67	30.6	1.67	31.4	1.67
1975	36.6	1.86	36.6	1.67	37.0	1.85
1980	42.5	2.04	42.5	1.70	42.4	2.01
1985	48.5	2.19	48.5	1.71	47.5	2.14
1990	54.4	2.33	54.4	1.66	52.1	2.25
1995	60.4	2.42	60.4	1.56	55.9	2.33
2000	66.3	2.47	66.3	1.41	57.7	2.38
Rainy River						
1970	13.6	.43	13.6	.43	8.4	.45
1975	16.3	.47	16.3	.43	10.3	.51
1980	18.9	.51	18.9	.45	12.4	.59
1985	21.6	.56	21.6	.48	14.9	.67
1990	24.2	.63	24.2	.53	17.7	.76
1995	26.8	.71	26.8	.56	21.7	.90
2000	29.5	.85	29.5	.53	28.8	1.19
WISCONSIN:						
Northeastern						
1970	41.4	.67	41.4	.67	25.5	.70
1975	48.5	.61	48.5	.51	29.0	.73
1980	55.7	.50	55.7	.38	32.6	.73
1985	62.8	.34	58.6	.23	35.8	.72
1990	55.5	.26	44.4	.22	38.7	.68
1995	52.2	.28	63.7	.24	40.9	.63
2000	66.5	.32	66.1	.24	41.6	.61
Northwestern						
1970	25.2	1.03	25.2	1.02	36.7	1.01
1975	29.5	1.15	29.5	.97	42.4	1.06
1980	33.9	1.26	33.9	1.03	48.1	1.08
1985	38.2	1.36	39.9	1.10	53.5	1.07
1990	48.1	1.41	56.9	1.16	58.7	1.02
1995	59.6	1.47	63.3	1.08	63.8	.99
2000	68.9	1.45	76.0	.86	68.7	1.00
Central						
1970	5.4	.35	5.4	.35	12.4	.34
1975	6.3	.50	6.3	.45	17.4	.43
1980	7.3	.68	7.3	.60	23.3	.52
1985	8.2	.90	8.5	.80	30.5	.61
1990	10.3	1.13	12.2	1.03	38.9	.68
1995	12.8	1.53	13.6	1.25	49.3	.76
2000	14.8	1.97	16.3	1.40	62.5	.91

cated to them to make up for the diminished cut in the Northeast Unit.

The projections also show that nearly all the cut coming from these three survey units after the cut is diminished will be from the 6- and 8-inch d.b.h. classes. By 1998 about 30 percent of the cut in the Northwest and Central Units and nearly all the cut in the remaining units will be from the 6- and 8-inch classes. If the forest industry will take this small diameter

Table 7.—Recent trends *projections of aspen growing stock, by survey unit, year, d.b.h., and cover type*
(Million cubic feet)[1]

MICHIGAN - EASTERN UPPER PENINSULA

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
1978								
6	17.1	18.4	27.6	50.0	0.6	120.5	4.9	239.1
8	4.8	9.1	7.6	15.5	.2	49.4	1.5	88.1
10	1.1	3.0	1.9	4.3	.1	15.6	.5	26.5
12	.5	1.2	.9	1.8	--	2.8	.2	7.5
14	.2	.8	.8	1.9	--	4.4	.1	8.2
16+	.1	.5	1.7	2.7	--	3.0	.2	8.2
Total	23.8	33.1	40.4	76.2	.9	195.7	7.4	377.5
1988								
6	20.7	19.7	35.8	64.0	.8	110.3	6.0	257.4
8	7.0	7.7	11.9	21.6	.3	7.0	2.2	57.7
10	2.9	3.7	5.0	8.5	.1	--	.9	21.2
12	1.1	1.7	2.1	3.3	--	--	.4	8.7
14	.4	.8	.9	1.4	--	--	.2	3.7
16+	.2	.6	1.4	1.7	--	--	.2	4.1
Total	32.4	34.1	57.2	100.6	1.3	117.4	9.8	352.8
1998								
6	19.5	17.6	34.6	61.6	.8	29.0	5.8	169.0
8	4.8	4.4	10.6	14.9	.2	2.5	1.9	39.3
10	3.2	2.7	5.7	9.8	.1	.1	1.1	22.9
12	1.9	1.9	3.4	5.8	.1	--	.6	13.8
14	1.0	1.0	1.8	2.9	--	--	.3	7.1
16+	.6	1.0	1.8	2.5	--	--	.3	6.2
Total	31.1	28.7	57.9	97.6	1.2	31.6	10.1	258.2

MICHIGAN - WESTERN UPPER PENINSULA

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
1978								
6	2.7	14.0	2.4	22.6	2.9	115.0	4.3	163.7
8	2.4	12.2	1.4	22.7	2.4	90.4	2.5	134.1
10	2.0	8.6	.5	20.4	1.3	63.0	2.3	98.2
12	1.6	7.0	.3	16.0	.6	38.2	2.2	66.0
14	1.3	6.9	1.1	14.6	.5	28.6	2.0	54.8
16+	.7	5.4	1.6	12.1	.4	20.8	1.1	42.2
Total	10.7	54.0	7.3	108.3	8.1	356.1	14.5	559.1
1988								
6	2.6	12.7	2.6	22.3	2.6	117.7	4.0	164.4
8	1.7	8.3	1.3	14.7	1.7	67.8	2.2	97.7
10	.7	3.6	.6	7.0	.7	27.2	.9	40.7
12	.5	1.8	.3	3.8	.3	11.7	.5	18.8
14	.8	3.6	.4	7.9	.3	18.3	1.1	32.5
16+	1.1	6.0	1.4	13.1	.5	25.6	1.7	49.4
Total	7.4	36.0	6.5	68.8	6.1	268.2	10.4	403.5
1998								
6	2.3	10.3	2.4	19.7	2.1	19.0	3.3	59.2
8	1.2	5.6	1.4	10.2	1.1	.9	1.7	22.2
10	1.0	4.1	.9	7.5	.8	--	1.2	15.5
12	.8	2.9	.6	5.6	.5	--	.8	11.2
14	.5	2.1	.4	4.3	.3	--	.6	8.2
16+	.9	2.9	1.0	6.2	.3	--	.9	12.2
Total	6.6	28.0	6.7	53.6	5.2	20.0	8.5	128.6

MICHIGAN - NORTHERN LOWER PENINSULA

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
1978								
6	6.5	9.7	2.8	22.7	23.0	191.8	6.7	263.4
8	3.8	6.8	3.2	22.5	19.8	172.8	6.9	235.6
10	2.1	3.9	2.5	18.6	15.2	125.9	4.5	172.8
12	1.4	2.6	2.1	17.2	10.3	84.9	2.6	121.3
14	.9	1.8	2.1	14.1	6.0	52.7	1.4	79.0
16+	.7	2.0	2.8	12.7	3.3	35.6	1.2	58.2
Total	15.4	26.8	15.5	107.8	77.6	663.7	23.3	930.3
1988								
6	6.6	8.0	2.9	21.1	20.2	183.4	6.1	248.2
8	3.5	5.2	2.0	14.6	13.7	118.3	4.4	161.7
10	1.2	2.0	.9	6.8	6.0	50.5	2.0	69.5
12	.6	1.0	.6	4.7	3.6	29.1	1.1	40.6
14	.5	1.0	.8	5.9	3.4	28.4	.9	40.9
16+	.9	2.0	2.1	11.9	4.6	41.2	1.2	63.9
Total	13.3	19.2	9.3	65.0	51.5	450.8	15.7	624.8
1998								
6	6.2	6.0	2.7	18.2	16.5	46.7	5.1	101.4
8	2.9	3.4	.5	9.6	8.9	2.7	3.0	31.1
10	1.7	2.8	.6	6.8	6.3	.1	2.1	20.2
12	.9	1.9	.3	4.6	4.1	--	1.3	13.2
14	.5	1.1	.2	3.1	2.3	--	.7	7.9
16+	.4	1.6	.7	7.0	3.2	--	.9	13.8
Total	12.7	16.9	4.9	49.3	41.3	49.5	13.1	187.6

(Continued on next page)

