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Site Classification of Ponderosa Pine Stands under Stocking Control in California

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IN BRIEF...

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Oxford: (794): 174.7 *Pinus ponderosa* — 114.7 [541 + 542]. *Retrieval Terms:* stocking density; soil productivity; *Pinus ponderosa*; site class assessment.

Several systems exist for determining site index in dense, unmanaged California stands of ponderosa pine. Each system involves height growth curves based on single measurements of tree height and age on temporary sample plots. Generally, such curves are anamorphic and fall short in reflecting the actual growth patterns of dominant trees grown under moderate stocking densities. This paper describes a new site classification system for California stands of ponderosa pine under stocking control. Additionally, a system for estimating site index in very young stands is described.

Stem analysis techniques were used in reconstructing periodic height and age for 135 dominant ponderosa pine in stands covering five physiographic provinces in northern California. These data formed the basis for polymorphic patterns of height growth to 80 years of age.

Tree growth on average and poorer sites was disproportionally less than on better sites during the first 15 years of stand development. Growth rates were proportional on all sites between stand ages of 20 and 60 years, but dropped rapidly on poor sites beyond 60 years of age. Contrary to trends described by most existing site index curves, rapid rates of height growth are possible to age 80, providing stocking densities are moderate and soils fairly deep.

Conventional systems for estimating site index are inaccurate when applied to very young stands. There are two reasons for this. First, young stands seldom are sampled extensively in collecting base data for conventional site index curves. Second, young trees on stoney soils often grow well during their early development, but their growth rates drop rapidly as competition mounts for limited site resources.

We tackled the problem of estimating site index in very young stands by stratifying dominant trees by types of soil parent material and correlating the length of the first four branch internodes above breast height (height intercept) with height at age 50. On most soil types, site index could be predicted as a linear function of height intercept. But on skeletal schists, trends were significantly different. There, site index was less than that indicated by early growth rates.

Both systems for estimating site index are described in detail, and guides are given for applying them in practice. Yield tables for plantations of ponderosa pine based on the first system will be issued separately.

Site index, the height attained by a stand's dominant or dominant and codominant trees at an arbitrary index age, has been the basic measure of site productivity in the United States for over half a century. In California, several site index curves are used for estimating productive potential of even-aged stands of ponderosa pine (*Pinus ponderosa* Laws.). All of these (Arvanitis and others 1964; Meyer 1938; Dunning and Reineke 1933) are based on single measurements of current heights and ages of trees on temporary sample plots in dense, natural, unmanaged stands. As Lynch (1958) and Oliver (1967) have shown, height growth—and site index—are depressed at high stocking densities in ponderosa pine. Existing site index systems do not describe adequately the growth patterns of pine that will be managed under stocking control in California.

Ponderosa pine is an important part of California's forest resource. Here, nearly 4 million acres (1.6 million ha) are classed as commercial pine type (Forest Survey Staff 1954). An additional 8 million acres (3.2 million ha) support commercial mixed conifers in which ponderosa pine is prominent. Since 1960, over 130,000 acres (53,000 ha) of National Forest land alone have been planted to ponderosa pine following logging, wildfire, or type conversion in California.[1] Site index will play a key role in future management decisions affecting these stands as silviculture is intensified.

Stands developing under uncrowded conditions show height growth trends differing significantly from those depicted by standard curves (Powers 1972). As part of a larger growth and yield study serving timber management needs in California,[2] we developed height growth curves for even-aged stands of ponderosa pine under moderate stocking density and managed for rotations of 80 years or less. These curves can be used to predict stand development and to assess site index for young-growth stands of ponderosa pine west of the Sierra Nevada crest and in the Warner Mountains of California.

This paper describes a system for estimating site index in stands where dominants have reached heights of at least 20 feet (6 m), and explains the method of its derivation. A second system, suitable for very young stands and allowing stratification by soil parent material class, is also described.

