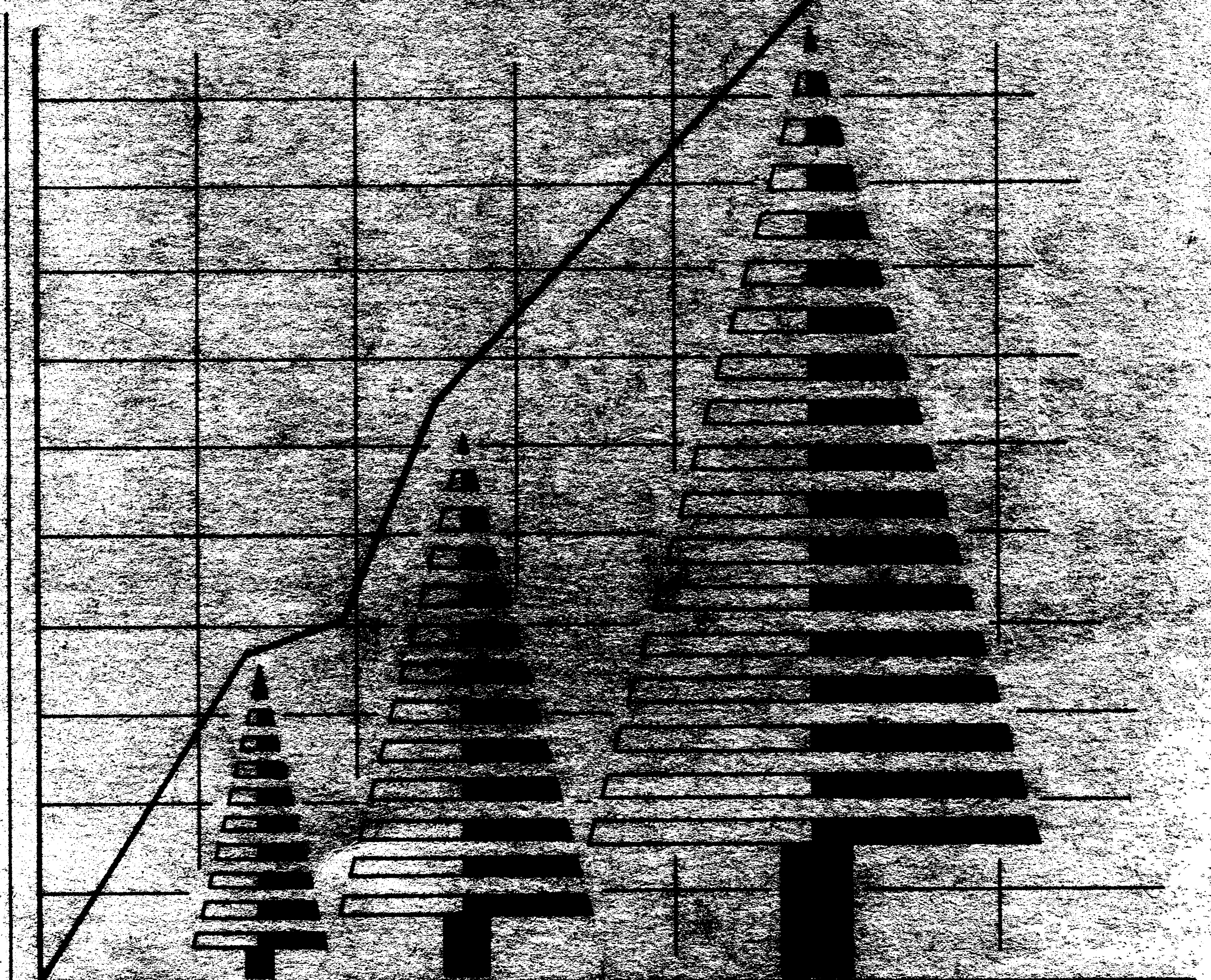
USDA FOREST SERVICE
RESEARCH PAPER NC-130

Estimating red pine site index in northern MINNESOTA

DAVID H. ALBAN



NORTH CENTRAL FOREST EXPERIMENT STATION
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WHAT DO YOU THINK?

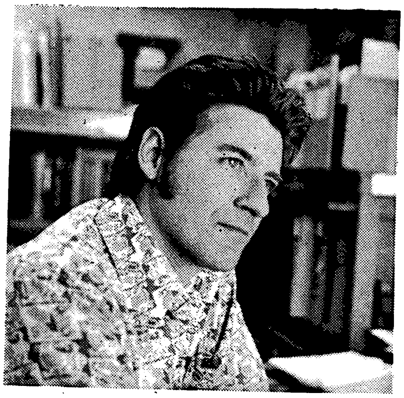
Realizing that the needs and interests of our two major "clients"--the scientist and the practitioner--are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. We would like to have your opinion.



THE AUTHOR

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ESTIMATING RED PINE SITE INDEX IN NORTHERN MINNESOTA

David H. Alban

Red pine (*Pinus resinosa* Ait.) is a commonly planted tree species in the northern Lake States. For best success, planting sites should be selected on the basis of their suitability for the species.

Several methods of estimating red pine site index (height of dominant and codominant trees at age 50) are available (Alban 1972, Carmean and Vasilevsky 1971, Gevorkiantz 1957a). This paper incorporates this earlier work and presents new information that allows site index estimates to be made from soil properties and from the growth rate of quaking aspen (*Populus tremuloides* Michx.). Methods of field sampling and laboratory analysis for this new information are detailed in the Documentation section.

APPLICATION

Most methods recommended here are applicable throughout the commercial range of red pine in northern Minnesota. However, most red pine stands occur on well drained sandy soils. Our sampling has been most intensive on these sites, and it is on similar sites where the proposed methods of estimating red pine site index are most reliable. The best method to use depends on the age of the red pine on the site in question and whether any red pine is indeed present.

