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Site-Index Curves for Young-Growth Ponderosa Pine in Northern Arizona

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The productive capacity or site quality of an area enters into nearly every phase of forest management from regeneration to final harvest. No standards or measures of site quality have been developed specifically for ponderosa pine in the Southwest, which handicaps the forest manager.

The major objective of the present study was to develop the basic site-index curves for young-growth ponderosa pine by means of which a relative growth capacity may be assigned to each forest condition in the forests of Arizona.

Secondary objectives were to test the applicability of suggested mensurational procedures for site curve construction (individual tree stem analyses, polymorphic curves, use of dominant trees only, age at breast height rather than total age), and effect of stand density upon height.

REVIEW OF LITERATURE

The term "site" or "site quality" is used in forestry to represent the sum total of environmental effects upon the quantity of wood grown upon an area by forest trees (Spurr 1952).[2] The one measure of growth found to be most independent of stand factors, and consequently most reliable for site evaluation, has been height of the dominant stand in relation to its age (Lynch 1958). As presently used, site index refers to the average height of dominant or codominant trees at a specific reference age, 100 years for most western species (Bruce and Schumacher 1950).

Site quality cannot be defined in an absolute sense. The same area may be capable of supporting different species, but their growth may be entirely different (Meyer 1953). A good site for pine may be a poor site for fir, even where both are found growing together.

The yield capacity of ponderosa pine has been studied in several other areas (Show 1925, Behre 1928, Dunning and Reineke 1933,

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[2]*Names and dates in parentheses refer to Literature Cited, page 7.*

Meyer 1938, Lynch 1958), but never in the Southwest. The major study of ponderosa pine yield and site index (Meyer 1938) included data from California, Oregon, Washington, Idaho, Montana, Wyoming, and South Dakota. The Southwest was not included in this study because the necessary conditions were considered unavailable.

Selection of the portion of the stand to be included in site-index determinations has been studied considerably in recent years. Several writers (Staebler 1948, Ker 1952, Spurr 1952, Hummel and Christie 1953) have shown that restricting the classes of trees used for site classification considerably reduces the number of measurements required for a given degree of accuracy. Use of only dominant trees reduces the variability in tree height and minimizes the subjective aspect of distinquishing both crown classes. Greater stability of the dominant stand is also advanced as an advantage of restricting sampling to dominant trees.[3] Guillebaud and Hummel (1949) found that 90 percent of the trees on permanent sample plots that were dominants at the beginning of the study were still dominants after 15 to 25 years.

A further aspect of site-index studies which has been revised with increased mensurational experience is the form and relationships of site-index curves. In the earlier yield studies in this country, height-age relations were defined as curves of the same form as the average site index, but differing therefrom by a constant ratio at all ages, in other words, anamorphic curves (Osborne and Schumacher 1935). Spurr (1952) has pointed out that this procedure involves some unsafe assumptions: (1) the sample must have included all ages and all sites, (2) the effect of site on height growth must be the same at all ages, and (3) the height-growth curves of trees on a good site must have the same shape as on a poor site.

Soundest procedure seems to be construction of polymorphic curves based upon stem analysis of individual trees (Bull 1931, Spurr 1952). The greatest weakness in this latter approach is that the curves developed represent height growth of individual trees rather than the stand. The more restricted the selection of trees for site determination, however, the less important this factor will be. Spurr (1952) advocated restricting site measurements to the tallest tree in the stand, claiming that the stem-analysis method was practically without error when this restriction was applied. A recent study of lodgepole pine, however, showed shifts in relative height of individual trees that introduced bias into height-age curves (Dahms 1963).

The effect of stand density on tree height growth, and correspondingly on determination of site index, has been a subject of considerable investigation and discussion in recent years. Variable and sometimes conflicting results have been reported for various species and locations. An excellent coverage of the subject of height and stand density is given by Lynch (1958). In a study of paired plots of ponderosa pine in the Inland Empire, he found a reduction in dominant heights on poorer sites (below 75) in overstocked stands.

COLLECTION OF DATA

Data were gathered from selected trees in uniform young-growth stands of ponderosa pine within a 100-mile radius of Flagstaff, Arizona. At most sample locations two trees were selected: (1) a dominant tree from a clump or group, and (2) an isolated dominant, at least 30 feet from the nearest tree, but of the same age and on the same apparent site as the group dominant. Sample trees were also required to be 100 to 150 years of age, be straight and sound with no apparent damage that would affect height growth, be free of insects and disease, and a core from breast height must show no evidence of fire scars or past mechanical damage.