STAND CHARACTERISTICS

Data used to derive the site index system came from well-stocked, even-aged, pure or nearly pure ponderosa pine stands free of any past suppression. Stands in five physiographic provinces in California north of latitude 37° were surveyed. We favored natural stands growing at stocking densities approaching those for optimal timber production—roughly two-thirds of normal basal area (Meyer 1938)—although young, unthinned plantations were also included. So that site index could be assessed accurately, only stands near 40 years of age and older were considered for study. Twenty-six plots were established in natural stands and unthinned plantations in the northern Coast Range, Klamath Mountains, southern Cascade Mountains, Basin and Range Province

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[1] Unpublished data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

[2] Oliver, William W., and Robert F. Powers. *Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California.* (Manuscript in preparation).

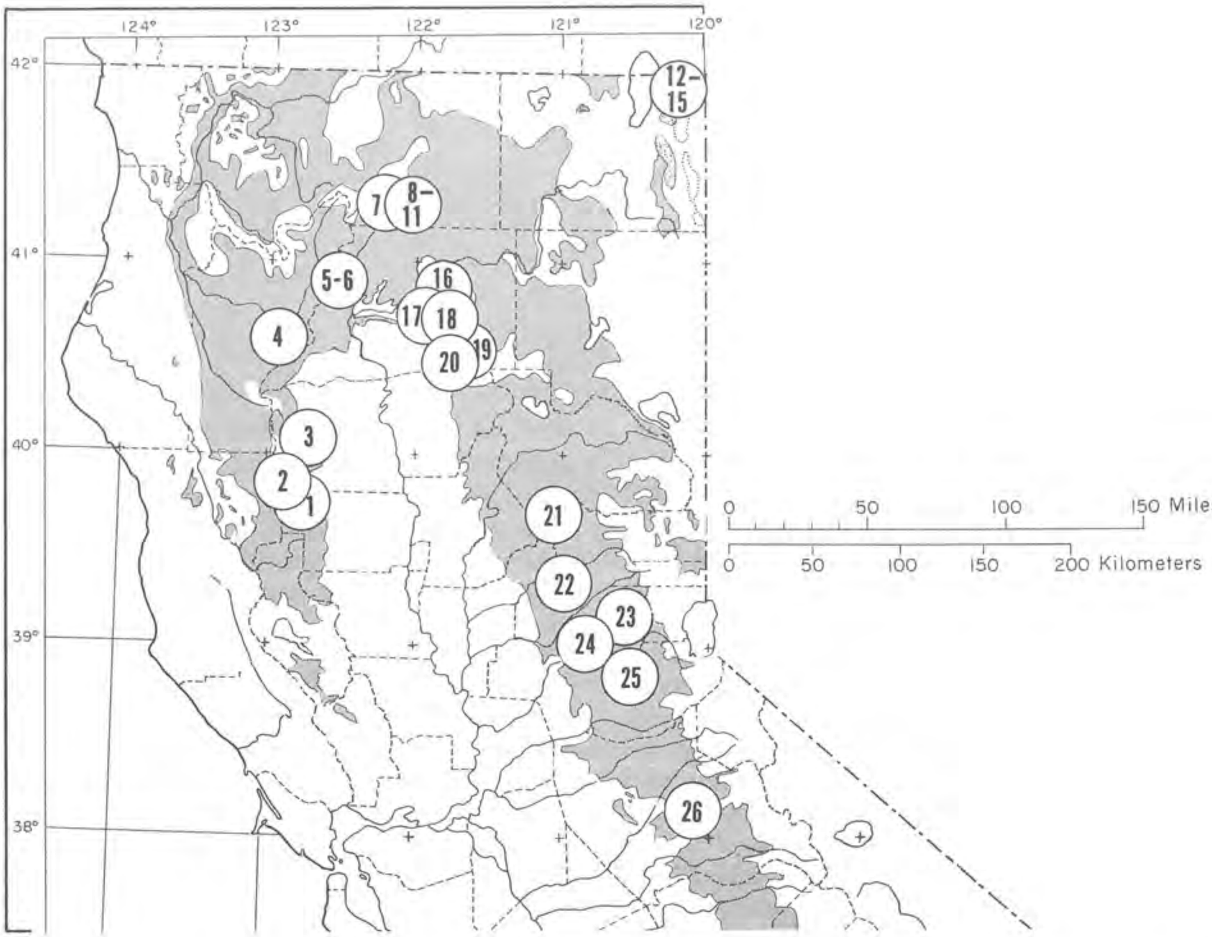


Figure 1—Study plots for ponderosa pine stem analyses were located throughout northern California. Characteristics of plots are described in *table 1.* Base map (adapted from Griffin and Critchfield 1972) shows distribution of ponderosa pine stands 2 miles wide or more (shaded area).

(Warner Mountains), and northern Sierra Nevada (*fig. 1*).

Soils supporting these stands were derived primarily from meta-sedimentary or basic igneous rocks (*table 1*). Despite the abundance of granitic rocks in the Sierra Nevada, none of our plots were located over this parent material. Timber stands associated with granitic soils in the northern Sierra Nevada are mainly the mixed-conifer and true fir forest types. And although many mixed-conifer sites have been planted to pine, no plantations on granitic soils were old enough for plot selection.

Stand ages ranged from 38 to 103 years (*table 1*). Point density estimates of basal area made on about half the plots yielded densities between 140 and 290 square feet per acre (32 to 67 sq m/ha). Basal area stocking in natural stands generally was less than the normal given by Meyer (1938), whereas stocking in plantations tended to be greater than normal. We attribute the greater basal