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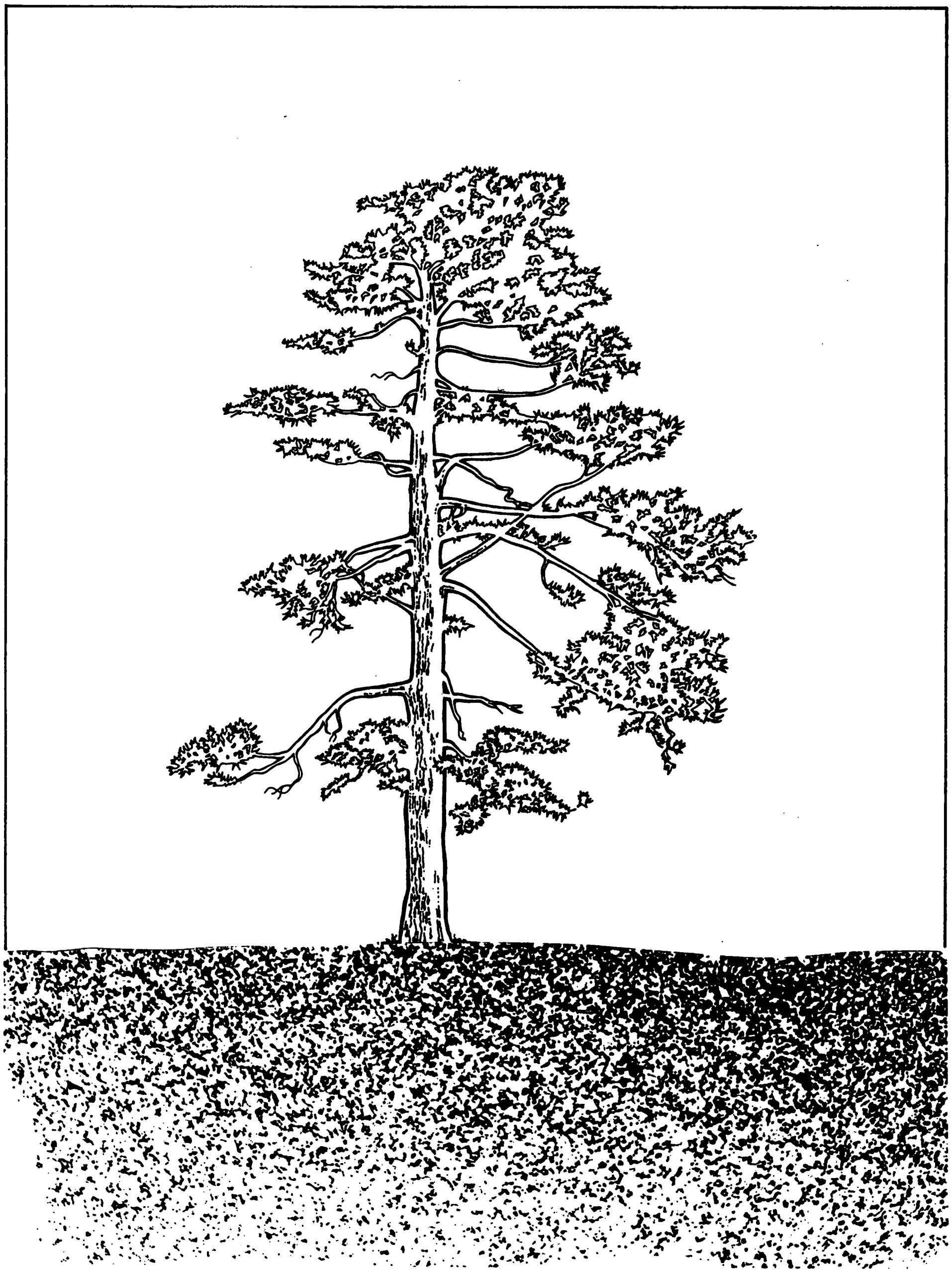

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Height growth was determined by stem analysis for red pine in 12 natural and 10 planted stands on well-drained, fine-textured soils. Growth closely followed the Gevorkiantz site index curves. When calculating site index, an age adjustment is desirable if the trees take longer than 8 years to attain breast height.

KEY WORDS: Alfisols, growth intercept, site index, *Pinus resinosa*.

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HEIGHT GROWTH OF RED PINE ON FINE-TEXTURED SOILS

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Growth and yield for red pine can be estimated from published reports if site index is known (Benzie 1977, Buckman 1962). Accurate estimates of site index depend on the site index curves depicting the actual tree height growth throughout the life of a stand. If tree height growth patterns differ from that of the site index curves, the "apparent site index" will vary depending upon the age at which the measurements are taken.