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
				MINNESOTA - LAKE SUPERIOR				
1978								
6	14.0	20.3	2.7	10.7	0.1	418.7	28.4	494.8
8	13.8	16.8	1.6	9.9	1.0	458.9	19.4	521.4
10	8.3	10.8	2.1	8.1	.7	349.8	14.9	394.7
12	3.6	5.8	2.2	5.1	.3	222.1	9.8	248.8
14	3.3	2.7	1.4	2.8	.1	124.3	4.9	139.6
16+	3.0	2.6	.6	1.3	--	69.8	2.2	79.6
Total	46.0	59.0	10.6	37.9	2.2	1,643.6	79.6	1,878.9
1988								
6	19.6	28.2	5.6	15.3	.1	361.0	39.6	469.3
8	16.7	22.2	3.1	12.4	.7	471.1	28.7	554.7
10	12.4	16.0	2.2	10.0	.8	427.1	20.5	489.0
12	7.6	10.5	2.2	7.5	.6	327.1	14.5	370.1
14	5.2	6.5	2.1	5.4	.3	234.0	9.9	263.4
16+	5.7	5.3	1.9	4.3	.2	199.4	7.9	224.8
Total	67.2	88.7	17.1	54.9	2.7	2,019.7	121.1	2,371.3
1998								
6	26.4	37.7	9.2	20.8	.2	310.4	53.4	458.1
8	21.0	29.0	5.4	16.1	.5	439.8	39.8	551.6
10	16.1	21.5	3.4	12.5	.7	449.8	28.6	532.5
12	11.9	15.7	2.6	9.9	.7	403.9	21.0	465.6
14	8.9	11.5	2.5	8.2	.6	349.7	16.1	397.4
16+	10.8	12.6	3.6	9.7	.5	434.3	18.4	490.3
Total	95.1	128.0	26.7	77.2	3.2	2,387.9	177.3	2,895.5
				MINNESOTA - CENTRAL PINE				
1978								
6	19.0	9.2	2.1	11.8	7.0	362.2	9.2	420.5
8	16.7	6.9	1.4	10.7	10.5	534.9	10.4	591.5
10	11.8	4.9	4.5	11.1	10.8	443.2	11.2	497.5
12	5.7	2.3	3.1	8.7	6.2	231.3	7.0	264.3
14	2.6	1.0	4.3	10.0	2.7	105.6	3.6	129.9
16+	1.2	.4	4.7	7.9	1.0	45.8	2.0	63.3
Total	56.9	24.8	20.2	60.3	38.2	1,723.1	43.4	1,967.0
1988								
6	18.7	9.1	3.3	13.1	7.2	274.4	10.6	336.4
8	19.7	8.8	2.2	12.9	10.0	487.1	11.5	552.3
10	16.3	7.0	3.3	12.3	11.2	512.8	11.9	574.8
12	10.0	4.2	3.2	9.6	8.3	353.0	8.9	397.2
14	5.6	2.3	3.5	9.0	5.4	214.1	6.1	245.9
16+	3.6	1.3	5.6	11.3	3.7	142.1	4.7	172.7
Total	74.0	32.7	21.1	68.2	45.8	1,983.7	53.8	2,279.3
1998								
6	17.5	8.5	4.2	13.7	7.0	204.6	11.7	267.2
8	20.0	9.3	3.1	13.8	9.2	392.8	12.5	460.6
10	18.8	8.4	3.0	13.3	10.6	485.7	12.6	552.5
12	13.5	5.8	2.8	10.5	9.0	404.9	10.1	456.7
14	9.3	3.9	3.1	9.4	7.3	311.7	8.1	352.8
16+	8.6	3.5	6.4	15.7	7.8	317.8	9.2	369.0
Total	87.8	39.4	22.7	76.4	51.0	2,117.5	64.1	2,458.8
				MINNESOTA - RAINY RIVER				
1978								
6	4.4	29.5	14.5	10.2	0.4	114.4	1.8	175.2
8	1.9	12.6	5.7	4.5	.2	113.2	.9	139.0
10	.7	6.9	2.3	5.5	.1	82.4	.6	98.4
12	.2	3.3	.9	5.2	--	39.4	.4	49.3
14	--	2.0	.4	4.4	--	16.4	.2	23.5
16+	--	1.0	.2	2.7	.1	7.3	.2	11.8
Total	7.3	55.3	23.9	32.6	.7	373.2	4.1	497.2
1988								
6	9.0	59.4	31.5	21.2	.7	94.1	4.9	220.8
8	4.0	26.5	13.3	9.4	.3	105.9	2.1	161.5
10	1.6	11.4	5.2	5.0	.1	77.7	1.0	102.0
12	.6	4.9	1.9	3.5	.1	45.3	.4	56.7
14	.2	2.8	.8	3.6	--	28.2	.3	36.0
16+	.1	1.7	.6	2.8	--	14.4	.4	19.9
Total	15.5	106.7	53.2	45.5	1.3	365.6	9.1	597.0
1998								
6	18.3	119.8	65.7	43.3	1.4	78.7	11.5	338.8
8	8.2	53.5	28.5	19.2	.6	92.6	5.3	208.0
10	3.2	21.2	10.8	7.8	.3	65.3	2.4	111.9
12	1.1	7.9	3.8	3.3	.1	37.4	1.0	54.7
14	.5	4.2	1.8	2.8	.1	30.3	.5	49.2
16+	.3	2.8	1.1	3.1	--	23.2	.4	30.9
Total	31.6	209.4	111.7	79.6	2.5	327.6	21.1	783.6

(Continued on next page)

Year and d.b.h. class	Red, white, and jack pine	Balsam fir-white spruce	Black spruce tamarack, and cedar	Northern hardwoods	Oak-hickory	Aspen	Birch, nonstocked and other	Total
				WISCONSIN - NORTHEASTERN				
1978								
6	7.8	10.6	7.7	33.6	6.4	178.2	6.9	251.3
8	4.1	6.0	3.2	19.0	4.3	111.4	4.6	152.7
10	2.5	3.3	1.2	11.4	2.2	55.6	2.6	78.8
12	1.2	1.4	.7	5.5	1.0	20.8	1.2	31.9
14	1.1	1.0	.3	4.7	.9	13.6	1.1	22.8
16+	1.2	.6	.3	4.6	.8	2.5	.9	11.0
Total	18.0	23.0	13.5	78.7	15.7	382.2	17.4	548.5
1988								
6	10.2	12.6	10.8	45.3	7.9	33.0	8.5	128.4
8	4.7	4.7	5.1	16.0	3.0	1.8	3.5	38.8
10	2.8	3.0	2.7	10.0	2.1	--	2.4	23.0
12	2.0	2.2	1.5	6.6	1.5	--	1.8	15.5
14	1.2	1.3	.8	4.0	.9	--	1.1	9.4
16+	1.8	1.3	.7	6.6	1.3	--	1.5	13.2
Total	22.7	25.1	21.6	88.6	16.7	34.8	18.8	228.3
1998								
6	10.2	11.8	11.0	45.5	7.6	61.8	8.5	156.3
8	7.6	4.0	8.3	13.3	5.5	5.5	6.1	50.2
10	5.0	3.9	5.2	13.1	3.5	.4	4.0	35.2
12	3.3	3.2	3.1	10.4	2.4	--	2.6	25.1
14	2.1	2.3	1.8	7.2	1.6	--	1.8	16.8
16+	3.0	2.7	1.7	10.3	2.1	--	2.8	22.3
Total	31.2	27.8	31.1	99.8	22.7	67.6	25.8	306.0
				WISCONSIN - NORTHWESTERN				
1978								
6	15.7	12.4	7.0	61.1	19.5	325.5	14.9	456.1
8	7.1	6.0	2.3	32.0	12.6	212.2	8.2	280.4
10	5.1	4.4	1.0	24.7	10.7	147.2	6.1	199.2
12	3.5	3.4	.6	21.7	8.9	95.6	4.9	138.5
14	2.1	2.5	.3	18.5	6.3	57.3	3.3	90.4
16+	1.5	1.9	.1	15.1	3.6	30.0	1.8	54.1
Total	34.9	30.7	11.3	173.1	61.6	867.9	39.3	1,218.7
1988								
6	25.9	19.3	12.8	101.3	29.8	391.2	23.6	604.0
8	11.9	9.3	5.3	48.2	15.7	240.0	12.0	342.3
10	5.4	4.4	1.9	23.2	8.6	131.9	6.1	181.4
12	2.9	2.5	.7	14.4	5.8	78.4	3.7	108.4
14	2.2	2.3	.4	14.2	5.5	61.3	3.1	89.0
16+	2.3	2.4	.4	17.0	5.6	53.5	3.0	84.1
Total	50.6	40.1	21.5	218.4	71.0	956.2	51.5	1,409.3
1998								
6	35.4	25.7	18.2	138.6	39.3	413.1	32.0	702.4
8	17.3	12.9	8.5	68.3	20.3	256.8	16.9	401.1
10	6.5	5.0	3.0	26.0	8.2	113.8	7.5	170.0
12	2.0	1.6	1.0	8.5	2.9	41.5	3.0	60.7
14	1.5	1.3	.5	7.7	2.9	37.6	2.2	53.8
16+	2.0	2.0	.4	12.8	4.7	49.1	2.9	73.9
Total	64.8	48.4	31.6	262.1	78.4	911.9	64.6	1,461.8
				WISCONSIN - CENTRAL				
1978								
6	13.7	0.5	2.3	27.4	42.9	179.0	7.2	273.1
8	4.8	.3	1.0	12.0	20.8	103.5	2.6	145.0
10	1.6	.3	.5	9.3	12.8	60.8	1.2	86.5
12	.7	.2	.5	7.0	8.9	33.7	.8	51.7
14	.4	--	.4	4.8	5.9	16.4	.5	28.4
16+	.2	--	.2	3.0	3.6	7.2	.3	14.5
Total	21.4	1.4	4.9	63.5	94.9	400.5	12.6	599.2
1988								
6	32.6	1.3	5.5	60.2	91.5	256.2	17.6	464.8
8	13.9	.6	2.4	28.0	44.3	167.9	7.6	264.8
10	5.6	.4	1.1	14.8	23.1	101.8	3.3	150.2
12	2.3	.2	.7	9.4	13.6	60.1	1.6	87.8
14	1.0	.2	.5	7.1	9.4	36.0	.9	55.0
16+	.6	.1	.5	6.9	8.4	25.4	.7	42.7
Total	56.1	2.8	10.8	126.3	190.3	647.5	31.7	1,065.4
1998								
6	63.1	2.4	10.6	112.8	169.3	321.5	34.4	714.1
8	31.2	1.3	5.3	58.1	88.8	241.7	17.3	443.7
10	14.9	.7	2.6	30.4	47.1	162.0	8.6	266.4
12	6.8	.4	1.4	16.9	25.9	102.7	4.2	158.3
14	3.2	.3	.8	11.2	16.2	67.1	2.2	100.9
16+	2.0	.3	1.0	13.1	17.3	63.1	1.8	98.6
Total	121.3	5.3	21.7	242.4	364.6	958.2	68.5	1,782.0