KEY TO METHODS FOR ESTIMATING RED PINE SITE INDEX IN MINNESOTA

	Recommended method	*Table or figure*
I. Soils moderately well to excessively drained[1]		
A. Sandy to loam soils		
a. Red pine present		
1. Age 25 yrs+	Site index curves	Figure 1
2. Age 15 to 25 yrs	Growth intercept	--
3. Age 0 to 15 yrs	Soil properties	Tables 1 and 2
b. No trees present	Soil properties	Tables 1 and 2
c. Other species present	Inter-species relations	Figure 2
	or	
	Soil properties	Tables 1 and 2
B. Finer textured soils		
a. Red pine present		
1. Age 25 yrs+	Site index curves	Figure 1
2. Younger trees	No method available	--
b. No trees present	No method available	--
c. Other species present	No method available	--
II. Poorly drained soils	Red pine not recommended	--

[1]*Soil drainage class are defined in Soil Survey Staff (1951).*

ESTIMATING RED PINE SITE INDEX FROM SITE INDEX CURVES

The best indicator of site quality for a tree species is its extended growth performance on the site in question. Indirect measures of site quality such as climate, soil properties, associated tree species, or understory plants must be related to tree growth and cannot be expected to be as precise as measuring the trees themselves. Site index trees should be dominants, free of disease, insect, or fire damage, and should be part of an even-aged, well stocked stand that has not suffered severe environmental disturbances such as fire, erosion, or overgrazing.

Measure tree height to the nearest foot, and estimate total age by adding 8 years to the ring count at breast height (Alban 1972). Ten to 20 trees should be measured throughout the stand, the number depending on the precision desired and the stand variation. Then refer to site index curves (Gevorkiantz 1957a) (fig. 1). Alternatively, height and age can be used to predict site index by using an equation that has been fitted to the site index curves (Lundgren and Dolid 1970):

$$\text{Site index} = \frac{\text{Height}}{[1.956 - 2.1757\, e^{(-0.01644)(\text{age})}]}$$

where: e = base of the natural logarithms (2.178).

ESTIMATING RED PINE SITE INDEX BY THE GROWTH INTERCEPT METHOD

For stands younger than 25 years, site index can be estimated from internode lengths (growth intercept method) as proposed by Day *et al.* (1960) and modified by Alban (1972).

To use growth intercept, measure the total length of 5 internodes on 10 to 20 dominant trees, beginning at the first limb above 8 feet. Estimate site index by the following equation:

Site index = 32.5 + 3.43 growth intercept

or table:

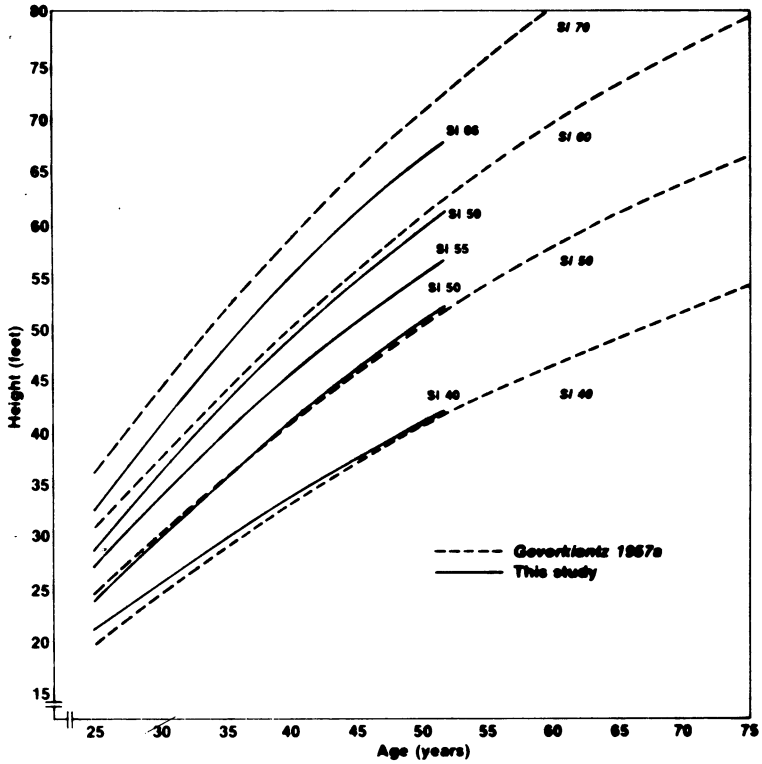

Figure 1.--*Red pine site index curves and height growth curves. Six stands averaged SI 40, 12 stands SI 50, 14 stands SI 55, 30 stands SI 59, and 10 stands SI 66.*

Length of five internodes above 8 feet (growth intercept) (feet)	*Site index* (feet)
4	46
5	50
6	53
7	57
8	60
9	63
10	67
11	70
12	74

ESTIMATING RED PINE SITE INDEX FROM SOIL PROPERTIES

Where no suitable red pine trees are present, soil properties can be used to estimate site quality. To estimate site index from soil properties the till material from which the soil developed must be identified as either Keewatin till (northwestern source) or Rainy till (northeastern source) (Arneman and Wright 1959). In nearly all red pine stands sampled in St. Louis or Lake counties the soils were derived from Rainy till whereas soils to the west were derived from Keewatin till.

Rainy Till Area

Rainy till soils commonly contain much coarse material (greater than 2 mm diameter); bedrock is generally shallow. The percent (by ovendry weight) of coarse material in the top 40 inches of soil and the total thickness of the A and B horizons are closely related to site index by the following equation:

$$\text{Site index} = 42.78 - 0.0864(X_1) + 6.504 \text{ Ln } (X_2)$$

where: X_1 = percent of coarse material by weight in the 0 to 40 inch layer, and X_2 = thickness of A and B horizons (inches).

