USDA FOREST SERVICE
RESEARCH PAPER **NC-166**

Estimating Site Potential from the Early Height Growth of **Red Pine** in the Lake States

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ACKNOWLEDGMENTS

I am grateful to employees of the Huron-Manistee National Forest for locating and measuring the check stands in Michigan's Lower Peninsula and to Douglas Stone for providing data from a stand in Upper Michigan.

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Manuscript approved for publication September 19, 1978

1979

ESTIMATING SITE POTENTIAL FROM THE EARLY HEIGHT GROWTH OF RED PINE IN THE LAKE STATES

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Foresters need site productivity information to make good management decisions. Site index is the most frequently used indicator of site productivity in the United States (Carmean 1975), and most yield tables are based on site index values. When stands are too young to measure site index by the conventional height-age approach, early height growth can be a useful estimater of site index. Wakeley and Marrero (1958) were the first to use the growth intercept approach. They found that for southern pines the length of 5 internodes (the growth intercept) beginning at the first whorl below breast height was closely related to total tree height. Others have since found a relation between the growth intercept and site index for *Pinus Strobus* L. (eastern white pine) (Beck 1971), *Pinus ponderosa* Laws. (ponderosa pine) (Oliver 1972), and *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) (Warrack and Fraser 1955). Growth intercept of young Pinus resinosa Ait. (red pine) plantations was found to be closely related to subsequent height growth in New York (Ferree *et al.* 1958) and to site index in Michigan (Day *et al.* 1960) and Wisconsin (Wilde 1964). For natural stands of red pine in Minnesota the growth intercept method estimated site index more closely if the measurements were made on internode lengths above 8 feet rather than above breast height (Alban 1972). An abbreviated intercept method (of 1 to 5 internodes) was developed to estimate site index of red pine damaged by European pine shoot moth (Schallau and Miller 1966).

In this study 165 red pine stands were used to evaluate the growth intercept method for plantations and naturally established stands, to compare results geographically within the Lake States, and to determine the minimum age at which reliable site index estimates can be made.

The site indices for these stands represent the entire range for red pine in the Lake States (table 1). Most stands are near or past site index age (50 years) and thus require little or no extrapolation to the 50-year site index age. Almost all stands are on deep well drained sandy soils where red pine occurs most frequently, but a few are on finer textured soils or on shallow soils underlain by bedrock. Red pine was not sampled on organic soils or poorly drained soils because of its infrequent occurrence on them. Because height growth of red pine on poorly drained sites has been shown to be abnormal (Stone *et al.* 1954), the results from this study are not applicable to these kinds of sites.

Table 1.— *Stand characteristics*

		Age		Site Index	
	Number	Mean	(Range)	Mean	(Range)
Natural Stands	86	68	(44-98)	56	(37-69)
Plantations	79	37	(26-71)	62	(38-77)

METHODS

Ninety-nine sample stands, about equally divided between plantations and natural stands, were used to develop equations relating site index to growth intercept and 66 additional stands (check stands) were used to test and verify them. About two-thirds of the stands are in Minnesota and the rest are in Wisconsin and Michigan.

In each stand data were collected on 3 to 20 dominant or codominant trees for site index (SI), growth intercept (GI), and number of years to

reach breast height (BH). Measurement trees in the sample stands were felled and total age determined by adding 2 years to the ring count at a 3- to 6-inch stump. Internode lengths were measured from the top of the tree down as far as they were visible. The bole of older trees without visible lower branches was sectioned at 1- to 2-foot intervals and ring counts made to construct a height-growth curve (Curtis 1964) from which growth intercept was estimated (Alban 1972). Measurement trees in about half of the check stands were not felled. For these trees total age was determined from increment cores, total height was measured with an abney, and internode lengths were measured with a calibrated 13-foot pole.

Site index was measured directly on most of the stands more than 50 years old by determining height at age 50 from stem analysis. For stands younger than 50 years and for older stands without stem analysis data, site index was estimated from total height and age using a site index equation (Lundgren and Dolid 1970) that was developed from site index curves (Gevorkiantz 1957). The site index equations result in good estimates of site index for this study because the stands are close to site index age (table 1) and because the height-growth of these stands was found to follow closely the red pine site index curves (Alban 1976). Site index determined by stem analysis or by site index equations is referred to as the *standard site* index and serves as the reference for comparing the various growth intercept estimates of site index. Differences between the standard site index and site index estimated from growth intercept are referred to as error. And the average error is the average difference between the standard site index and site index estimated from growth intercept for all stands.