No attempt was made to select the tallest tree from the stand or group, because analysis of repeated measurements of large sample plots at the Fort Valley Experimental Forest indicated considerable stability in the dominant crown class for local ponderosa pine. Of

[3] *Turnbull, K. J. Stem analysis techniques and applications, and some studies of second-growth Douglas-fir in western Washington. 1958. (Unpublished master's thesis on file at College of Forestry, Univ. of Wash., Seattle.)*

50 randomly selected trees, tallied as dominant upon reaching 8 inches d.b.h. in 1930, 86 percent were still dominant as of February 1963. The remaining 14 percent were codominant or declining dominants.

The selected trees were felled (with stump height as low as possible, not to exceed 10 inches), total height was measured from ground to tip, and age was determined at the stump, at breast height, and at 10-foot intervals from stump to tip. In addition, basal area around the felled dominant tree (group dominant) was recorded by angle count, with a basal-area factor of 10 square feet per acre per tallied tree.

A total of 91 trees was measured; 43 paired samples plus 5 other trees chosen for certain characteristics for which no paired tree was available. Ages ranged from 85 to 158 years, site indices from 45 to 98 feet.

For each tree, ring counts on each section were converted to age from stump and age from breast height. Heights were then plotted over ages to permit exact determination of site index (total height at 100 years) on both total age and breast-height age bases. Distribution of sample trees according to site index (based on age at breast height), together with total number of sections counted, is shown in the following tabulation:

	Sample trees (No.)	Sections analyzed (No.)
Site index (ft.):		
45	2	12
50	5	29
55	10	63
60	9	63
65	16	119
70	12	94
75	9	71
80	6	51
85	9	82
90	8	77
95	4	39
100	1	9
Total	91	709

ANALYSIS OF DATA

Age Basis of Site Curves

Conventionally, site index is based upon total age of the dominant stand or tree. Methods of age determination normally involve count of annual rings on an increment core extracted at breast height (4.5 feet above ground) plus an arbitrary correction for number of years to reach breast height.

The time required for the 91 trees studied to reach breast height averaged 14.3 years, and ranged from 6 to 29 years.

	Trees (No.)	Years to breast height (Average)	Years to breast height (Range)
Site index (ft.):			
50	12	16.2	9 - 27
60	22	14.9	8 - 29
70	28	14.6	6 - 24
80	12	12.5	9 - 17
90	15	12.7	9 - 25
100	2	13.5	12 - 15
All trees	91	14.3	6 - 29

Such variation makes an average correction seem very dubious, particularly at younger ages when an error of only 2 or 3 years may cause a 10-foot difference in estimated site index.

No definite relation was found between site index and age to breast height. Range within site classes was nearly as great as for all trees.

As described by Pearson (1950), ponderosa pine reproduction is subject to damage by drought, tipmoth, white grubs, gophers, porcupines, rabbits, small rodents, cattle, sheep, and deer. Early height growth can be expected to vary extremely because of these factors. Since all of the sample trees originated prior to the period of intensive livestock grazing in Arizona, variation in the sample is less than would be encountered in present-day regeneration.

DENSITY

In view of the reported instances where density has affected height of ponderosa pine (Weaver 1947, Krauch 1949, Baker 1953, Mowat 1953, Lynch 1958), an attempt was made in the present study to evaluate the effect of density by comparing growth of paired trees at the same age. The dominant tree from a group represented the small, even-aged, dense clumps typical of ponderosa pine in the Southwest, while the isolated tree at least 30 feet from the group was assumed to be free of extremes of competition.

In 21 of the 43 pairs studied, the group dominant was taller at age 100 at breast height, in 17 pairs the isolated tree was taller, and in 5 pairs heights were identical. Differences in height between paired trees averaged 4.9 feet, and ranged from 0 to 14 feet, at 100 years of age. When differences were plotted over site index, no trend could be discerned.

Heights of the paired trees at 50 years of age at breast height were analyzed similarly. In 24 pairs the group dominant was taller, in 13 the isolated tree was taller, and in 6 pairs the heights were identical. Differences in height averaged 3.9 feet, with a range from 0 to 13 feet. During the 50 years from age 50 to age 100, relative position changed in 21 of the 43 pairs.

Relation of basal areas to heights was also tested. No usable trends were found. Differences in heights of paired trees increased irregularly with increasing basal area up to 140 square feet, and decreased irregularly thereafter. This study showed no consistent effect of basal area on height.

Site-Index Curves

A first problem of the present study was to find a satisfactory form of equation for height in terms of age. The common transformation, found applicable to many species in the United States (Schumacher and Coile, 1960):

$$\log H = a + b\left(\frac{1}{A}\right)$$

in which H is dominant height in feet and A is age, did not prove satisfactory for the trees studied. Many transformations were attempted, until an equation of the form

$$H = a + b\sqrt{A}$$

was finally adopted. This equation corresponded quite well to the shape of the height-growth curves for all sites, and for breast height ages from 10 or 20 years up to 140 years. Accordingly, the data were computed to this range of ages.