This equation accounts for 86 percent of the site index variation ($R^2 = 0.86$), and has a standard error of estimate of 3.0 feet.

As an alternative, use table 1.

Where bedrock is less than 40 inches from the surface, its weight (which must be added to the weight of coarse materials) can be calculated from its density, which is estimated at 2.65 g/cm^3 (165 lb/ft^3) (Wilde 1958). If the coarse material fraction is known by volume, it can be converted to weight (fig. 2).

Keewatin Till Area

Keewatin till soils tend to have thicker solums and to be sandier than Rainy till soils, but have far less coarse material. Coarse soil material and depth of the A+B horizons are related to site index in the Keewatin area as in the Rainy area. In addition to these two properties, the presence or absence of finer textured bands is closely related to site index. Forty out of the 52 stands sampled had sandy soils of glacial outwash or lacustrine origin, and about half of these had strong texture bands below the solum. These bands commonly occur as irregular layers or lenses ranging in texture from sandy loam to clay but always finer than the adjacent layer.

On the basis of texture bands or underlying finer materials, the Keewatin area soils are divided into two categories.

Table 1.--*Red pine site index in Rainy till area based on soil coarse fraction and thickness of A and B horizons*[1]

Coarse fraction 0-40 inch depth (percent by weight)	Thickness of A and B horizons (inches)						
	2	5	10	15	20	25	30
0			58	60	62	64	65
10			57	60	61	63	64
20			56	59	61	62	63
30			55	58	60	61	62
40			54	56	59	60	61
50			53	56	58	59	61
60		48	53	55	57	59	60
70	41	47	52	54	56	58	
80	40	46	51	53			
90	40	46	50				
95	39	45					

[1] Based on: Site index = 42.78 - 0.0864 (coarse material percent) + 6.504 ln (thickness of A + B horizons).

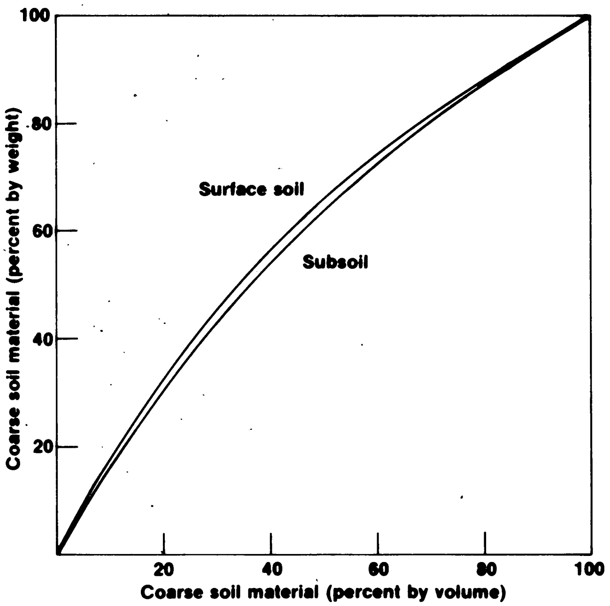

Figure 2.--*Relation between soil coarse fractions expressed on a volume and weight basis.*

Group I soils have textural bands that total more than 6 inches in thickness (to a depth of 9 feet), those developed in sandy soils underlain by finer materials, or those developed within finer materials. The Group 0 soils are sandy and lack either strong textural banding or underlying finer materials.

Estimate red pine site index from soil properties on Keewatin till areas by using the following equation:

$$\text{Site index}=49.03-0.317(X_1)+0.313(X_2)+4.98(X_3)$$

where: X_1 = percent of coarse material (> 2 mm) by weight in 0 to 10 inch layer, X_2 = thickness of A and B horizons (inches), and X_3 = 1 for Group I soils and 0 for Group 0 soils.

This equation accounts for 57 percent of the variation ($R^2 = 0.57$) and has a standard error of estimate of 4.4 feet.

As an alternative, use table 2.

ESTIMATING RED PINE SITE INDEX FROM THE GROWTH OF OTHER SPECIES

The growth of red pine can be predicted from the growth of several other species growing on the site. In northern Minnesota, data from soil and forest survey plots can be used to estimate red pine site index from the site index of jack pine (*Pinus banksiana* Lamb.)(66 plots), white pine (*Pinus strobus* L.)(58 plots), and white spruce (*Picea glauca* Moench.)(15 plots)(Carmean and Vasilevsky 1971). The site index prediction equations follow:

$$\text{Site index}_{rp}=1.0(\text{Site index}_{jp})-2.81 \quad r^2=0.40$$

$$\text{Site index}_{rp}=0.95(\text{Site index}_{wp})+3.57 \quad r^2=0.47$$

$$\text{Site index}_{rp}=0.70(\text{Site index}_{ws})+18.90 \quad r^2=0.65$$

From a similar study on 26 plots in Minnesota (Documentation Section) red pine site index can be estimated from the site index of quaking aspen:

$$\text{Site index}_{rp}=0.44(\text{Site index}_{qa})+27.88 \quad r^2=0.53$$

A graph of these equations facilitates species comparisons (fig. 3). Site index for jack pine, white pine, white spruce, and aspen can be determined from total height and age by using published site index curves (Gevorkiantz 1956a, 1956b, 1957b, 1957c).