1/ The program was written to print volume estimates by d.b.h. class only every ten years consequently these estimates are for years ending in "8" instead of "0." Table may not add to totals due to rounding.

stock, the region as a whole can support the projected cut until about 1995. At that time, the east half of the U.P. will suffer a reduction in cut that is not likely to be offset by available growing stock in the Northwest and Central Units.

The growing stock projections explain why cut will be diminished. The rapid and steady decrease in the Northeast and U.P. Units in the early years will result in a resource base incapable of supporting the cut. The inventory will finally level as cut is reduced and then will begin a slow climb upward.[3]

The growing stock in the Northwest Unit will increase at a decreasing rate as it is allocated more cut. The Central Unit's increase in growing stock will be rapid and occurs in the projections because the aspen type increased in the *recent trends* and because historically the Unit supplied only 7 percent of the Wisconsin cut. Actually, one would expect cut to shift into the Central Unit as the supply diminished in other units resulting in less growing stock.

The proportion of volume in 10-inch and smaller d.b.h. classes is about the same in 1998 as in 1968 in the Northeast and west half of the U.P. Units; about 10 percent higher in the Northwest and east half of the U.P. Units; and about 5 percent lower in the Central Unit.

Breakup

Under the *breakup* assumptions the cut will be reduced 3 to 5 years sooner in those units that previously had a reduced cut, will drop more sharply, and usually will reach a lower level.[4] Once again the region as a whole supports the total cut until the cut in both units in the U.P. has diminished and then virtually all the cut comes from the 6- and 8-inch d.b.h. classes. The pattern in 1998 is also similar to *recent trends* except now almost all of the Northwest Unit's cut is in the 6-, 8-, and 10-inch d.b.h. classes.[5]

The growing stock volume will follow the same general pattern as that in *recent trends* but will be lower. One exception is the Northwest Unit which dropped sharply during the last 10 years. On the average, 95 percent of the growing stock volume is in trees 10 inches d.b.h. and smaller in 1998.

Positive Practices

Under the *positive practices* assumptions each unit will be able to support its allocated cut. Essentially, the cut will be further reduced in those units where cut had already been diminished and increased in the Northwest and Central Units. In 1998, 65 percent of the cut will come from the 6- and 8-inch d.b.h. classes; individual units will range between 47 and 79 percent—an improved distribution.

The growing stock picture is heartening but not good. In units where cuts had previously been diminished, the inventory level will be higher than under either of the previous sets of assumptions but still will show a downward trend. A lower level and a downward trend will prevail in the Northwest Unit as it sustains much more of the cut than before, and the inventory in the Central Unit will increase at an increasing rate but will reach more realistic levels. The amount of growing stock volume in the 6-, 8-, and 10-inch d.b.h. classes in 1998 will decrease in the Northeast and west half of the U.P. Units, remain about constant in the Northwest and the Central Units, and increase in the east half of the U.P. Unit.

In summary, a diminished cut is likely in the Northeast Unit in 15 to 20 years and in the two U.P. Units in 20 to 25 years. The cut in these units, both immediately preceding and continuing after cut has been reduced, will be almost all in the 6- and 8-inch

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[3] *The inventory increases after a diminished cut because cut is limited by growing stock; e.g., cut must be less than 80 percent of the growing stock. This means that a larger absolute amount of growing stock must be available each year before it can be cut again when, as in these projections, the amount of cut keeps increasing.*

[4] *In some cases, such as the Northeast Unit, the* breakup *cut recovers sooner than the* recent trends *cut. This happens because cut is diminished sooner allowing the growing stock to recover sooner and support the cut.*

[5] *The Northwest and Central Units show a higher cut under the* breakup *than under the* recent trends *assumptions. This is caused by the greater diminished cut in the Northeast and west half of the U.P. Units being allocated to these units and their growing stock levels being high enough to support the increased cut.*