areas in plantations, compared with normal stands, to initial spacing control. Mean stand diameters for plantations tend to be greater than those found in dense natural stands of the same age and dominant height because of early advantages in growing space per tree. Unthinned plantations often reach greater basal areas but may have more stem taper than normal yield stands of the same age and dominant height, because there is less intertree competition.[1] Thus, "percent of normality" carries a different meaning in respect to basal area for plantations than it does for natural stands.

Table 1—*Location and characteristics of plots and stands chosen for ponderosa pine stem analyses*

Plot[1]	Physiographic province	Parent material	Stand age	Height at age 50[2]	Basal area as percent normal[3]	Number of trees
			Years	*Feet*		
1. Alder Springs 1 (N)	N. Coast Range	Schist	70	82	71	5
2. Alder Springs 2 (N)	N. Coast Range	Schist	81	75	—	5
3. Pollard Corral (N)	N. Coast Range	Schist	66	71	—	5
4. Chanchelulla (N)	Klamath Mtns.	Gabbro alluvium	103	88	58	5
5. Shasta Lake 1 (P)	Klamath Mtns.	Metavolcanic	40	42e	—	8
6. Shasta Lake 2 (P)	Klamath Mtns.	Metavolcanic	40	54e	129	4
7. McCloud Flat (N)	Cascade Mtns.	Volcanic ash and alluvium	81	88	115	5
8. Show 1 (N)	Cascade Mtns.	Volcanic ash and alluvium	74	83	132	5
9. Show 2 (P)	Cascade Mtns.	Volcanic ash and alluvium	50	69	102	5
10. Show 3 (P)	Cascade Mtns.	Volcanic ash and alluvium	50	80	116	5
11. Henry's Find (P)	Cascade Mtns.	Volcanic ash and alluvium	46	76e	107	8
12. Sugar Hill 1 (P)	Basin and Range	Basalt	38	31e	92	5
13. Sugar Hill 2 (P)	Basin and Range	Basalt	38	40e	129	10
14. Sugar Hill 3 (P)	Basin and Range	Basalt	38	45e	113	5
15. Sugar Hill 4 (P)	Basin and Range	Basalt	38	54e	142	3
16. Round Mtn. (N)	Cascade Mtns.	Basalt	56	109	—	4
17. Buckhorn (N)	Cascade Mtns.	Andesite	64	98	93	5
18. Tamarack (N)	Cascade Mtns.	Basalt	88	95	—	5
19. Shafco (N)	Cascade Mtns.	Andesite	52	89	—	4
20. Midway (N)	Cascade Mtns.	Basalt	65	76	—	4
21. Forbestown (N)	Sierra Nevada	Metabasalt	97	92	70	5
22. Red Dog (N)	Sierra Nevada	Placer mine tailings	83	59	—	5
23. Elliot Ranch (N)	Sierra Nevada	Basalt	103	104	—	5
24. Foresthill (N)	Sierra Nevada	Schist	61	104	—	5
25. Sly Park (N)	Sierra Nevada	Basalt	51	117	—	5
26. Shanahan Flat (N)	Sierra Nevada	Schist	84	94	—	5