Table 2.--*Red pine site index in Keewatin till area based on soil coarse fraction and thickness of A and B horizons*[1]

Coarse fraction 0-10 inch depth (percent by weight)	Group I[2] Thickness of A + B (inches)				Group 0 Thickness of A + B (inches)			
	10	20	30	40	10	20	30	40
0	57	60	63	66	52	55	58	62
5	56	59	62	65	51	54	57	60
10	54	57	60	63	49	52	55	58
20	51	54	57	60	46	49	52	55
30	48	51	54	57	43	46	49	52
40	44	48	51	54	40	43	46	49

[1] Based on: site index = 49.03 - 0.317 (coarse material percent) +0.313 (thickness of A + B horizons) + 4.98 (presence of finer textured layers).

[2] Group I plots are those with fine textured soil layers or bands as explained in the text; group 0 plots lack this feature.

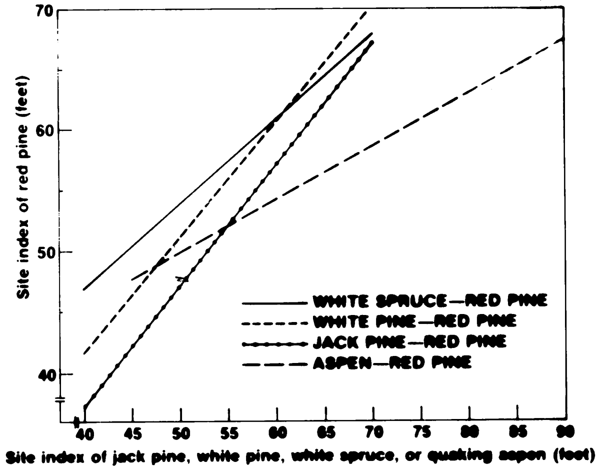

Figure 3.--*Estimates red pine site index from the site index of jack pine, white pine, white spruce, or aspen.*

DOCUMENTATION

RED PINE GROWTH

Red pine height growth patterns are remarkably similar throughout the species' range. Spurr (1955), for example, found a single set of site index curves to be adequate for red pine stands (including plantations) from Minnesota to New England and into Canada. His curves are similar to those used in Minnesota (fig. 1). Similarly, the height-growth pattern to age 25 of red pine in Minnesota (plantations and natural stands) was found to match that in the northeastern United States on similar sites (Alban 1972).

In Minnesota the best natural red pine stands have a site index of about 70, and the best plantations (by extrapolation for about 15 years) a site index of 75 to 80. Others have found an upper limit to red pine site index of about 70 (Richards *et al.* 1962, Spurr 1955, Wilde *et al.* 1965). A few reports (Ek 1971) claim red pine site index values as high as 112 but these estimates of high site index were made in young plantations and later measurements usually show the apparent site index to be decreasing with age.

Volume growth in young trees may be different in plantations than in natural stands because of more uniform stocking in plantations. But, as the stands close and fully occupy the site (at perhaps 20 to 30 years), volume growth rates would probably be similar on similar sites.

The height growth of red pine stands at least 50 years old is the most reliable indicator of site index available. Stand height and age are measured directly and site index read from site index curves (Gevorkiantz 1957a). The accuracy of these curves is substantiated by our stem analysis of 231 trees in 71 Minnesota natural stands (fig. 1).

When red pine trees 15 to 25 years old occupy a site, the site index can be estimated by the growth intercept method (Alban 1972). This method is easier to use than standard site index curves and eliminates the need to measure total height and age, each of which can be a source of error. However, the growth of red pine stands younger than about 10 years is not a reliable indicator of site index (Alban 1972).

SOIL PROPERTIES

Where red pine trees are absent or very young, soil properties are useful indicators of site quality. Emphasized here are soil properties that can be measured in the field and in the laboratory with simple techniques such as weighing and sieving.

FIELD SAMPLING OF NATURAL RED PINE STANDS

A 0.1-acre plot was established in each of 71 natural red pine stands in northern Minnesota. Seventy-nine percent of the plots sampled occurred in Lake, St. Louis, Itasca, Cass, or Beltrami counties, which contain 74 percent of the total red pine acreage in Minnesota (Stone 1966). Most stands occurred on gently rolling, well drained upland soils of sand to sandy loam texture developed from glacial outwash or lacustrine sands. The major criteria of stand selection included: (1) uniformity of topography and surface soil texture, (2) even-aged stands more than 40 years old, and (3) more than 75 ft^2/acre basal area, of which at least 75 percent was red pine. None of the stands has a history of crop or pasture use, and none shows evidence of severe fires, early suppression, or insect or disease damage. A summary of soil and stand properties for these stands is shown in table 3.

On each 0.1-acre plot, diameter outside bark was measured at breast height for each tree larger than 1 inch in diameter at breast height. Three to seven randomly selected dominant trees were felled, total height measured, and the bole 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. On each section the diameter and bark thickness were measured and the annual rings counted. Total age was estimated by adding 2 years to the ring count at the 6-inch stump. From the ring counts on each section a single average height-growth curve was constructed for each plot. From this curve total height at age 50 (site index) as well as heights at various other ages and the number of years required to reach breast height were determined.

Table 3.--*Soil, stand, and climatic factors for the study area*[1]

Property	Northeastern Minnesota: Rainy till plots Mean	Northeastern Minnesota: Rainy till plots Range	North-central Minnesota: Keewatin till plots Mean	North-central Minnesota: Keewatin till plots Range
Site index (ft)	56	39-69	57	37-68
Basal area (ft^2/acre)	172	104-224	171	110-235
Stand age (yr)	67	48-86	66	44-94
Average annual precipitation (in.)	--	26-29	--	22-26
Average summer temperature (^{o}F)	--	61-64	--	64-66
Forest floor weight (lb./acre/1,000)	32	13-59	24	7-40
Surface soil (0-10 inches)				
Silt + clay (percent)	32	11-49	20	3-85
Bulk density (g/cm^3)	1.27	1.08-1.33	1.33	1.21-1.43
pH	5.3	4.5-5.8	5.6	5.2-6.0
N (Kjeldahl) p/m	749	254-2,100	394	260-639
P (0.01N HCl) p/m	12	0.2-30	28	10-53
Ca (Exch.) p/m	349	190-850	330	160-750
K (Exch.) p/m	75	39-156	52	31-79
CEC meq/100 g	3.7	2.2-6.4	2.7	1.8-4.0
Available H_2O storage cap percent	15	6-22	9	4-23
Coarse material (0-40 inches) percent	39	0-97	7	0-43

[1] The climatic data are from Baker *et al.* (1967), and Baker and Strub (1965); all other data measured on samples collected from 71 natural red pine stands in Minnesota.