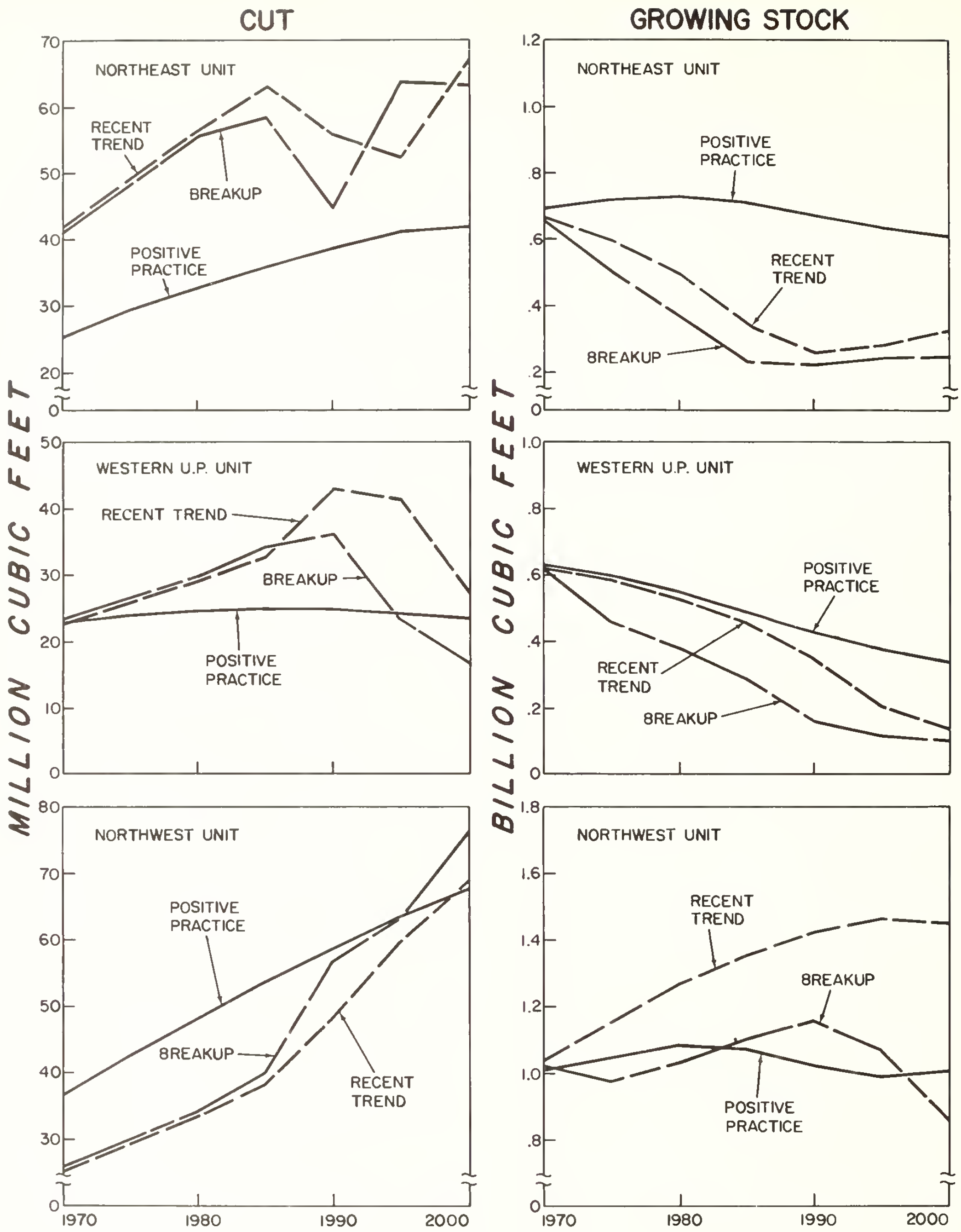

Figure 3.—Projections for Wisconsin—U.P. region, 5-year average every 5 years.

d.b.h. classes. The region as a whole can compensate for the diminished cut in the Northeast Unit but, by assumption, not in the east half of the U.P. Unit. Inventory will continue to decrease except under the *recent trends* projections in the Northwest Unit and all projections in the Central Unit. This is true even in the *positive practices* assumptions where ingrowth is doubled after the 25th year of projections.

Implications

Several implications can be drawn from these results. First, wood-using industries will have to shift

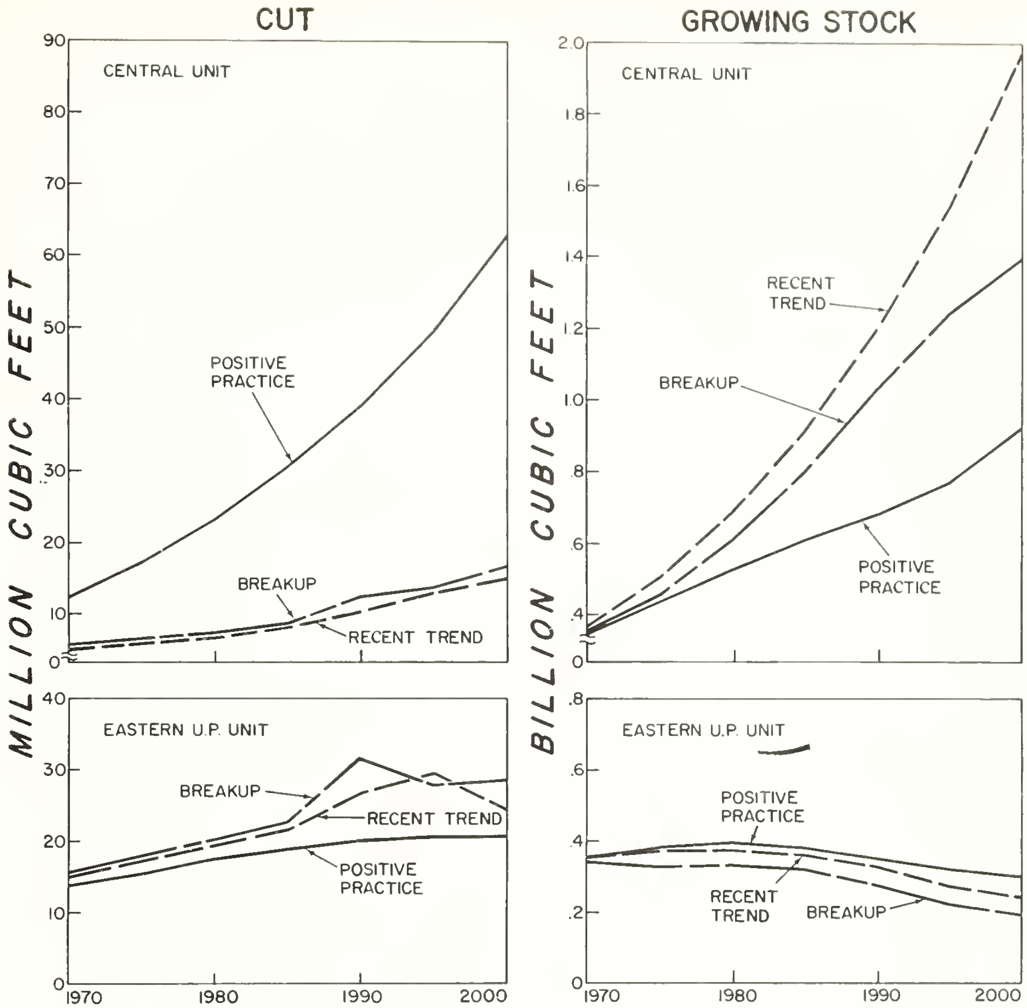

Figure 3 continued

their wood procurement areas or plan on using less aspen. In the early years of the projections this means a substantial shift to the Northwest and Central Units. This shift would certainly increase costs, probably mostly in transportation and in developing or shifting the producer-procurement organization. Determining the amount of these costs is beyond the scope of this study and whether they will be worthwhile or not must be assessed by the individuals incurring them. However, prices of aspen in those units would be expected to increase in future years as the supply is decreased, so costs should increase regardless of whether procurement is shifted or not.

One response to decreased aspen availability would be to substitute more abundant species for aspen. Whether there will be sufficient volumes of other species at acceptable prices is also beyond the scope of this study. Another alternative would be to increase capacity only in regions where aspen or a suitable substitute is available.

A second implication is that mills should avoid installing new capital equipment or processes that can only use aspen. This would give them greater flexibility if they found it necessary to substitute other species for aspen.

The third implication stems from the projected small diameters cut in the *recent trends* and *breakup* projections. The dependency of materials handling systems on lineal rates of flow means that handling costs may increase as the diameter of the stock cut decreases. New harvesting and processing systems will probably have to be developed if costs are to be held at a reasonable level.

Fourth, the projected decreased diameter of aspen cut and growing stock should make it increasingly difficult and expensive for nonpulping industries, such as sawtimber and veneer, to obtain their raw materials.

A fifth implication flows from the *positive practices* assumptions. These demonstrate there are steps we can take to improve the future resource. The long time it takes our actions to be reflected in increased inventory and a more smoothly flowing cut means there is little time to lose. The actions we take today will not be reflected in merchantable timber for 20 to 25 years.

Northern Lower Peninsula

In this region, consisting of only one survey unit, cut will be maintained under both the *recent trends* and *positive practices* assumptions until the final years of the projections (fig. 4). The *breakup* assumptions will reduce the cut again, about 5 years *earlier* than the *recent trends* projections. Almost all the cut will be in the 6- and 8-inch d.b.h. classes by the time it is diminished (a trend common by now) except under *positive practices* where only 70 percent will be in these classes.

In all projections the growing stock shows a sharp downward trend and the volume in trees smaller than 12 inches d.b.h. ranges from 90 percent for *breakup* to 73 percent for *positive practices*. Because there is only one unit in this region the reallocation of cut under *positive practices* does not have the significance it usually does.[6] However, the effect of doubling the ingrowth after the 25th year should still be reflected.