The red pine site index curves are harmonized (Gevorkiantz 1957). That is, region-wide height and age data were used to construct a single average height-age curve. From this curve a family of curves representing good to poor sites were developed by proportionally adjusting the average curve. For many species harmonized curves have been shown to be inadequate and height growth for them is better described by polymorphic curves—those developed specifically for different soils, locations, or site productivity classes (Carmean 1975). For red pine the height growth of most stands in the Lake States has been shown to closely follow the Gevorkiantz site index curves (Alban 1979, Van Eck and Whiteside 1963). However, examples of significant deviations from the site index curves have been shown for poorly drained soils (Richards *et al.* 1962) and for some sites with compact subsoils (Van Eck and Whiteside 1963).

Most natural stands of red pine in the Lake States occur on sandy soils (Eyre and Zehngraff 1948), and it was primarily from such stands that the Gevorkiantz site index curves were developed. Hence it is not surprising that most natural stands closely follow the site index curves. However, many red pine plantations have been established on finer-textured soils in the Northeast and North-central states (DeMent and Stone 1968, Stone 1976, Wilde *et al.* 1965). No systematic evaluation has been made of the applicability of the site index curves to the growth of red pine on these fine-textured soils. Now that many of the plantations are approaching 50 years of age, such an evaluation is possible; the purpose of this paper is to make that evaluation.

Study Areas

Ten planted and 12 natural stands of red pine ranging in age from 44 to 86 years and in site index from 39 to 68 feet were sampled (table 1). The 12 natural stands were part of an earlier study (Alban 1979) and were the only natural red pine stands found on fine-textured soils out of 250 stands examined. All stands were in Minnesota except for one in northwestern Wisconsin. Eight of the stands had been thinned within the last 15 years, but this should not affect the height growth of the remaining dominant and codominant trees (Day and Rudolph 1972, Von Althen *et al.* 1978).

The soils were all well drained and finer textured than commonly associated with red pine. Surface soil texture ranged from sandy loam to clay with silt + clay of from 34 to 85 percent (table 1). Most soils were finer textured in the subsoil than in the surface soil, but two stands had sands below the surface soil and two were underlain by bedrock at less than 8 inches (table 1). Most soils were in the order Alfisol (Soil Survey Staff 1975).

Methods

The soils of each study area were identified by soil scientists from the Superior or Chippewa National Forests or the Soil Conservation Service. Surface soil samples were collected from 1-4 soil pits per stand to determine particle size.

Table 1.—*Vegetation and soil characteristics of study areas*

Stand age	Basal area	Site index[1]	Time to reach breast height	Silt + Clay in surface soil	Soil
	Ft^2/A	Feet	Years	Percent	
			Planted Stands		
48	187	68	8	52	Unnamed (Glossic Eutroboralf)
48	156	65	10	55	Unnamed (Glossic Eutroboralf)
49	145	64	10	57	Unnamed (Glossic Eutroboralf)
46	222	62	10	59	Unnamed (Glossic Eutroboralf)
46	224	64	11	58	Unnamed (Glossic Eutroboralf)
44	147	65	7	61	Unnamed (Glossic Eutroboralf)
44	157	67	6	62	Unnamed (Glossic Eutroboralf)
52	257	68	8	36	Warba (Glossic Eutroboralf)
45	179	61	6	53	Itasca (Glossic Eutroboralf)
44	171	60	8	34	Unnamed sandy loam over loam
			Natural Stands		
68	179	50	7	77	Taylor (Aquic Eutroboralf)
72	199	58	8	40	Unnamed sandy loam over loamy sand
68	235	57	8	85	Nebish (typic Eutroboralf)
70	161	59	8	66	Nebish (typic Eutroboralf)
70	191	60	7	45	Nashwauk (typic Glossoboralf)
53	190	65	7	43	Nebish (typic Eutroboralf)
58	184	62	6	51	Rockwood (typic Fragiboralf)
58	175	66	9	41	Unnamed sandy loam over sandy loam
86	133	56	7	45	Unnamed sandy loam over coarse sands
58	193	41	8	48	Quetico (Lithic Udorthent)
70	134	39	10	41	Quetico (Lithic Udorthent)
71	139	56	6	50	Unnamed sandy loam over loam

[1]Height at age 50 based on three to five felled sample trees.