The forest floor horizons (L, F, and H) were collected from five locations on each plot with a 1-square foot sampling frame. Two soil pits 6 feet deep were dug on each plot (if not prevented by bedrock or a water table) and borings 3 to 4 feet deeper were made; soils were described and soil samples collected from each of the major horizons. In addition two smaller pits were dug 3 feet deep, and soil from each of the four pits was combined to form two composite soil samples per plot, one from the 0 to 10-inch depth and another from the 10 to 40-inch depth. All rock material greater than 1 inch in diameter was weighed in the field. Bulk density was determined in the deeper soil pits using a core sampler for the sandy soils, and excavation for the finer textured soils.

PLANTATIONS

Twenty additional plots were established in red pine plantations averaging 30 years of age to compare the pattern and early growth rates of red pine from plantations and natural stands. Stem analysis was performed on these trees as for the older trees in natural stands. The soils were examined from auger borings or nearby road cuts, but no detailed soil sampling or analysis was done.

SAMPLING AND ANALYSIS OF ASPEN STANDS

Twenty-six plots were established throughout northern Minnesota in aspen stands in which height growth and site index had previously been determined by stem analysis (Schlaegel 1974). All plots were on sandy to loam soils. The stands ranged in age from 19 to 81 years (mean 47 years) and in site index from 47 to 90 (mean 72). Eighteen of the plots occurred on Keewatin derived soils and eight were on Rainy till.

Four pits were dug on each plot, from which coarse material content, depth of A and B horizon, and presence of fine textured layers were determined. These values were applied to the appropriate equations (p.3~~4~~4) to estimate red pine site index. The statistical relation between red pine and aspen site index values was then determined following Carmean and Vasilevsky (1971) who compared site index of red pine with jack pine, white pine, and white spruce.

LABORATORY SOIL ANALYSIS

Mineral soil samples were air-dried, hard structural peds crushed, and the soil sieved on a 2 mm screen. That portion passing through the 2 mm screen was used for subsequent analysis and adjustments made in results for moisture in the air-dry soil and for coarse material content.

Soil reaction was measured in a 1:1 soil and water mixture. Nitrogen was measured by the macro Kjeldahl method. Soil phosphorous was extracted with 0.01N

HCl and determined colormetrically. "Exchangeable" Ca, Mg, and K were extracted with 1N NH_4OA_c and determined by atomic absorption. "Exchangeable" H and Al were extracted with 1N KCl and determined by titration with N_aOH and HCl (Yuan 1959). Cation exchange capacity was taken to be the sum of all determined cations. Particle-size distribution was determined by hydrometer, and available water-storage capacity was determined as the difference between water held at 0.1 atm and 15 atm of tension in pressure apparatus.

Forest floor samples were air-dried and ground in a Wiley mill to pass a 20 mesh screen. Nitrogen was determined by the macro Kjeldahl method. Subsamples were ashed at 525°C for 2 hours and taken up in dilute HCl. Total Ca, Mg, K, and P were determined in the HCl extract by the same methods as used for the mineral soils. Reaction was measured in a 1:4 sample and water mixture.

CONVERSION OF PERCENT BY VOLUME COARSE MATERIAL TO A WEIGHT PERCENTAGE

The most accurate way to measure coarse materials is by weight because it is difficult to estimate the volume of the smaller gravels. But because coarse materials are often estimated on a volume basis, a graph was constructed to convert coarse material percentage from a volume to weight basis (fig. 2). In constructing the graph it was assumed that density of the coarse materials is 2.65 g/cm^3 and that the soil bulk density is 1.30 g/cm^3 for the surface soil and 1.45 g/cm^3 for the subsoil. The soil bulk density values are averages found in the present study for soils supporting red pine in northern Minnesota.

STATISTICAL ANALYSIS

Individual soil properties were graphed and regressed against red pine site index to determine those properties most closely related to site index. Properties examined included stand age and basal area; depth to or thickness of various soil horizons, textural bands, water table, carbonates, gravel layers; coarse material content, particle size distribution, and water-holding capacity; pH, cation-exchange capacity, and nutrients (N, P, K, Ca, Mg) in forest floor and mineral soil. For the present report only the field observable and easily determined laboratory properties were combined into multiple regression equations. The equations were constructed beginning with the soil property having the best correlation with site index and adding other properties one at a time. Addition of new variables was terminated when the last failed to increase R^2 by 0.03 or if its coefficient was not different from zero at the 10 percent confidence level.

STRATIFICATION OF STANDS ON BASIS OF TILL

The Keewatin till is distinguished by the presence of limestone, the frequent presence of shale, a low rock content, buff color, and generally a loamy or silty texture. The rainy tills are sandy, brown to reddish brown in color, and have a high rock content. A third Minnesota till, the Superior, is found in the area to the southwest of the Lake Superior basin and at one time supported considerable red pine. But, because of extensive logging, fire, and farming, too few suitable stands of red pine were found on this till material to be included in this report. More detail about the characteristics of the tills can be found in the report of Arneman and Wright (1959).