[1] N = natural stands; P = plantation.

[2] e indicates that height has been extrapolated.

[3] existing basal area ÷ normal basal area (Meyer 1938) × 100 for stands of comparable age and dominant height.

METHODS

Field Procedure

Dominant trees in each candidate stand were examined for signs of past suppression or damage. Bole development and patterns of annual rings on increment cores taken at breast height were inspected, and any indication of restricted growth was cause for rejecting a tree from further study. An average of 15 dominant sample trees per acre (37/ha) were selected on plots ranging in size between 0.05 and 0.5 acres (0.02 to 0.2 ha). Plot areas varied with tree spacing and with the dimensions of stand units where site quality seemed homogeneous.

Total age was chosen as our time variable because it is directly applicable to management of plantations, where ponderosa pine silviculture will be practiced most intensively in the future. Unlike well-managed plantation trees, those in natural stands often suffer strong competition from other vegetation during early development. Consequently, early growth rates in natural stands often fail to reflect true site potential. There, breast-height age provides a more useful variable, but an adjustment factor must be used to obtain an estimate of total age that would reflect conditions of minimal competition. For our natural stands, total age was estimated from ring

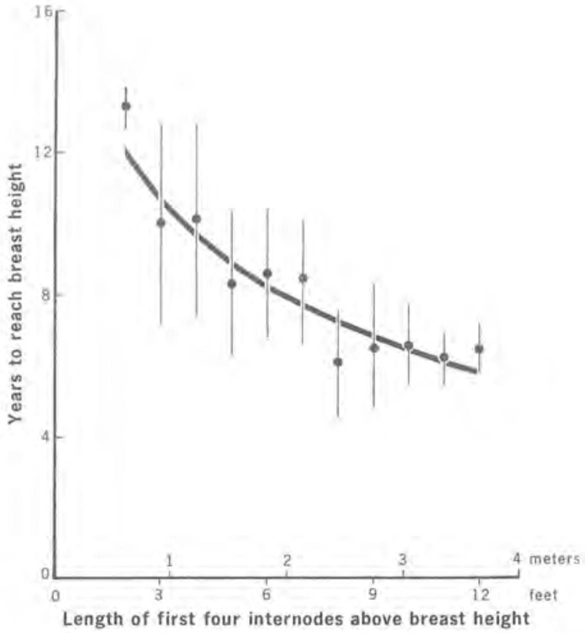


Figure 2—Total age of dominant ponderosa pine can be estimated from breast height age and the length of the first four branch internodes above breast height. Means and standard deviations for years to reach breast height are shown by 1-foot internode classes.

counts at breast height, using an adjustment factor based on the total length of the first four branch internodes above breast height (*fig. 2*). This factor supersedes the one we reported previously (Oliver and Powers 1971). Planting date (rather than age from seed) was the base age for the plantations we sampled. By the time trees reach breast height, little size difference is apparent between naturally seeded and planted stock, providing that sites have been prepared properly and that genetic differences are few.