In every stand DBH of each tree was measured on three 1/10 acre plots, and three to five dominant or codominant trees were felled. For planted stands, the internodes between all visible whorls were used to measure height growth, and age from seed was determined from plantation records. For natural stands, whorls were often not visible on the lower part of the stem, so the boles were sectioned (at intervals of 1 foot up to a height of 8 feet, and at 3-foot intervals thereafter and the rings were counted on each section. Total age was estimated by adding 2 years to the ring count at the stump. Previous work has shown that height growth curves constructed from measurements of internodes or from ring counts on sections are equivalent (Alban 1972). A single height-age curve was constructed for each stand by averaging the data from the three to five sample trees. For planted stands younger than 50 years, the curves were extended up to 50 years using height growth predicted from the Gevorkiantz site index curves. Only minor errors occurred from this procedure because the extrapolation was for just a few years (table 1). From the height growth curve for each stand, tree height at each age was read including age 50 (site index). The average height growth curve for each stand was compared with the Gevorkiantz site index curve as described by the equation of Lundgren and Dolid (1970):

$$\text{Height} = (\text{Site index})(1.956 - 2.1757e^{-0.01644\,\text{Age}}).\quad\text{(Eq. 1)}$$

This equation was developed so that at age 50 tree height equals site index. It has a maximum error in describing the site index curves of 1.4 feet (Lundgren and Dolid 1970).

For red pine only a weak relation exists between the time required for trees to attain breast height

(BH) and later height growth (Alban 1979, Day *et al.* 1960, Ferree *et al.* 1958). Weather, stock quality, planting techniques, plant competition, and animal damage may strongly affect early growth and mask the effects of site on growth. Thus to make the best possible comparison of height growth with that predicted by the site index curves, early growth must be disregarded.

By age 15 most red pine are past the age at which factors strongly affecting early growth have had their major impact (Alban 1979). Thus comparisons of height growth on fine-textured soils with site index curves are most meaningful if made at ages beyond 15 years. Such comparisons avoid the variation associated with early height growth and enable determination of the accuracy of the site index curves in describing height growth for specific stands. For each stand studied, height growth from age 15 to 50 was determined as a measure of site quality relatively free from the variable effects of early height growth. The Gevorkiantz site index curve with the same height growth from age 15 to 50 as measured for each stand was calculated from the equation of Lundgren and Dolid (1970) and the height at age 15 for that curve was determined. The entire height growth curve for each stand was then adjusted upward or downward so that actual height at age 15 corresponded to height at age 15 predicted from the Gevorkiantz curve. This procedure sets the height at age 15 for each stand equal to height at age 15 of the appropriate site index curve and facilitates graphical or statistical comparison between height growth and the Gevorkiantz site index curve.

RESULTS AND DISCUSSION

A. Height growth patterns

The adjusted height growth curves from this study closely follow the Gevorkiantz site index curves. Values are typical for four of the older natural stands representing a wide range of site indexes (fig. 1). From age 15 to 50 the maximum deviation from the site index curves was about 2 feet, and the maximum deviation was greater than 1.5 feet for only one planted and two natural stands. The oldest stand examined had the largest deviation from the site index curves (fig. 1). But even for this stand the maximum deviation was only 3 feet at age 86, and use of the site index curves would result in a maximum error of only 2 feet. The magnitude of these deviations is similar to the 1.4 foot maximum error noted by Lundgren and Dolid (1970) for their equations describing the site index curves.

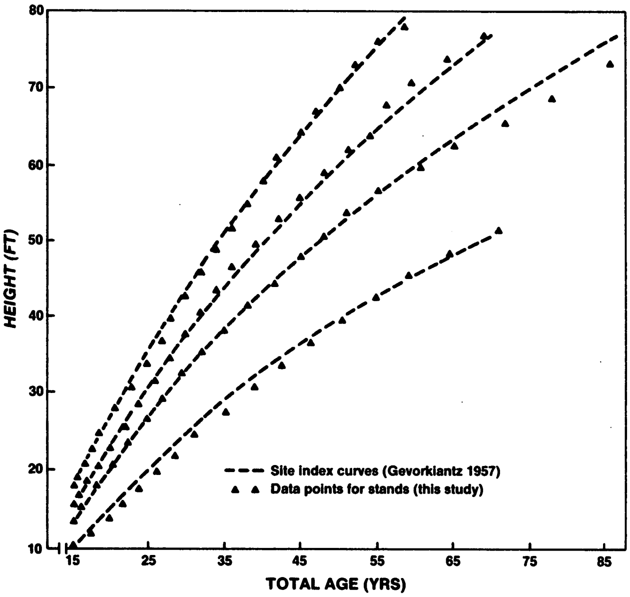

Figure 1.—*Height growth of four natural stands of red pine compared with site index curves.*

Some of the deviations noted in figure 1 are due to measurement errors and to short-term growth fluctuations caused by weather, insects, etc. To smooth out some of these variations, master site index curves were computed separately for natural stands and for planted stands using all the stands. The curve model (see Eq. 1) was that of Lundgren and Dolid (1970).