Red pine occurs on both the tills themselves and on the outwash and lacustrine deposits derived from the till. Most red pine plots in St. Louis County and eastward were on soils formed from Rainy till, whereas soils to the west of St. Louis County were derived primarily from the Keewatin till. Usually the geographical location of a site will be an excellent indicator of the kind of till from which the soil was developed. Where in doubt, particularly along the St. Louis-Itasca County boundary, the soils must be examined to determine the till source.

RELATION OF SOIL PROPERTIES TO RED PINE SITE INDEX

In general, red pine stands occur on well drained sandy soils and commonly in association with jack pine or white pine. The presence of fine textured layers in or below the solum of sandy soils or the presence of fine textured material underlying sandy soils results in better red pine growth than on sandy soils without these features (Alban 1974a, Hannah and Zahner 1970, Van Eck and Whiteside 1963, White and Wood 1958). On these soils red pine growth is better than its hardwood competitors, such as aspen and sugar maple, which do poorly on these sites. The hardwoods reach their best growth on the finer textured soils (Post 1968, Stoeckeler 1960) but here red pine growth may be only slightly better than on many sandy soils (Alban 1974a, Wilde *et al.* 1965). Poorly drained soils are not suited to red pine (Dreisinger *et al.* 1956, Stone *et al.* 1954, Wilde and Voigt 1967).

In both the Rainy and Keewatin till areas, the content of coarse material and the thickness of the A and B horizons are important in estimating red pine site index. Hence the determination of the depth to the bottom of the B horizon becomes very important. B horizons in both the Rainy and Keewatin till soils are characterized by various accumulations of clay, organic matter, and sesquioxides. The B horizons characteristically have darker brown or more reddish-brown color, and slightly more clay than surrounding horizons. Bedrock or coarse sand or gravel is sometimes found beneath the B horizons; more commonly soil material similar to the B horizon but little affected by soil-forming processes occurs below this horizon.

Both horizon depth and coarse material content can vary greatly even within small areas. To obtain reasonable estimates of these soil properties requires a minimum of four soil pits on even small (perhaps up to 40 acres) management tracts, the number needed depending on the precision desired, and on the variability of the soils, which would become apparent after examining the first few pits. Soil variability for certain properties of northern Minnesota soils and methods for estimating adequate sample size have been reported (Alban 1974b).

The coarse material in the Rainy till soils is crucial because the higher the coarse material content the lower storage capacity for nutrients and water. Hence, adding terms for soil nutrients or water-holding capacity to the equation improves its accuracy only slightly. On the other hand, for stands on Keewatin till, more precise equations were developed when using soil nutrients as factors (Alban 1974a). For example, an equation with terms for surface soil N, P, and K and for Groups I and 0 resulted in an R^2 value of 0.79. However, these properties are easily altered by vegetation changes or by man's activities, so the use of more stable properties is preferred because they are more reliable indicators of long-term site productivity.

The presence or absence of textural banding in Keewatin till soils greatly affect red pine site index. About 40 percent of the red pine stands sampled on soils of Keewatin till had 1 to 10 bands up to 10 inches thick each, within the top 9 feet of soil. All bands have abrupt boundaries with the surrounding sandy material, and many roots are concentrated at the top of and within the thicker bands. Similar bands have been described and analyzed in detail for Michigan soils (Wurman *et al.* 1959). No significant relations were found between site index and depth to the band or the texture of the band.

Surface soil texture (or silt + clay content) was not significantly related to site index, and even large differences in texture had little or no effect on site index. For example, in Keewatin stands the 6 plots occurring on glacial till (silt + clay content of surface soil greater than 30 percent) averaged 61 site index. This is higher than the average for all Keewatin plots (57) but almost identical to the average for the Group I (banded) plots. Thus, the moderately heavy textured soils (heavy sandy loam to silt loam) are not better red pine sites than the better sandy soils. This agrees with similar findings in Wisconsin (Wilde *et al.* 1965). In New York, heavier textured but well drained soils had higher red pine site index than sandy soils (DeMent and Stone 1968), but the sandy soils in that area are commonly abandoned farms that are deficient in K and Mg. Neither of these elements is likely to be found deficient in northern Minnesota sandy soils (Alban 1974a).

Because of the importance of coarse materials, particularly in the Rainy till area, the modifiers of soil textural class, such as gravelly or very gravelly, do indicate a reduced site index. For example, of the poorest 9 sites (mean site index = 50) 7 had gravelly surface soil, whereas of the 10 best sites (mean site index = 60) only 1 had a gravelly surface soil.

Slope and aspect, which in other regions strongly affect site quality (Ralston 1964), are of little importance for red pine in Minnesota, primarily because of the subdued character of the landscape. In the Rainy till area, for example, only 4 of the 19 plots sampled had slopes greater than 5 percent (maximum 15 percent) and, although this is clearly a limited sample, none of these 4 was among the best or the poorest of the red pine sites. In both till areas, plots located on narrow ridgetops or at the tops of small knolls were of poor site quality, but such areas occupy only a small percentage of any stand examined. Further, these topographic positions nearly always have more coarse material and thinner solums than soils of the surrounding area. And these factors serve adequately to estimate site index.

None of the Rainy till stands had a water table within the sampling depth. Ten of the 52 Keewatin stands had water tables ranging from 3 to 9 feet below the soil surface, but neither the presence of a water table nor the depth to it was related to site index. The average site index for the 10 plots with a water table was 55, which is close to the average value for all Keewatin plots of 57. The seven best Keewatin sites had no water table within 9 feet, indicating that a shallow water table is not necessary for good growth.

SOIL MAPPING UNITS

Ideally, we would like site productivity to be an easily mappable feature of the landscape. And to this end many attempts have been made to relate soil mapping units to tree growth with various degrees of success. Most soil series are too heterogenous to be useful for predicting forest productivity (Jones 1969). Subdividing soil series into phases based on properties shown to be important to tree growth could reduce variation within series (Carmean 1961). But lack of detailed knowledge of the factors limiting growth, and of detailed knowledge of the range in these properties within soil mapping units have limited the application of this refinement.