Many of the implications discussed in the Wisconsin-U.P. region also apply to this region. The wood-using industries would either have to shift their procurement to another area (a costly and unlikely prospect) or decrease their use of aspen. Both the materials handling and nonpulping industry difficulties could also exist. The cut would be *diminished* about 2 years later than in the combined region—about the same time as in the U.P. However, things would not be as bleak as they appear if the southern

[6] *Cut allocation by volume does have another effect. More cut goes to the 6- and 8-inch d.b.h. classes which consequently have lower volumes, particularly in the later years. The growth percents for this unit are 0 for the 14-inch-and-larger class and less than 1 for the 10- and 12-inch classes. The redistribution of volume to d.b.h. classes where growth is low causes the* recent trends *projections to have higher growing stock levels and cut than* positive practices.

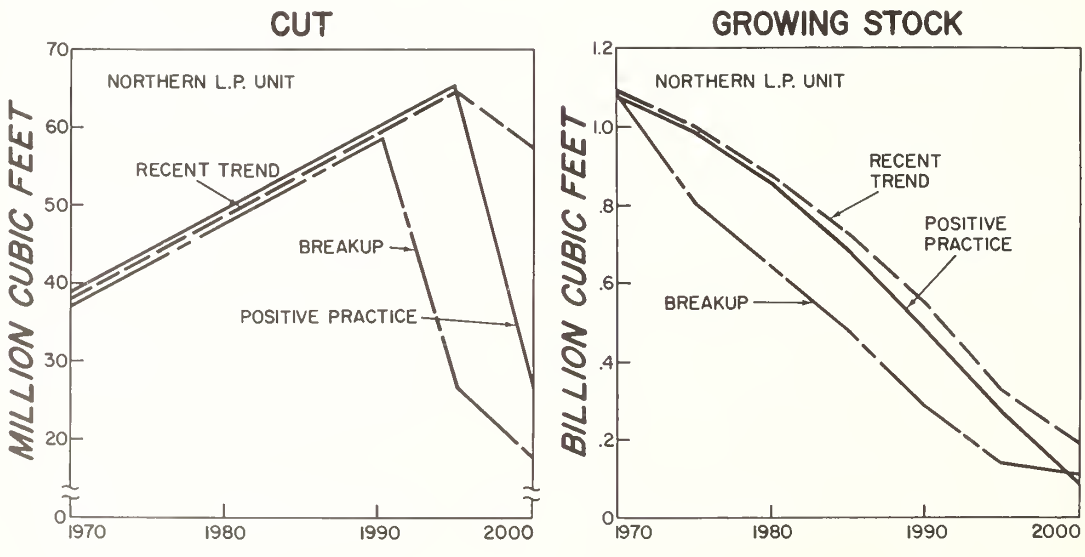

Figure 4.—Projections for Northern Lower Peninsula region, 5-year average every 5 years.

half of the L.P. Unit were able to support some of the cut under the *positive practices*. Unfortunately, time was not available to make this analysis.

The generally poor response of the resource to the *positive practices* assumptions is due, at least in part, to the inability of the model to shift cut to another unit and in part to the low growth percents in this unit. These percents, as discussed in the appendix, might increase if the positive practices are instituted resulting in increased inventory. In summary, it appears this region will not support its historical trend and diameter distribution of cut indefinitely and some rather strong steps must be taken if we desire to maintain the resource at its present level.

Minnesota

The results of the Minnesota projections are the least reliable of those reported here. The forest survey statistics are the oldest (1962) and in the interim data collection and computation techniques have been constantly improving. Moreover, the Minnesota survey included data supplied by cooperators. In many cases these data were not available for this study or were not in a form adaptable to current computer techniques and so some data from surveys of other States were substituted. For example, the growth percents for Wisconsin's Northwest Survey Unit were used for the Lake Superior and Rainy River Survey Units.

Regardless of the assumptions used, the projected cut is supported in each of the units over the entire period of the projections (fig. 5). The *recent trends* and *breakup* projections show about 40 percent of the cut in d.b.h. classes 12 inches and larger in both 1968 and 1998. The *positive practices* projection, because it allocates cut in proportion to aspen volume, shows 13 percent and 50 percent in these classes in 1968 and 1998, respectively.

The results of the different assumptions are more apparent in the growing stock projections. If *recent trends* continue there is a large increase in growing stock in every survey unit. Even under the *breakup* assumptions, the Lake Superior and Rainy River Units first show increasing and then decreasing inventories although the Central Pine Unit registers a fairly sharp drop.

The *positive practices* projections show a redistribution of inventory to more realistic levels in the two larger survey units, although the total inventory is slightly lower throughout the projection period than in *recent trends*. The advantage, if any, accrues to improved volume distribution by diameter. The *positive practices* assumptions show about 5 percent more volume in the Lake Superior and Central Pine Units and about 20 percent more volume in the Rainy River Unit in the 12-inch and larger d.b.h. classes in 1998 than the *recent trends* projections.

Many foresters believe northern Minnesota has the best aspen sites in the Lake States. If this is true, the growth percents should be higher than those in the Northwest Unit and the Minnesota volume projections in the Lake Superior and Rainy River Units are conservative.

The future of aspen for timber in the Minnesota region is bright. The projected cut is supported by the resource and well distributed by d.b.h. class. The growing stock, which in two units is conservatively estimated, responds well regardless of the assumptions used. The only exception is the *breakup* projection in the Central Pine Unit which shows growing stock remaining constant for 15 years and then sharply dropping. This may indicate the resource conditions should be closely monitored in this unit in future years. The consistently high growing stock levels under other assumptions and for other survey units may indicate the region can support a cut even greater than projected.

SUMMARY AND CONCLUSIONS

We cannot expect today's apparent surplus of aspen to continue indefinitely in all regions of the Lake States if the historical trends of cut, growth, and utilization continue into the future. The degree to which historical trends cannot be followed varies by geographical location.

The northeastern survey unit in Wisconsin and all of Michigan's Upper Peninsula show a generally