In view of the possible polymorphism of site curves derived from stem analyses, separate equations were developed for each 5-foot site class. The data were sorted by site-index classes based upon actual tree height at 100 years of age at breast height.

The stem analyses provided ages, at 10-foot intervals, from breast height to the tip of the tree. Excluding sections at 4.5 feet, the 91 felled trees supplied a total of 709 ages at known height. Because conventional site curves express height in terms of age, a reversal of variables is involved. Spurr (1952) states that this is not usually a serious problem due to the high degree of correlation between the variables.

In this study, however, a separate regression analysis was made for each site class in the form

$$\sqrt{A} = a + bH$$

and the equation was then inverted to give a solution for dominant height (H) in terms of breast height at age (A):

$$H = \frac{1}{b}(\sqrt{A}) - \frac{a}{b}$$

From study of the equations of height in terms of age for each site class, it appeared that the inverted regression coefficients (1/b) were linearly related to site index. Accordingly an equation of the form

$$\frac{1}{b} = c + d(S)$$

was fitted. The resulting equation, based upon 12 observations, is:

$$\frac{1}{b} = -1.4003 + 0.1559\ (S)$$

Appropriate analysis of variance showed both coefficients to be significant.

Substituting this relation, wherein site index (S) is an independent variable, gives for the original equation:

$$H = [c + d\ (S)]\ \sqrt{A} + [c + d\ (S)]\ (-a)$$

Introducing the reference age for site index (100 years) then gives:

$$H = S + [c + d\ (S)]\ [\ \sqrt{A} - \sqrt{100}\ ]$$

or, for ease of computation,

$$H = S + c(\sqrt{A} - \sqrt{100}) + d(S)\ (\sqrt{A} - \sqrt{100})$$

With the substitution of the previously computed values of c and d, the final equation becomes:

$$H = S - 1.4003\ (\ \sqrt{A} - 10) + 0.1559\ (S)\ (\ \sqrt{A} - 10)$$

RESULTS AND APPLICATIONS

Results of the study are summarized in table 1, and in the previous tabulations. Figure 1 presents the site-index curves derived from the final equation for height in terms of age and site index.

Field Application

To determine the site index of a given area, total height and age at breast height must be measured for selected dominant trees. From samples taken to test accuracy of site classification, it was found that, for a typical young-growth clump, a single dominant tree would give as good results as the average of several trees. In larger, uniform areas of young growth, however, a sample of five or more dominants is required for accurate site measurement.

The sample tree or trees must meet the following specifications:

1. must be young-growth ponderosa pine (blackjack or young intermediate);
2. must be a true dominant or an isolated tree with dominant characteristics;
3. must have no top damage; no crooks, scars, or forks due to squirrel, porcupine, snow or ice damage;
4. must be free of insects and disease;
5. a core at breast height should show no fire scars, mechanical injuries, nor any extended period of suppression followed by release.

Table 1. --Height of dominant trees, by age at breast height and site index (SI)

Age at breast height (years)	Height of dominant trees						
	SI 40	SI 50	SI 60	SI 70	SI 80	SI 90	SI 100
	Feet						
20	13	15	16	17	19	20	22
30	18	21	24	27	30	33	36
40	22	26	31	35	39	44	48
50	26	31	37	42	48	53	58
60	29	36	42	49	55	62	68
70	32	40	47	54	62	69	77
80	35	43	52	60	68	77	85
90	38	47	56	65	74	84	93
100	40	50	60	70	80	90	100
110	42	53	64	75	85	96	107
120	45	56	68	79	91	102	114
130	47	59	71	83	96	108	120
140	49	62	75	87	100	113	126