Site index was related to growth intercept using several curve forms including linear, 2nd and 3rd order polynomial, log and log-log. The best fit was obtained using the form:

$$\text{Site Index} = b_0 + b_1 (GI) + b_2 (GI)^{-2}$$

RESULTS AND DISCUSSION

Growth Intercept Above 8 Feet

The relation between red pine site index and the total length of 5 internodes beginning at the first whorl above 8 feet (GI_8) is significant at the 0.01 probability level (fig. 1):

$$\text{Site Index} = 36.9 + 3.356\ (GI_8) - 192.474\ (GI_8)^{-2} \quad (1)$$

$R^2 = 0.79$, SE = 4.11 feet, n = 99

The potential site index of a red pine stand can be obtained by measuring the growth intercept of suitable trees and utilizing either equation (1) or the following:

Growth intercept (GI_8)[1] (feet)	*Site index* (feet)
4	38.3
5	46.0
6	51.7
7	56.5
8	60.7
9	64.7
10	68.5
11	72.2
12	75.8

[1] GI_8 = the total length of 5 internodes beginning at the first whorl above 8 feet.

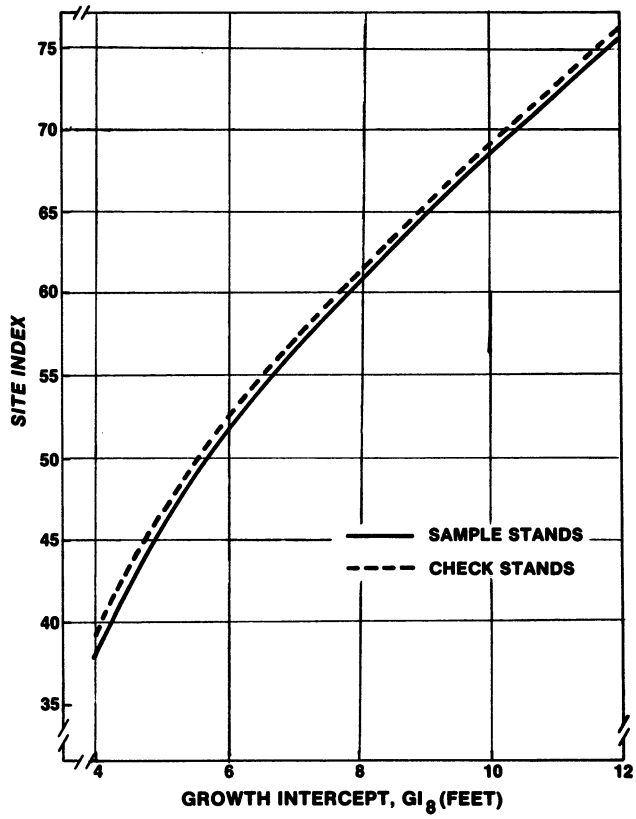

Figure 1.—*Relation between red pine site index and 5-year growth intercept beginning at the first whorl above 8 feet for sample and check stands.*

The trees used for measuring growth intercept should be dominant or codominant trees that have never been suppressed or had serious insect, disease, animal, or storm damage. They should be part of a well-stocked even-aged stand that has no evidence of major fire or other environmental disturbance of the site since stand establishment. In addition, of course, the growth intercept method requires the presence of branch whorls beginning at least as low as 8 feet.

In our experience the average growth intercept of uniform stands can be estimated within a few tenths of a foot by measuring from 10 to 20 trees scattered throughout the stand. Of course, if soils or topography vary significantly within the stand, stratification will be necessary. To estimate site index to the same level of precision more growth intercept measurements are required from the poorer sites because the curve is steeper for poor sites than for good sites (fig. 1). For example, a 1-foot error in measuring a 4-foot growth intercept would result in an error in site index estimation of nearly 8 feet whereas a 1-foot error in a 12-foot growth intercept would result in a site index error of only 4 feet.

The growth intercept is easy to measure and the method doesn't require the determination of tree age or height. Growth intercept may be useful for rapidly appraising the site index for older stands, but its most important application will be in young stands.