Soil series and phases in relation to red pine plantation growth have been studied in Michigan (Van Eck and Whiteside 1963), New York (DeMent and Stone 1968), and Wisconsin (Wilde *et al.* 1965). Each of these studies showed a few soil units that related to poor red pine site quality because of shallowness to bedrock, extreme droughtiness, or restricted drainage. But, except for the very poor sites, soil mapping units in these studies were of limited help in distinguishing red pine productivity units.

In Minnesota the Soil Conservation Service, in cooperation with the North Central Forest Experiment Station, has evaluated tree growth in relation to soil mapping units as part of its interpretive program for soil surveys. The results for red pine have not been encouraging. For example, in north-central Minnesota at least four sample plots were found on nine soil mapping units (Hiwood, Kinghurst, Marquette, Menahga-banded, Menahga-nonbanded, Rockwood, Swatara, Taylor, and Todd) (USDA, SCS, and NCFES, 1968). There were no significant differences in red pine site index among these nine units. Similarly, when soils were grouped into broad "Woodland Suitability Groups," no significant differences in red pine site index were found among the five groups containing red pine.

In the present study most plots were in areas for which there are no detailed soil maps so as mapping progresses new units will undoubtedly be needed and older ones will be redefined. Hence, assigning many plots to defined soil mapping units is tenuous at best. However, in the Keewatin till area, four reasonably secure mapping units were represented by enough plots to present a useful sample of productivity (table 4). Clearly, there is little if any difference between the sands (Menahga) and the fine sands (Shawano). There is more difference between banded and nonbanded soils, as would be expected, but the differences are not significant. The average range of site index on these four soils is 14, which is about half the total site index spread for red pine and represents large differences in volume growth (Buckman 1962).

In view of all this, we must conclude that soil mapping units as presently constituted are of little help in evaluating red pine site index for specific stands; they may, however, aid in evaluating other aspects of forest management such as seedling survival, erosion hazard, brush competition, frost heaving, wildlife suitability, etc.

Table 4.--*Red pine site index on four soil mapping units on the Keewatin till area*

Soil	Plots	Site index range	Mean site index	Standard error
	Number			
Menahga (sand-loamy sand)	6	51-63	55	3.1
Menahga (sand-loamy sand) banded phase	8	55-68	61	1.9
Shawano (fine sand-loamy fine sand)	6	48-61	55	3.5
Mosomo (fine sand-loamy fine sand) banded	6	51-68	60	6.4

The soil factors closely related to red pine growth, however, can be used to estimate red pine site index on a stand-by-stand basis. To expand this information to a mapping unit basis requires evaluating the range of each factor within the various soil mapping units. In general, the information on ranges necessary for this elaboration is not now available and probably will not be for some time. In specific cases, however, available data can be used in conjunction with the equation or tables presented in this report. For example, the Insula soil series has been described as being 8 to 20 inches thick over bedrock and having 15 to 35 percent (volume basis) coarse fragments (Erickson *et al.* 1971). If we assume that the A and B horizons extend to bedrock, that the soil bulk density is 1.3 g/cm^3, and the rock density is 2.65 g/cm^3, we can calculate the estimated range of Insula site index values for red pine as ranging from 48 to 56 by using the appropriate equation (p. 3).

ASSOCIATED SPECIES

When suitable red pine does not occupy a site and soil sampling is not feasible, the growth of other tree species can give an estimate of the site's potential for red pine (fig. 3). Because of the rare occurrence of red pine on poorly drained or heavy textured soils, the applicability of interspecies relations to these kinds of soils is unknown, so they should be used only on well drained sandy to loam soils. This is particularly important for white spruce, white pine, and aspen, which are known to grow better on the heavier soils (Wilde *et al.* 1965, Stoeckeler 1960). Red pine, as pointed out earlier, has similar growth rates over a wide range of soil textures.

Red pine site index is consistently 2.8 lower than that for jack pine (fig. 3). Within the common range of site index (40 to 70), red pine has a slightly higher value than white pine, but the difference is never more than 1.6 feet, so for practical purposes we can assume identical site index for these two species. On the poorer sites, red pine has better site index than white spruce or aspen, whereas on the better sites the reverse is true.

Similar site indexes for two species do not necessarily indicate similar biological or economic tree yield and may mask large differences in wildlife suitability or other facets of the site. For example red and jack pine will generally have nearly identical site indexes on a given site, but their volume growth may differ appreciably. Thus once site index is known for several species, the yields of these species should be determined and compared.

LITERATURE CITED

Alban, David H. 1972. An improved growth intercept method for estimating site index of red pine. USDA For. Serv. Res. Pap. NC-80, 7 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Alban, David H. 1974a. Relationship between soil and foliar nutrients and site index of red pine. For. Sci. 20:261-269.

Alban, David H. 1974b. Soil variation and sampling intensity under red pine and aspen in Minnesota. USDA For. Serv. Res. Pap. NC-106, 10 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Arneman, H. F., and H. E. Wright, Jr. 1959. Petrography of some Minnesota tills. J. Sediment Petrol. 29:540-554.

Baker, Donald G., Donald A. Haines, and Joseph H. Strub, Jr. 1967. Climate of Minnesota. Part V. Precipitation facts, normals and extremes. Univ. Minn. Agric. Exp. Stn. Tech. Bull. 254, 43 p.

Baker, Donald G., and Joseph H. Strub, Jr. 1965. Climate of Minnesota. Part III. Temperature and its application. Univ. Minn. Agric. Exp. Stn. Tech. Bull. 248, 63 p.