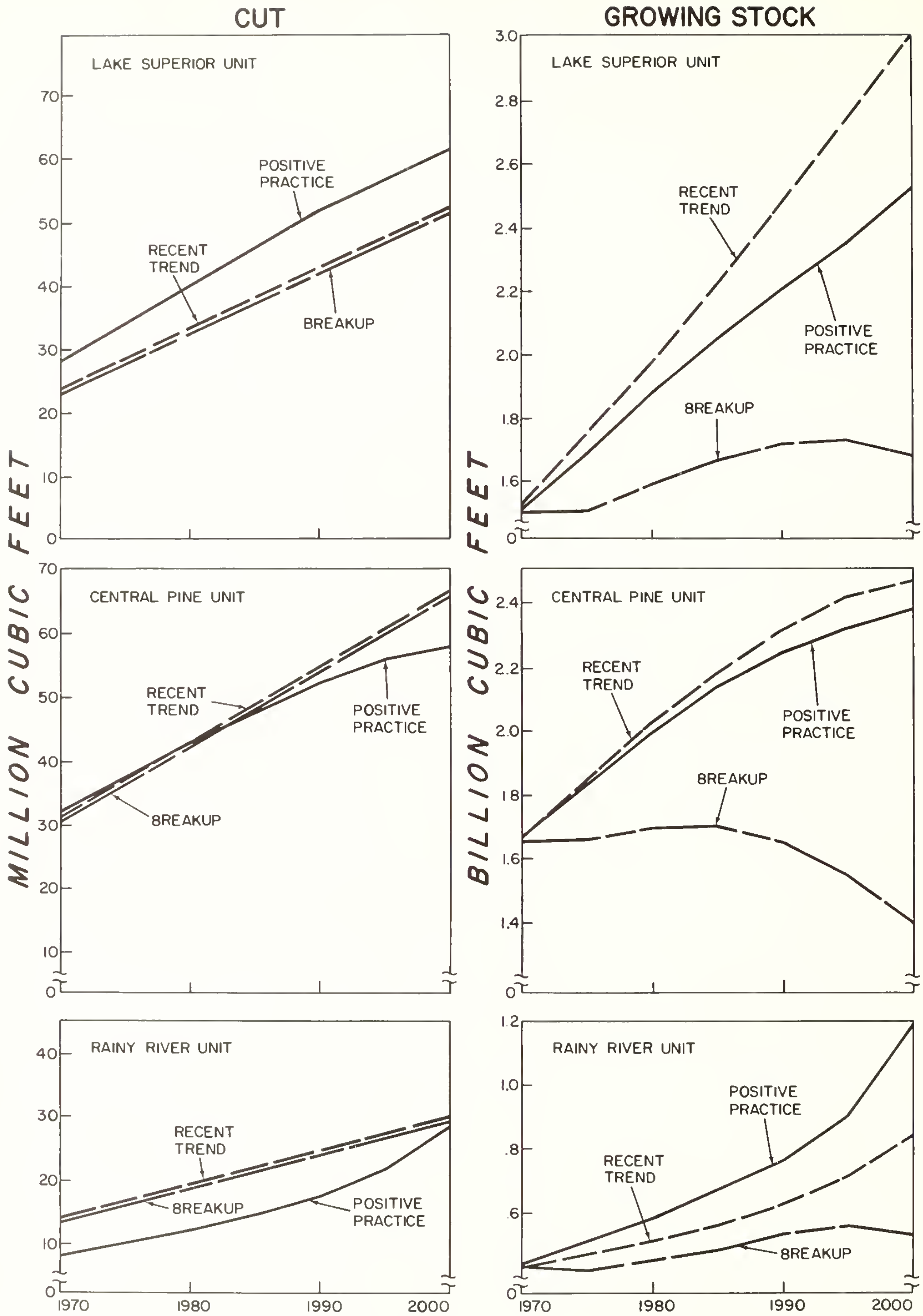

Figure 5.— Projections for Minnesota region, 5-year average every 5 years.

unfavorable picture. The historical cut is likely to be diminished in the Northeast Unit in 15 to 20 years and in the U.P. in 20 to 25 years. In addition, after cut is reduced in these units, most of it will be in the 6- and 8-inch d.b.h. classes. With a few exceptions the growing stock projections show a generally deteriorating picture. However, the *positive practices* projections indicate each survey unit can support its reallocated cut and that the overall condition of the resource can be improved from what it would have been if historical trends continued. These projections also show more cut and growing stock volume in the larger diameter classes.

Michigan's Northern Lower Peninsula supports its historical trend of cut during most of the projection period but at the expense of a constantly deteriorating resource. Even the *positive practices* projection shows a continued sharply decreasing inventory although the diameter distribution of the cut improves.

The northernmost survey units in Minnesota, which currently contain almost half the estimated aspen growing stock in the study area, have the brightest outlook. The projected cut is supported and the ending inventory is higher than present in all cases except the *breakup* projections in the Central Pine Unit. The consistently higher inventory may indicate the region can support more than the projected cut.

Unfortunately, these projections do not answer many questions for wildlife managers and sportsmen. The ability of the resource to support future deer and grouse populations depends in part on which set of assumptions most closely represents future practices. However, there is an opportunity to improve wildlife habitat, regardless of future growing stock levels, if wildlife managers are consulted when timber sales are made. The spatial design of the sale, the amount of residual stand, and other items can have either a positive or negative effect on wildlife populations.

Several conclusions can be drawn from these projections. First, forest industries drawing their aspen from Michigan and Wisconsin must plan to procure their wood elsewhere within these States, substitute other species for aspen, or cut less than the projected amount of wood during the next 15 to 25 years. Further, firms planning replacement of their capital equipment would be wise where possible to install equipment and processes that can substitute other wood species for aspen at minimum cost.

Second, the diminished cuts of aspen are almost always accompanied by increased cutting in small diameter trees. If these diameters are unacceptable, users will have to reduce their cut even further. In addition, the smaller diameters may mean increased materials handling costs from harvesting through the chipper or saw and increased difficulty and expense for industries requiring large diameter aspen as a raw material.

On the other hand, the *positive practices* projections indicate, particularly in the Wisconsin-U.P. region, that actions taken by land managers could maintain an even and increasing flow of aspen from most survey units over time while improving the relative condition of growing stock inventories.

However, the actions necessary to effect a change mean that costs must be borne by the public and/or private sectors. As in most forestry investments, the costs are incurred today whereas the benefits are received in the future and it is not always certain that the parties bearing the costs will receive the benefits. Whether these costs would, or more importantly, should be incurred is not answered by this study. We have demonstrated, however, that it is possible to maintain both an increasing aspen cut and the resource in the Lake States if we choose to do so.

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APPENDIX

This appendix explains the projection model more fully and presents and discusses the estimated values of the variables used in the projections.

Calculating Commercial Forest Area

The first step in the program is calculating commercial forest area (fig. 2). The change in commercial forest area in a type within a survey unit is the product of the acres in that type at the beginning of the year and the percent of acreage changed in the aspen type (PACHG) between the two most recent forest surveys. The amount of breakup occurring in the intersurvey period is therefore automatically reflected in the acreage change.

The net change may be either positive or negative. However, we know some acres enter commercial forest from such things as abandoned farms even while others leave, so it was assumed that a net acreage decrease consisted of 1 acre entering the system for every 2 acres leaving it. Conversely, a net increase was assumed to have 1 acre leaving for every 2 acres entering.

The changes in growing stock volume due to changes in acreage are derived from these estimates and assumptions. Subtracted from growing stock volume is the average volume per acre (by type and survey unit) in the current year of the projection multiplied by the acres calculated above having a negative sign. Additions to volume are the number of acres with a positive sign that would have entered 25 years before times 100 cubic feet per acre for nonaspen types and 400 cubic feet per acre for the aspen type.

The latter step assumes there is no volume on additions to acreage and that it takes 25 years for measurable volume to appear. The estimate of 25 years and 400 cubic feet is based on Kittredge and Gevorkiantz (1929) and Schlaegel (1971). Due to lack of better data the nonaspen ingrowth was set at 25 percent of this or 100 cubic feet per acre.

Calculating and Allocating Cut

Annual cut is calculated and allocated next. First, the cords of aspen pulpwood cut in a particular year and State are calculated and this figure is divided by the proportion of cut used for pulpwood (PCTPW) and multiplied by 80.0 to obtain cubic feet. This is the total estimated aspen cut in the State.

The cut allocated to a survey unit is the State cut multiplied by the historical proportion of the cut coming from that survey unit (PSUCUT). The amount of diminished cut from any preceding survey units is then added in proportion to the remaining original State cut. For example, if there are three survey units in a State, with historical proportions of the cut of 0.2, 0.3, and 0.5 respectively, and if the first survey unit cut has diminished 1,000,000 cubic feet, the second unit will be allocated $0.3/(0.3 + 0.5) =$ three-eighths or 375,000 cubic feet and the third unit will be allocated five-eighths or 625,000 cubic feet.

Survey unit cut is then allocated to d.b.h. class within the survey unit based on the historical proportion of the cut coming from each d.b.h. class (PBHCUT). The cut in a particular d.b.h. class is next allocated to cover type in the proportion of the aspen growing stock volume in that type and d.b.h. class to the total aspen growing stock volume in the d.b.h. class in the survey unit.

Under this system of allocation, it is assumed the user will try first to maintain the geographical location (survey unit) from which his cut has historically come because it is probably where his freight cost is at a *minimum* (Wynd and Manthy 1971) and his procurement organization is already established and functioning there. The diameter of the trees is assumed next in importance because of its effect on materials handling costs in both the woods and the mill. The buyer is assumed not to care what cover type the aspen is in as long as the diameter is large enough and there is a high enough volume per acre (the latter is accounted for by PCUGS below). For lack of better data, it is assumed the proportion of aspen growing stock in a cover type reflects its availability.

The amount of cut is then limited so it does not exceed a certain percentage of the growing stock (PCUGS). If it does not exceed that percentage the volume in that type, d.b.h. class, and survey unit for the beginning of the next year is calculated. If it is equal to or greater than that percentage, the cut for that type and d.b.h. is set to zero and the amount of the cut is distributed to the other types in that d.b.h. class in proportion to their aspen growing stock volume.

The cut in these types is again tested. If it passes the test, the volume for the beginning of the next time period is calculated. If it fails the test, the cut in that type is set back to what it was before the diminished cut was added and that part of the diminished cut is added to the cut in the pure aspen type and distributed over all d.b.h. classes.