Generally, red pine stands more than 16 years old will be tall enough to measure growth intercept. Up to an age of 25 years the growth intercept method will give a more accurate estimate of site index than measurement of total height and age and use of site index curves (Alban 1972). This is so primarily because with growth intercept one avoids the erratic early height growth that is often related to factors other than site. From ages 25 to 30 these two methods of site index estimation work about equally well, but beyond about 30 years site index curves will usually give the best measure of site index and should be used where precise determinations are desired.

Testing of Results

The reliability of the growth intercept method was evaluated on 66 check stands. The check stands are about equally divided between plantations and natural stands, and about half are in Minnesota and half are in Wisconsin and Michigan. The check stands represent approximately the same range and average SI values as the sample stands. The equation developed from the sample stands (equation 1) estimated site index of both sample and check stands with the same average error (table 2). And the percent of stands with site index errors less than 5 or 10 feet was nearly identical for sample and check stands. About 80 percent of the site index estimates are within 5 feet of the actual site index.

An equation was developed to estimate site index from the growth intercept of the 66 check stands. The coefficients of this equation did not differ significantly (0.05 level) from those developed from the sample stands, and the R^2 value (0.80) and SE (4.23) were nearly identical to those of the sample stands. Site index estimates from this equation differed by less than 1 foot from those developed from the sample stands (fig. 1). Because the sample stands and the check stands obviously represent the same population, their data were combined to make a larger sample size for statistical testing.

Natural Stands vs. Plantations

To directly compare the relation between site index and GI_8 for plantations and natural stands, separate equations were developed for all of the natural stands (both sample and check stands, n=86) and similarly for all plantations (n=79) (fig. 2). Up to a growth intercept of 10 feet the natural stands and plantations differ little in predicted site index and both are close to the SI estimated from the sample stands. At a GI_8 of 10 feet the estimated site indices of plantations and natural stands begin to diverge and by a GI_8 of 12 feet they differ by about 3 feet.

However, we found no natural stands with a GI_8 greater than 10 feet, and the site index for the plantations at a GI_8 of 12 feet differs by only about 1 foot from that estimated from the sample stands. Thus, equation (1) should be applicable to both plantations and natural stands within the common range of GI_8 values. This is verified by the similar precision with which equation (1) predicts site index for plantations and natural stands

Table 2.— *Reliability of the GI_8 method when applied to check stands, sample stands, plantations, natural stands, and to different geographical areas*

Stands	Average site index	Average error in estimated site index	Stands with site index estimated within		
			±2.5 feet	±5 feet	±10 feet
	Feet		*Percent*		
Sample	58	3.3	45	79	100
Check	59	3.3	39	80	98
Natural	56	3.1	47	85	99
Plantation	62	3.4	39	77	100
Minnesota	58	3.2	44	83	99
L. Michigan	57	3.4	42	71	100
Wisconsin + U. Michigan	60	3.3	39	82	100

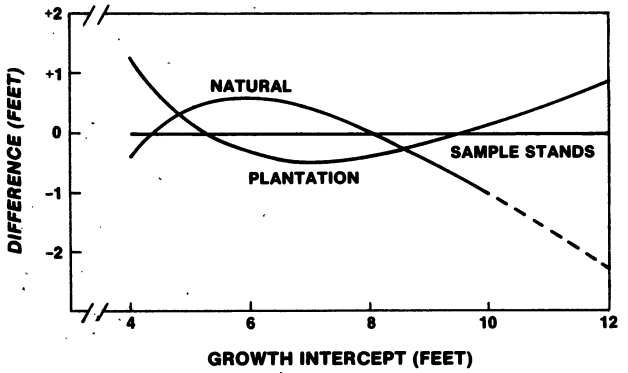

Figure 2.— *Difference of site index predicted from equations developed for plantations or natural stands from those developed for sample stands.*

(table 2). For both kinds of stands the average error in estimating site index is about 3 feet. Site index was estimated within 5 feet for about 80 percent of all stands and only one natural stand had a site index error greater than 10 feet.

Geographical Effects

Stands from Minnesota, Lower Michigan, and Wisconsin plus Upper Michigan all have site index reliably estimated from equation (1). The average error in estimated site index ranged from 3.2 feet for Minnesota to 3.4 feet for Lower Michigan (table 2).

A SI—GI_8 relation developed from all of the Minnesota stands (n=113) was compared with one developed from all of the stands from Michigan plus Wisconsin (n=52) and with all stands from Lower Michigan (n=24). Solving the equations for site index and comparing the results with site index estimates from the sample stands (equation 1) shows little difference (fig. 3). Site indices estimated from the Minnesota stands differ from those estimated from the Upper Michigan and Wisconsin stands by less than 2 feet, and neither of these differs from those estimated from the sample stands by much more than 1 foot. Larger differences occurred for the Lower Michigan stands but even here the differences were less than 3 feet within the common range of GI_8 values.