To determine mean height at 5-year age intervals, heights to the first five branch nodes above breast height, then to each fifth node, and to the top of each tree were measured. A sectional pole was used for measuring heights to 40 feet (12 m) and an engineer's transit used thereafter. In all, 135 dominant trees were measured.

Analysis of Data

Periodic heights of sample trees were averaged for each of the 26 plots. The resulting data (mean heights of dominant trees at 5-year age intervals) suggested a sigmoid growth trend (*fig. 3*). The height attained at 50 years total age defined the site index for trees on each plot. Heights ranged from 31 to 117 feet (9.4 to 35.7 m). Height at age 50 was estimated from past growth trends for the seven plots younger than index age (*table 1*). We felt justified in extrapolating growth trends on these plots because they were the poorest sites we measured and patterns are unlikely to change much in 10 to 12 years.

As a preliminary approach to describing site index curves, we applied to the data simple regression techniques developed for stem analyses (Johnson and Worthington 1963, Dahms 1975). Separate linear regressions were calculated for the relation of plot site index to the heights shown by plot dominants at successive age intervals above and below index age.

Each of the 15 data sets describing the relation of dominant height to site index at 5-year intervals for stand ages 10 through 80 years were plotted and inspected. A linear relation between mean dominant height and site index was shown clearly for stand ages 20 through 65 years, suggesting that proportional curves of the same basic form should describe growth accurately in this range. But nonproportional patterns appeared both at younger and older ages, suggesting that medium