The cut in each d.b.h. class in the aspen type is tested again. If the test is passed, the new volume is calculated; if it is failed, the volume in that d.b.h. class is set to what it was before the diminished cut was added and the diminished cut is added to the remaining survey units as explained above.

The rationale for this procedure is the same as before. It implies that costs of moving to a different survey unit exceed the costs of cutting smaller diameter trees and therefore any diameters available within the aspen type are cut before changing survey units.

Calculating Growth

The third step is to calculate growth for a type and d.b.h. class. The program first tests for a maximum volume per acre. This constraint was set high enough (1,000 cubic feet per acre) to be virtually ineffective because it was impossible to estimate a maximum volume *by d.b.h. class* and type. However, average volume per acre for all d.b.h. classes in each type and survey unit were checked visually for reasonableness.

Next, growth out of a particular diameter class was calculated as a proportion of the volume in that diameter class (PGOUT). This becomes the growth into the next diameter class for all but the 6-inch class. This step reflects the growth of trees out of one d.b.h. class and into the next.

The growth into the 6-inch d.b.h. class, on acreage that has been commercial forest, reflects the amount of aspen reproduction. In the pure aspen type the absolute cubic foot ingrowth (ASINGRW) is added; in a nonaspen type the proportion of ingrowth to the volume of the 6-inch class (PGIN) is multiplied by the volume in the 6-inch class to obtain the ingrowth estimate. This procedure reverses the direction of causality and is purely empirical, but was forced by lack of data.

Calculating Beginning Volume

The final step is to calculate growing stock volume for the beginning of the next year for a specific d.b.h. class within a cover type and survey unit by the formula:

$$(1)\ VOLT_{t+1} = VOLT_t - CUT_t + AAVOLT_t - SAVOLT_t + GRWTHP\left(\frac{CUT_t}{2} + \frac{AAVOLT_t}{2} + VOLT_t - CUT_t - SAVOLT_t\right) + GIN_t - GOUT_t$$

where:

t	=	the t^{th} time period (year) of the projection.
VOLT	=	the total growing stock volume for a specific d.b.h. class within a cover type and survey unit.
CUT	=	the estimated cut as explained above in "CALCULATING AND ALLOCATING CUT."
AAVOLT	=	total additions to growing stock volume due to additions to commercial forest acreage as explained above in "CALCULATING COMMERCIAL FOREST ACRES."
SAVOLT	=	total subtractions from growing stock volume due to subtractions from commercial forest acreage as explained above in "CALCULATING COMMERCIAL FOREST ACRES."
GRWTHP	=	growth percent for a specific d.b.h. class and survey unit.
GIN	=	volume of ingrowth as explained above in "CALCULATING GROWTH."
GOUT	=	volume of outgrowth as explained above in "CALCULATING GROWTH."

A fuller discussion of this formula and its theoretical considerations is found in Leuschner (1972).

Estimating the Variables

The variables are discussed in the order mentioned in the preceding sections on the projection model.

Commercial Forest Acres

The commercial forest acreage by survey unit and cover type are published in all forest survey reports. The projection model required all estimates be for the year 1968. There was no need to update Wisconsin acres, because the year of the survey was 1968.

An unpublished estimate of commercial forest acreage was available at the North Central Forest Experiment Station for Michigan and Minnesota. The compound rate of change between this estimate and the survey year was calculated and the commercial forest acreage in each of the cover types and survey units changed in this proportion. The amount of error in Michigan is probably negligible because the update was only for 2 years; that in Minnesota may be greater because the update was 6 years.

Percent Acreage Change (PACH)

This variable was used to calculate the annual net acreage change in commercial forest acres. It was derived from the compound rate of change in the aspen-birch type between the two most recent forest surveys in Michigan and Wisconsin (table 8, 1st column). In Minnesota the overall compound rate of change in commercial forest acreage discussed in the last paragraph above was used for each survey unit because cover type definitions changed significantly between surveys.

State Pulpwood Cut

The derivation of the basic model for calculating cut is contained in Leuschner.[2] The cut estimate represents the intersection of short term supply and demand functions where demand is price inelastic. The simultaneous solution of these functions results in a model where the quantity cut is a function of woodpulping capacity in the State. This made it necessary to project woodpulping capacity which was accomplished by a simple time trend (table 9). The regression equations used to calculate both cut and capacity by State are:

(2) $CAP_{Mi} = 675.524 + 83.071\ T$

$R^2 = 0.85;\ F = 105.4;\ d.f. = 1/19;\ DW = 0.665$

(3) $CUT_{Mi} = 97.420 + 0.257\ CAP_{Mi}$

$R^2 = 0.75;\ F = 55.6;\ d.f. = 1/19;\ DW = 1.363$

(4) $CAP_{Mn} = 1{,}251.638 + 61.829\ T$

$R^2 = 0.94;\ F = 213.1;\ d.f. = 1/13;\ DW = 1.145$

(5) $CUT_{Mn} = -393.525 + 0.364\ CAP_{Mn}$

$R^2 = 0.84;\ F = 73.1;\ d.f. = 1/13;\ DW = 1.313$

(6) $CAP_{Wi} = 3{,}162.026 + 87.464\ T$

$R^2 = 0.97;\ F = 673.5;\ d.f. = 1/20;\ DW = 1.183$

(7) $CUT_{Wi} = -797.579 + 0.302\ CAP_{Wi}$

$R^2 = 0.91;\ F = 192.1;\ d.f. = 1/18;\ DW = 2.152$

where:
- Mi = the State of Michigan
- Mn = the State of Minnesota
- Wi = the State of Wisconsin
- CAP = the woodpulping capacity of pulp and paper mills in the State in daily tons.
- CUT = the annual cut of aspen pulpwood in the State in thousands of cords.
- T = a time trend where T = 1948 = 1.
- DW = The Durbin-Watson statistic for serial correlation.

Table 8.— Estimated values for projection variables.

Survey Unit	Acreage change	Proportion of State cut to S.U.	Ingrowth into aspen type	Ingrowth into nonaspen types
	Percent		M cu. ft.	Percent
Michigan:				
Eastern Upper Peninsula	-2.4	0.20	2,585	2.7
Western Upper Peninsula	- .1	.30	4,827	2.9
Northern Lower Peninsula	- .2	.50	7,370	2.7
Minnesota:				
Lake Superior	- .2	.35	1,696	4.7
Central Pine	- .2	.45	1,435	2.8
Rainy River	- .2	.20	315	9.3
Wisconsin:				
Northeast	-1.1	.58	6,361	3.7
Northwest	-1.6	.35	13,474	5.7
Central	1.4	.07	7,718	7.1

The calculation of capacity as a time trend has its obvious disadvantages. However, a full scale study of capacity trends in the Lake States was impossible because of the time and money it would have involved. The time trend approach did not seem unreasonable in this light and because we want to project the long term trend rather than the level in any specific year.

Table 9.— Projected woodpulping capacity by State (In daily tons)

State	Year 1970	1980	1990	2000
Michigan	2,586	3,417	4,248	5,078
Minnesota	2,674	3,292	3,910	4,529
Wisconsin	5,174	6,048	6,923	7,798

Proportion of Cut that is Pulpwood (PCTPW)

The estimate of cut must be increased to account for other uses of aspen because the regressions estimate only cords of pulpwood. This variable was estimated as of the forest survey year and is derived from the "cut by product" statistics presented in the survey. One value was used for the entire State:

State	*PCTPW*
Michigan	0.80
Minnesota	.68
Wisconsin	.85

PCTPW is somewhat lower in Minnesota than the other two States indicating that more aspen is used for nonpulpwood products. If this figure is too low the total Minnesota cut is estimated too high and even higher inventory levels would be found in Minnesota than are reported.

Proportion of State Cut to Survey Unit (PSUCUT)

The proportion of cut from a survey unit was obtained by plotting the aspen pulpwood cut by survey unit for 1959 through 1969. The approximate rather than precise proportion was chosen recognizing that the historical proportions would not remain precisely the same throughout the projection. Data were from Blyth (1970) and earlier reports of the same title. Notice the sum of PSUCUT for a State equals 1.0 (table 8, 2nd column).