Thus, based on direct site index comparison (table 2) and on equations developed from each area (fig. 3), there is no significant geographical

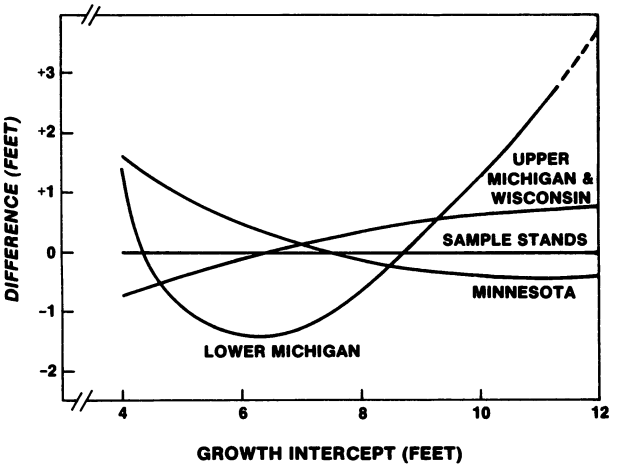

Figure 3.— *Difference of site index predicted from equations developed for stands from Minnesota, Wisconsin, and Michigan from those developed for sample stands.*

difference in the SI-GI_8 relation. Consequently, equation (1) is applicable to red pine stands throughout the Lake States and may be applicable to red pine throughout its natural range (Alban 1972).

Growth Intercept BH or 8 Feet?

All stands that had measurements of growth intercept above breast height and 8 feet (n=152) were used to compare these two starting heights for growth intercept. Equations of the form $SI=b_0+b_1(GI)+b_2(GI)^{-2}$ were developed for growth intercepts above BH and 8 feet. In addition the site index of each stand was estimated from the growth intercept equation of Day *et al.* 1960 [Site Index= $-0.0002+12.529(GI_{BH})-0.5166(GI_{BH})^2$]. The actual site index of each stand was compared with site index estimated by each of these three methods (table 3).

The growth intercept above 8 feet is clearly superior to that above breast height for estimating site index. The average site index error was 3.3 feet for the GI_8 method compared to 4.9 and 5.2 feet for the GI_{BH} methods. When the GI_8 method was used, less than 1 percent of the site index estimates were off by more than 10 feet. However, when the GI_{BH} methods were used, 9 and 14 percent of the stands had errors more than 10 feet and a few plots had errors larger than 15 feet.

It is not surprising that a growth intercept measured higher up the tree is a better estimater of site index than one measured lower because early red pine height growth is not well correlated with later height growth. For example the years required for red pine to reach breast height is not closely related to either site index or growth intercept (Alban 1972, Day *et al.* 1960, Ferree *et al.* 1958). Climate, stock quality, planting techniques, brush competition, and animal damage all affect early height growth more than later growth. These early effects may influence growth after the trees attain breast height but become much less pronounced after the trees reach 8 feet (Alban 1972).

Use With Younger Stands

GI_{BH} is a less reliable estimator of site index than GI_8, but it can be used at an earlier age. In the current study, GI_{BH} could be used to estimate site index at an average stand age of 13 years while GI_8 could not be used until a stand reached an age of 16.

To examine the possibility of lowering the age at which growth intercept could be used to estimate site index, height growth for from 1 to 4 years above 8 feet was correlated with site index for all

Table 3.— *Comparison of growth intercept methods*

Growth intercept[1]	Stands	Average error in estimated site index	Stands with site index estimated within ±5 feet	±10 feet	±15 feet	Regression equations R^2	$S\bar{x}$
	No.	*Feet*	*Percent*				
$GI_{8/5}$	[3]152	3.3	79	99	100	0.78	4.2
$GI_{BH/5}$	152	4.9	57	91	99	.54	6.1
[2]$GI_{BH/5}$	152	5.2	57	86	99	.84	5.7
$GI_{8/4}$	[3]96	3.9	76	94	100	.75	5.0
$GI_{8/3}$	96	4.1	65	94	100	.72	5.3
$GI_{8/2}$	96	5.1	52	90	100	.58	6.4
$GI_{8/1}$	96	5.9	49	82	99	.45	7.4
$GI_{BH/5}$	96	5.0	59	89	99	.60	6.4
$GI_{BH/3}$	96	5.8	48	82	96	.46	7.4

[1]The symbol preceding the slash is the height above which GI is measured, and the number after the slash is the number of internodes included in the GI measurement.