The coefficients for planted stands do not differ significantly from those for natural stands and neither differs from those of Lundgren and Dolid (table 2). Within the range of ages (15-70) and site indexes (40-75) the equations developed from planted or natural stands predict height closely to that from Lundgren and Dolid's equation: the maximum difference being 1.4 feet. Even when extended far beyond the range of the data to 100 years, the maximum difference was only 4 feet. Beyond age 100,

Table 2.—*Regression coefficients*[1] *for red pine height growth*

	Lundgren & Dolid (1970)	Alban & Prettyman (This study)	
		Natural stands	Planted stands
bo	1.956	1.913	1.800
b1	-2.176	-2.170	-2.046
b2	-0.0164	-0.0176	-0.0188

[1]Equation form:
Height = (site index) (bo + b1 e^{b2Age})

when polymorphism in height growth may be more common (Carmean 1975), we have no data. But the implications for forest management of height growth deviations from the site index curves beyond age 100 are minor, particularly under the more intensive management likely to be practiced in the future.

Clearly, height growth on the fine-textured soils of this study closely follows the site index curves beyond age 15. Because these stands represent both natural and planted stands, and a wide range of soil conditions and site quality, it appears that the standard site index curves are adequate for describing the height growth of red pine on well-drained, fine-textured soils.

B. Height growth of young stands

Even though height growth of red pine on fine-textured soils follows the appropriate site index curve beyond age 15 (fig. 1), large errors are possible when site index is estimated from young stands. This is so for two reasons: (1) early height growth is strongly influenced by many factors unrelated or weakly related to later growth, and (2) the site index curves were developed from trees 20 years and older and their extrapolation to younger ages is a possible source of error. Lundgren and Dolid (1970) attempted to extend the site index curves to younger ages by developing a more complex equation that goes through the origin (fig. 2):

$$\text{Height} = (\text{Site index})(1.89)(1-e^{-0.01979\ \text{Age}})^{1.3892}. \qquad \text{(Eq. 2)}$$

At age 10 many of the stands in this study fell below the height predicted for a very poor site (fig. 2). In addition, the site index curves predict that height of dominants and codominants at age 10 will be greater than 10 feet for all stands with site index greater than 57 feet. We found no stands in this study taller than 10 feet at age 10 even when the attained site index was very high (fig. 2). Others who have done stem analysis of red pine trees also found that height at age 10 is seldom if ever over 10 feet. (Hannah 1967, Richards *et al.* 1962, Van Eck and Whiteside 1963). Thus the site index curves extended to young ages by Lundgren and Dolid's equation 2 are inaccurate and if site index is estimated from total height and total age, its value will vary greatly depending on the age of measurement (fig. 2).

This problem is not unique to red pine growth on fine-textured soils, but it is perhaps most serious on these sites because brush or grass competition is more intense than on sandier sites. Therefore the conclusion (Alban 1979) that site index curves are not an accurate way to estimate site index until age 25

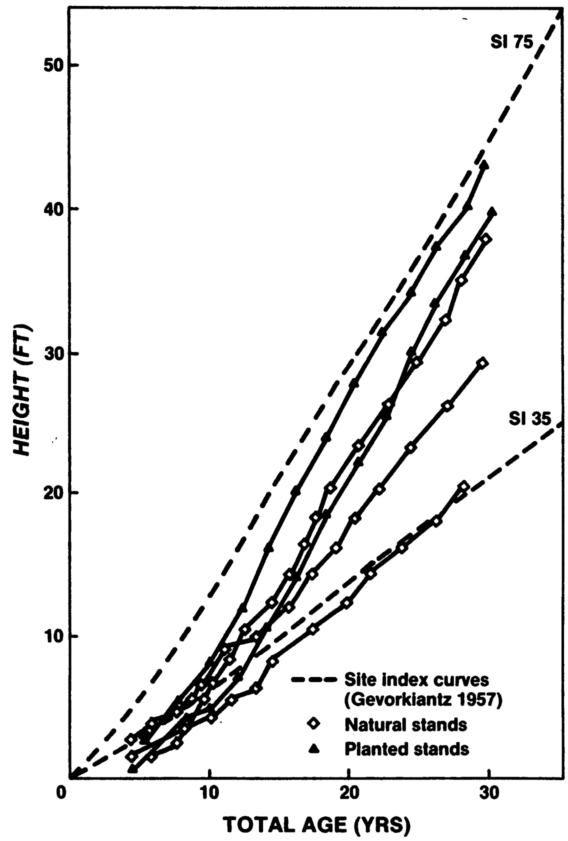

Figure 2.—*Early height growth of dominant and codominant red pine trees from two planted and three natural stands.*

appears particularly valid for red pine on fine-textured soils. However, site index at the younger ages can be estimated by the growth intercept method (Alban 1979) or by the use of soils (Carmean 1975) or habitat types (Kotar and Coffman 1982).