Proportion of Cut by d.b.h. Class (PBHCUT)

These values were estimated from forest survey stump counts made in the year of the survey. Actual proportions of volume cut were estimated and the distribution ocularly smoothed (table 10). Wisconsin estimates were used in Minnesota because Minnesota apparently had missing data. They were also used for the entire Wisconsin-U.P. region because the program allowed for only one estimate per d.b.h. class and Wisconsin's was judged likely to be most correct for the majority of the volume cut in the region.

Proportion of Cut to Growing Stock (PCUGS)

This variable is the proportion of growing stock to which projected cut is constrained and is another variable easy to include but difficult to evaluate. It was estimated by calculating the proportion of growing stock by State, with a density at least 5 cords per

Table 10.— Proportion of cut initially allocated to d.b.h. class

D. b.h. class	Region: Minnesota	Wisconsin - U.P.	Northern Lower Peninsula
6	0.07	0.07	0.10
8	.22	.22	.20
10	.30	.30	.30
12	.22	.22	.20
14	.07	.07	.10
16	.05	.05	.05
18	.04	.04	.02
20	.02	.02	.02
22+	.01	.01	.01
Total	1.00	1.00	1.00

Table 11.— Proportion of cut to growing stock

Forest type	Region: Minnesota	Wisconsin - U.P.	Northern Lower Peninsula
Red, white, and jack pine	0.38	0.29	0.34
Balsam fir-white spruce	.58	.37	.24
Black spruce, tamarack, and cedar	.25	.19	.59
Northern hardwoods	.57	.41	.32
Oak-hickory	.34	.37	.35
Aspen	.90	.94	.95
Birch	.45	.38	.36
Other	0	0	0

acre in the nonaspen types and 2½ cords per acre in the aspen type (table 11). Cut in each d.b.h. class (within a type and survey unit) had to be less than the product of this variable and the growing stock in that class. The Wisconsin data were used for the entire Wisconsin-U.P. region following the rationale discussed under PBHCUT.

The reader may feel the proportions used are too high. However, a larger proportion than the reader suspects may be available over the long run due to such things as changes in ownership and decreasing harvesting costs. (Remember, absolute land withdrawal is accounted for in the reduction of commercial forest acreage.) PCUGS was estimated using density because this may be one of the more constant limiting factors.

If estimates of PCUGS are too high, too much growing stock was available for cutting and the diminished cuts occurred later than they should have. Diminished cuts could take place in other survey units as well, depending on how high the estimates were. There would also be higher levels of growing stock at the end of the projection period because lower estimates of PCUGS would mean less growing stock would be subtracted as cut.

Proportion of Volume Growing Out (PGOUT)

Growth of volume between d.b.h. classes must be estimated because the program estimates volume and growth by d.b.h. The growth out of one d.b.h. class becomes the growth into the next. The Wisconsin forest survey included a radial growth equation for the aspen-birch type which was used to estimate the proportion of the volume growing out of one diameter class into the next (table 12).

Table 12.— Proportion of volume growing out of a diameter class

D.b.h. class	Proportion	D.b.h. class	Proportion
6	0.059	16	0.076
8	.074	18	.052
10	.084	20	.028
12	.089	22+	.500
14	.086		

The value for the 22-inch and larger class was arbitrarily set at 0.5. This means that half of any volume in that class is "killed" in any particular year unless it is cut. This assumption seems reasonable in light of the relatively short life span of aspen and the age a tree must have reached to enter this diameter class.

The values in table 12 are from Wisconsin data but were used for all survey units because in Minnesota there were no radial growth equations and in Michigan it would have been necessary to have an estimate of site index, basal area, and stand age for each d.b.h. class, and these were impossible to obtain.

Aspen Ingrowth (ASINGRW and PGIN)

Ingrowth into the 6-inch d.b.h. class was estimated separately for the aspen and nonaspen types. Consultation with the forest survey project revealed net annual growth in the 4-inch class was an estimate of the ingrowth into the 6-inch class and the growth on that ingrowth. Consequently, this figure, estimated by survey unit, was assumed to be the ingrowth into the aspen type over the entire projection period (table 8, 3rd column).

Estimating ingrowth of aspen into the nonaspen types was a problem because there were no data. Therefore, the net annual growth in the 4-inch d.b.h. class in the aspen type was taken as a proportion of the aspen growing stock volume in the 6-inch d.b.h. class and used to estimate the ingrowth into the nonaspen types (table 8, 4th column). Each year the growing stock volume in the various nonaspen 6-inch d.b.h. classes was multiplied by PGIN to obtain the estimate of aspen ingrowth. As mentioned, this procedure reverses the causality and is purely empirical. However, no other reasonable alternative appeared available.

Growth Percent (GRWTHP)

Growth percent was estimated for each d.b.h. class in each survey unit by dividing the net annual growth by the growing stock volume (table 13). The estimate therefore includes (1) increment on trees in the d.b.h. class at the beginning and end of the year; (2) increment on trees entering the class during the year (but not the volume of the trees entering the class); and (3) mortality.

The estimate does not take into account trees that become unmerchantable during the year. Unfortunately, there was no way to estimate this volume but it was decided that the amount of the loss was probably insignificant in relation to the total amount of the estimate. Nonetheless, there is an upward bias in GRWTHP causing an upward bias in estimates of growing stock volume.

This is counterbalanced somewhat in the *positive practices* projections. Net annual growth is likely to be a function of stand age, condition, and other variables. This may be partly reflected in the lower growth percents in Michigan where the stands tend to be the oldest and past cutting the heaviest. The positive management practices simulated by these projections would probably increase the net annual growth and hence increase GRWTHP. If this is true the growing stock volumes in *positive practices* are biased downward by some amount.

Table 13.—Recent trends *growth percents by d.b.h. class and survey unit*

Survey Unit	D. b. h. class								
	6	8	10	12	14	16	18	20	22+
Michigan:									
Eastern Upper Peninsula	3.4	1.8	1.6	1.2	1.1	0.8	0.1	0.1	0.0
Western Upper Peninsula	3.4	1.6	1.4	1.1	.9	.6	.1	.0	.0
Northern Lower Peninsula	3.3	1.4	.8	.3	.0	.0	.0	.0	.0
Minnesota:									
Lake Superior	Assumed same as Northwest								
Central Pine	3.7	5.2	4.9	2.2	1.2	.8	.4	.2	.0
Rainy River	Assumed same as Northwest								
Wisconsin:									
Northeast	4.8	4.6	4.2	3.6	2.8	2.0	1.3	.9	.6
Northwest	4.9	4.7	4.3	3.6	2.8	1.8	1.1	.4	.5
Central	4.7	4.7	4.6	4.1	3.4	2.7	1.3	1.1	.0

☆U.S. Government Printing Office: 1972 – 760-951

SOME RECENT RESEARCH PAPERS OF THE NORTH CENTRAL FOREST EXPERIMENT STATION

Crosscut Shearing of Roundwood Bolts, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-68, 21 p., illus. 1971.

Storm Flow from Dual-Use Watersheds in Southwestern Wisconsin, by Richard S. Sartz. USDA For. Serv. Res. Pap. NC-69, 7 p., illus. 1971.

Annotated Bibliography of Walnut—Supplement No. 1, by Martha K. Dillow and Norman L. Hawker. USDA For. Serv. Res. Pap. NC-70, 23 p. 1971.

Fire Whirlwind Formation Over Flat Terrain, by Donald A. Haines and Gerald H. Updike. USDA For. Serv. Res. Pap. NC-71, 12 p., illus. 1971.

The Changing Hardwood Veneer and Plywood Industry of Michigan and Wisconsin, by Gary R. Lindell and Lewis T. Hendricks. USDA For. Serv. Res. Pap. NC-72, 8 p., illus. 1972.

Estimating Force & Power Requirements for Crosscut Shearing of Roundwood, by Rodger A. Arola. USDA For. Serv. Res. Pap. NC-73, 8 p., illus. 1972.

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Fire Weather and Behavior of the Little Sioux Fire, by Rodney W. Sando and Donald A. Haines. USDA For. Serv. Res. Pap. NC-76, 6 p., illus. 1972.

Canoeist Suggestions for Stream Management in the Manistee National Forest of Michigan, by Michael J. Solomon and Edward A. Hansen. USDA For. Serv. Res. Pap. NC-77, 10 p., illus. 1972.

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As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

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