[2]Equation of Day *et al.* (1960) applied to stands of the current study.

[3]The total number of stands in this study is 165. However, GI_{BH} and individual internode lengths were not measured for all stands.

stands that had clearly visible whorls down to breast height (n=96) (table 3). These stands were about equally divided between natural stands and plantations, and their mean and range of values for site index and GI_8 were nearly identical to those of the sample stands.

We found that the precision of estimating site index increased as the number of internodes above 8 feet used for the estimation increased (table 3). Using only one internode resulted in large errors due probably to year-to-year climatic variations. The differences in the precision of site index estimation from 3 to 5 internodes was not large, but the use of 5 internodes was the most accurate. Of interest is the fact that using only 2 internodes above 8 feet predicts site index to almost the same level of precision as using the full 5 years above breast height (table 3).

The first 2 internodes above 8 feet are generally the last 2 internodes of the GI_{BH} growth intercept. The fact that the last 2 internodes are able to predict site index as accurately as the full 5 above BH indicates the limited usefulness of the first few internodes above breast height. In the current study the first 3 years' height growth above breast height were related to site index by an R^2 of only 0.46, with a standard error of 7.4 feet (table 3). Growth intercept for 3 years above BH resulted in large errors in estimated site index for many stands, and both the average error and the distribution of errors are similar to those obtained using only the first internode above 8 feet (table 3). Clearly the first few internodes above breast height are of limited usefulness in estimating site index.

Our data indicate that the youngest age at which a reliable estimate of site index can be made is about 2 years after the trees reach 8 feet, which is usually when the trees are about 13 years old. Attempts to determine site index from height growth at younger ages may result in large errors and the forester is best advised to either find other methods of estimating site potential (adjacent stands, understory, soil) or to delay until the stands are older.

Once the stand has grown for at least 2 years past the 8-foot height, reasonable site estimates can be made using the average internode length for 2 to 4 internodes above 8 feet from the following tabulation:

Average annual height growth (feet)	Site index (feet)
0.8	40
1.0	47
1.2	52
1.4	57
1.6	61
1.8	65
2.0	69
2.2	73
2.4	77

The larger the number of internodes included in the measurement, the more accurate will be the estimate and for best results, the full 5-year growth intercept above 8 feet should be used.

Polymorphic Height Growth

Site index determined by either the growth intercept method or by site index curves will be in error if the site's early height growth pattern is different from that of the sites used to develop the site index curves or the SI-GI relation. (Carmean 1975, Wilde 1964). In the current study a few stands had abnormal height growth patterns. We found normal early growth followed by growth declines on shallow soils over bedrock and on sandy soils underlain by infertile beach sands, and we found slow early growth followed by growth increases on soils with deep fertile layers. But these deviations were the exception and the vast majority of sites closely followed the height growth patterns expected from the site index curves (Gevorkiantz 1957).

SUMMARY AND CONCLUSIONS

We developed equations—based on the close relation between the total length of the first 5 internodes beginning at the first whorl above 8 feet (growth intercept) and site index—that accurately predict site index for young red pine stands. This growth intercept method can be applied in stands as young as about 16 years and with some loss in precision even in stands as young as 13 years. Up to a stand age of 25 or 30 years, the growth intercept method will estimate site index better than

conventional site index curves. The equations are applicable to red pine stands throughout the Lake States and to natural stands as well as plantations.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1979--666648/264

Alban, David H.
1979. Estimating site potential from the early height growth of red pine in the Lake States. U.S. Dep. Agric. For. Serv., Res. Pap. NC-166, 7 p. North Cent. For. Exp. Stn., St. Paul, Minnesota.

Red pine stands throughout the Lake States were sampled to determine the relation between site index and bole internode lengths. The total length of 5 internodes beginning at the first whorl above 8 feet is a good estimater of site index (average error 3.3 feet) for both plantations and natural stands throughout the Lake States.

OXFORD: 541:561.1:174.7 (Pinus resinosa):(77). KEY WORDS: Growth intercept, internode length, site index, stem analysis.

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Plant a tree...trees give oxygen.