Buckman, Robert E. 1962. Growth and yield of red pine in Minnesota. U.S. Dep. Agric. Tech. Bull. 1272, 50 p.

Carmean, W. H. 1961. Soil survey refinements needed for accurate classification of black oak site quality in southeastern Ohio. Soil Sci. Soc. Am. Proc. 25: 394-397.

Carmean, Willard H., and Alexander Vasilevsky. 1971. Site-index comparisons for tree species in northern Minnesota. USDA For. Serv. Res. Pap. NC-65, 8 p. North Cent. Forest Exp. Stn., St. Paul, Minn.

Day, M. W., C. F. Bey, and V. J. Rudolph. 1960. Site index for planted red pine by the 5-year growth intercept method. J. For. 58:198-202.

DeMent, James A., and E. L. Stone. 1968. Influence of soil and site on red pine plantations in New York. II. Soil type and physical properties. Cornell Univ. Agric. Exp. Stn. Bull. 1020, 25 p.

Dreisinger, B. R., D. V. Baxter, and S. H. Spurr. 1956. Decline of red pine on heavy loam soils. Univ. Mich. School Nat. Resour. For. Note 14, 2 p.

Ek, Alan R. 1971. Evidence of extremely rapid height growth in Wisconsin red pine plantations. Univ. Wis. For. Res. Note 155.

Erickson, R. A., G. F. Harms, and R. H. Rust. 1971. Minnesota soil atlas, Hibbing sheet. Univ. Minn. Agric. Exp. Stn. Misc. Rep. 110.

Gevorkiantz, S. R. 1956a. Site index curves for aspen in the Lake States. Lake States For. Exp. Stn. Tech. Note 464, 2 p.

Gevorkiantz, S. R. 1956b. Site index curves for jack pine in the Lake States. Lake States For. Exp. Stn. Tech. Note 463, 2 p.

Gevorkiantz, S. R. 1957a. Site index curves for red pine in the Lake States. Lake States For. Exp. Stn. Tech. Note 484, 2 p.

Gevorkiantz, S. R. 1957b. Site index curves for white pine in the Lake States. Lake States For. Exp. Stn. Tech. Note 483, 2 p.

Gevorkiantz, S. R. 1957c. Site index curves for white spruce in the Lake States. Lake States For. Exp. Stn. Tech. Note 474, 2 p.

Hannah, P. R., and R. Zahner. 1970. Non-pedogenic texture bands in outwash sands of Michigan; their origin, and influence on tree growth. Soil Sci. Soc. Am. Proc. 34:134-136.

Jones, John R. 1969. Review and comparison of site evaluation methods. USDA For. Serv. Res. Pap. RM-51, 27 p. Rocky Mt. For. Range Exp. Stn., Fort Collins, Colorado.

Lundgren, A. L., and W. A. Dolid. 1970. Biological growth functions describe published site index curves for Lake States timber species. USDA For. Serv. Res. Pap. NC-36, 9 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Post, B. W. 1968. Soil-site relations. In Sugar Maple Conf. Proc. p. 15-19. Mich. Tech. Univ.

Ralston, C. W. 1964. Evaluation of forest site productivity. Int. Rev. For. Res. 1:171-201.

Richards, N. A., R. R. Morrow, and E. L. Stone. 1962. Influence of soil and site on red pine plantations in New York. I. Stand development and site index curves. Cornell Univ. Agric. Exp. Stn. Bull. 977, 24 p.

Schlaegel, B. E. 1974. Estimating the weight yield of Minnesota quaking aspen (*Populus tremuloides* Michx.). In IUFRO Biomass Studies, Univ. Maine, Coll. Life Sci. and Agric. p. 387-398.

Soil Survey Staff. 1951. Soil Survey Manual. U.S. Dep. Agric., Agric. Handb. 18, 503 p.

Spurr, Stephen H. 1955. Soils in relation to site index curves. Soc. Am. For. Annu. Meet. Proc. 1955:80-85.

Stoeckeler, J. H. 1960. Soil factors affecting the growth of quaking aspen forests in the Lake States. Univ. Minn. Agric. Exp. Stn. Tech. Bull. 233, 48 p.

Stone, Robert N. 1966. A third look at at Minnesota's timber. USDA For. Serv. Resour. Bull. NC-1, 64 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Stone, E. L., R. R. Morrow, and D. S. Welch. 1954. A malady of red pine on poorly drained sites. J. For. 52:104-114.

United States Department of Agriculture, Soil Conservation Service, and North Central Forest Experiment Station. 1968. Soil survey interpretations for woodland conservation. Land Resource Area 88 Minnesota, 20 p.

Van Eck, W. A., and E. P. Whiteside. 1963. Site evaluation studies in red pine plantations of Michigan. Soil Sci. Soc. Am. Proc. 27:709-714.

White, Donald P., and Robert S. Wood. 1958. Growth variations in a red pine plantation influenced by a deep-lying fine soil layer. Soil Sci. Soc. Am. Proc. 22:174-177.

Wilde, S. A. 1958. Forest soils. 537 p. Ronald Press.

Wilde, S. A., J. G. Iyer, C. Tanzer, W. L. Trautmann, and K. G. Watterson. 1965. Growth of Wisconsin coniferous plantations in relation to soils. Univ. Wis. Agric. Exp. Stn. Res. Bull. 262, 81 p.

Wilde, S. A., and G. K. Voigt. 1967. The effect of different methods of tree planting on survival and growth of pine plantations on clay soils. J. For. 65:99-101.

Wurman, E., E. P. Whiteside, and M. M. Mortland. 1959. Properties and genesis of finer textured subsoil bands in some sandy Michigan soils. Soil Sci. Soc. Am. Proc. 23:135-143.

Yuan, T. L. 1959. Determination of exchangeable hydrogen in soils by titration method. Soil Sci. 88:164-167.

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