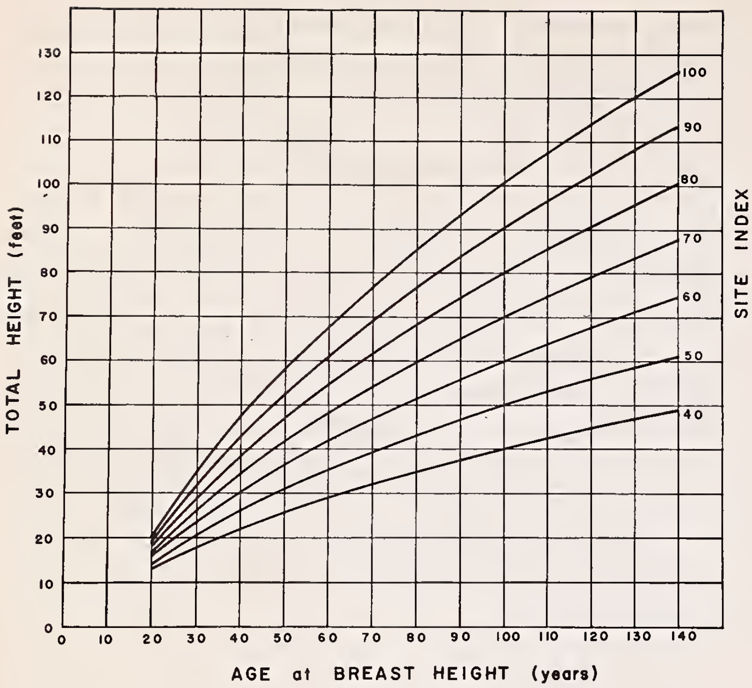

Figure 1.--Ponderosa pine site index.

Precautions in the actual measurement of age and height may seem superfluous. As pointed out by Coile and Schumacher (1953), however, mistakes in site classification can and do result from errors in measurement of both height and age.

For correct site evaluation, the height readings should be taken from a measured base line, not paced distance; corrections for slope must be made, though where possible the observer should measure out along the contour; repeated sights to tree base and tip are advised; increment cores for age should be extracted to the pith; and rings must be correctly identified and counted (use of a core slicer and hand lens is recommended).

If ages and/or heights of selected trees differ markedly, it is recommended that, instead of averaging the measurements, a separate site index be read for each to check for correspondence or for faulty sampling. This procedure will usually identify any abnormality or error in measurement of the sample tree.

Should it be desired to record site index closer than to the nearest 10-foot class, it is recommended that the following equation be solved, instead of attempting to interpolate from the table or graph:

$$S = \frac{H + 1.4003(\sqrt{A} - 10)}{1 + 0.1559(\sqrt{A} - 10)}$$

where
S = site index
H = dominant height in feet
A = age at breast height in years

TESTS OF SITE CURVE ACCURACY

Site curves developed in this study were field checked to test their validity. Accuracy of a given curve was tested by measuring trees of different ages growing close enough together (on similar soils, slope, and aspect) to be of the same apparent site index. The site index of each study tree was computed. Errors in predicted site index were determined from any differences in calculated site between trees of different ages.

Field checks were made at 70 different locations in Arizona, and 5 in New Mexico, representing 8 National Forests and one Indian Reservation, (table 2). The field checks in New Mexico were conducted by the U.S. Forest Service.

SUMMARY

The present study was conducted to develop site-index curves specifically for young-growth ponderosa pine for use in Northern Arizona. Secondary objectives were to test certain newer mensurational procedures in site-curve development.

Stem-analysis data were collected on 91 sample trees in the vicinity of Flagstaff, Arizona. To evaluate the effect of density on height growth, paired trees were selected, when possible; a dominant from a dense clump, and an isolated dominant tree on the same apparent site. Only dominant trees were selected, because preliminary study had indicated relative stability within this crown class for local ponderosa pine.

No consistent effect of density on height was found through the paired-tree technique described above. Differences in height between the paired trees could not be related to location, site, or basal area.

Table 2.--Summary of field checks for site curves in Arizona and New Mexico

Area	Number of locations sampled	Range in age per location		Error in predicted site index per location	
		Average	Maximum	Average	Maximum
		Years		Feet	
ARIZONA:					
Coconino National Forest					
South	15	31	42	1.2	3
Lake Mary	5	64	109	5.0	9
Fort Valley	10	58	86	4.1	7
Prescott National Forest	12	35	52	6.4	17
Sitgreaves National Forest	8	64	94	2.9	6
North Kaibab National Forest	4	81	122	6.0	10
Apache National Forest	6	61	107	4.7	10
Fort Apache Indian Reservation	5	70	87	4.2	8
Tonto National Forest	5	38	60	9.6	16
NEW MEXICO:					
Carson National Forest	3	74	82	8.5	12
Cibola National Forest	2	46	53	7.7	8

Due to extreme variability in the time required (6 to 29 years in the sample trees) for local ponderosa pine to reach breast height, site curves were based upon ages at breast height rather than upon total ages.

Site curves are presented for site indices of 40 to 100 feet, ages 20 to 140 years. In the analysis of data, separate equations were calculated for each 5-foot site class. The regression coefficients were found to be linearly related to site index, however, and accordingly site was introduced as a variable in the final equations.

The curves were field checked on adjacent trees of varying age at 75 locations in Arizona and New Mexico. Errors in predicted site between young and old trees averaged less than 5 feet per location.

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