Even when site index curves are used for stands greater than age 25, significant errors can occur in estimating site index if early growth was greatly different from average. For example, plantation records plus ring counts and/or whorl measurements indicate that several planted stands in the current study took about 6 years from seed to attain a height of 6 inches. It is not known why this is so (no replanting was recorded), but the effect is to make the early growth of these stands indicate very poor site quality which is not reflected in later growth.

Early height growth of red pine on fine-textured soils is not closely related to site index (fig. 3) as was found earlier for red pine in general (Alban 1979). If early growth factors such as stock conditions, planting techniques, and plant competition can be controlled (Wittenkamp and Wilde 1964), or if sites can be stratified into habitat types (Kotar and Coffman 1982),

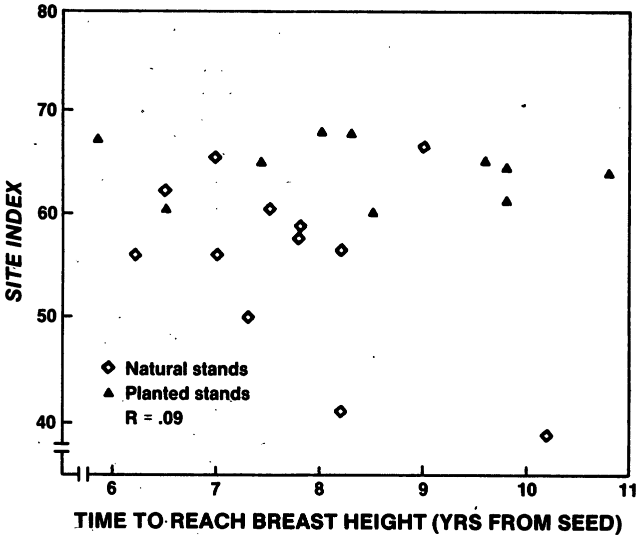

Figure 3.—*Affect of site index on the number of years for red pine trees to reach breast height.*

a relation between site quality and time required to reach breast height may be established. If so, it may be possible to extend the site index curves to younger ages and their usefulness would be greatly increased. However, at the present time the early height growth relations of red pine are poorly understood. And because of the extreme importance of weather conditions at the time of stand establishment, it is likely that the precision of the site index curves will continue to be lower at young ages than later in the life of the stand.

This early height growth should be taken into account when using the site index curves to estimate site index. It would seem prudent to calculate the years required to attain breast height and the growth intercept for each stand in which site index is estimated. These values should aid in interpreting the reasonableness of site index estimates made from the site index curves. For example, the current study as well as previous ones (Alban 1972) indicate that red pine takes about 8 years from seed to reach breast height irrespective of site. If stands take significantly longer than 8 years to reach breast height, total age can be adjusted accordingly and site index can be recalculated on this basis.

This is equivalent to using ring count at BH rather than total age, for site index determination (Husch 1956). In practice this is what is frequently done because total age is usually estimated by adding 8 years to ring count at breast height. As an example, one site of the current study took 5 years to reach a 6 inch height and 11 years to attain breast height. This slow early growth suggests a poorer site index than indicated by later growth, and the effect is most pronounced at the younger ages. Site indexes (Eq. 1) for this stand based on total height at total ages of 46, 30, and 20 years was 64.0, 58.5, and 52.6 feet, respectively. Recalculating site index based on an assumed 8 years to reach BH (i.e., subtracting 3 years from the three ages above) results in site index estimates of 67.7, 65.5, and 66.0 feet, respectively. The age-adjusted site index values are similar to those estimated by the growth intercept method 67.4 (Alban 1979) and are undoubtedly more realistic estimates of site index than those determined from total height and unadjusted age, particularly at the younger ages.

CONCLUSIONS

Red pine height growth on fine-textured, well-drained soils is accurately depicted by the Gevorkiantz site index curves beyond age 15. At younger ages the site index curves do not accurately describe red pine height growth. To confidently estimate a red pine stand site index from the site index curves the number of years to attain breast height should be determined. If this time is more than 2 or 3 years greater than the regionwide average of 8 years, an adjusted stand age will improve the accuracy of site index determinations.

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