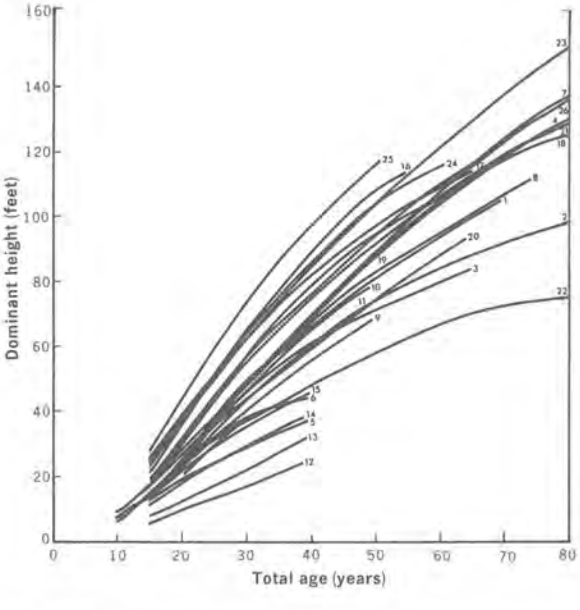
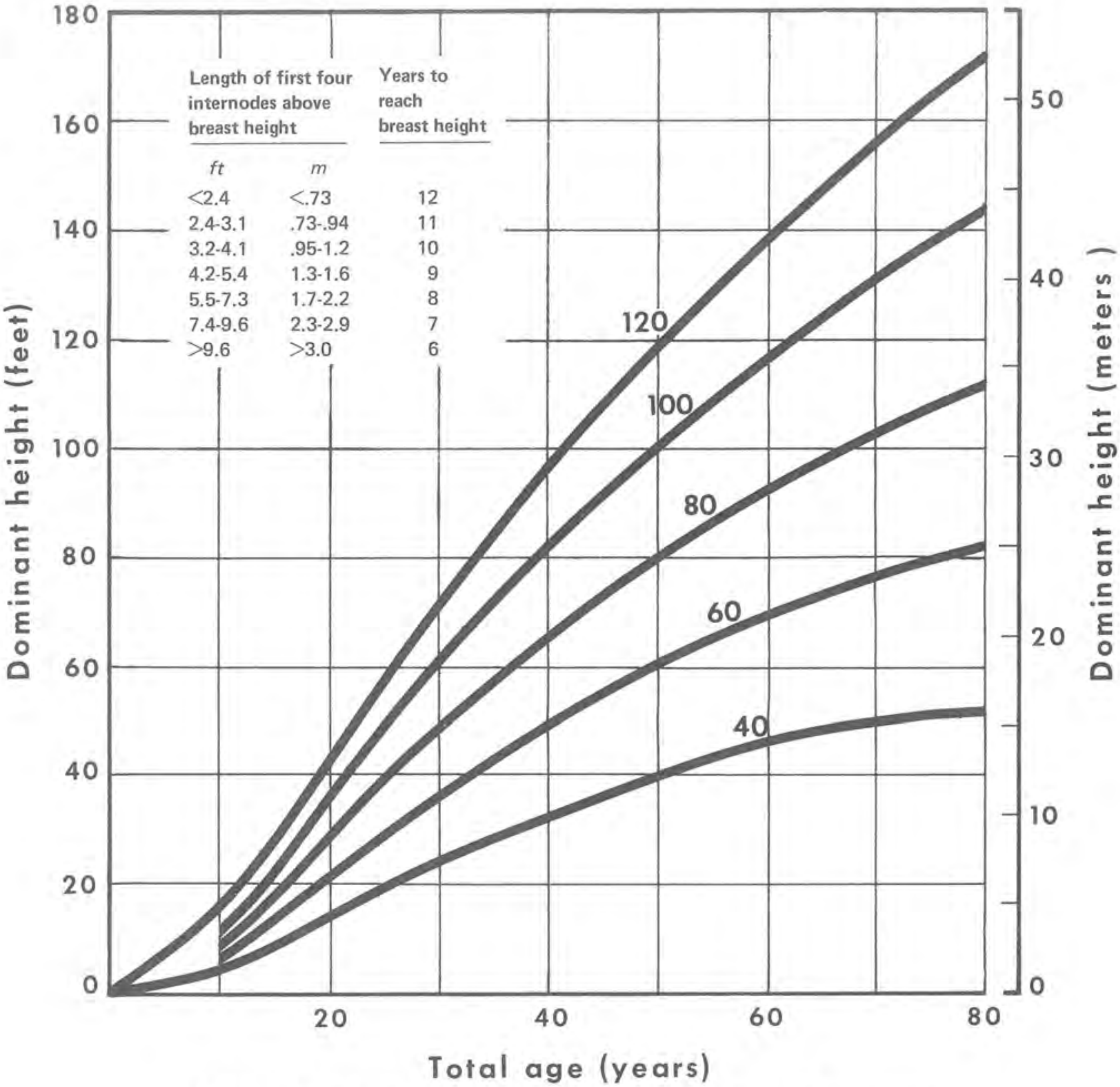


Figure 3—Mean patterns of height growth were plotted for dominant sample trees from plots described in *table 1*. Growth continued to be rapid at advanced ages, providing stocking density was not too high.



Length of first four internodes above breast height		Years to reach breast height
ft	*m*	
<2.4	<.73	12
2.4-3.1	.73-.94	11
3.2-4.1	.95-1.2	10
4.2-5.4	1.3-1.6	9
5.5-7.3	1.7-2.2	8
7.4-9.6	2.3-2.9	7
>9.6	>3.0	6

Site index curves for plantations and young natural stands of ponderosa pine

Figure 4—Site index curves for even-aged westside ponderosa pine were developed from stem analyses. Adjustment factors are shown for converting breast height age to total age.

Table 2—*Periodic height of dominant ponderosa pine in relation to site index*

Total age (yr)	Dominant tree height when site index is . . . 40	60	80	100	120
			Feet		
10	5	7	9	11	16
15	9	13	17	23	29
20	14	21	29	36	43
25	20	29	39	49	59
30	24	37	49	61	73
35	29	43	58	72	86
40	33	49	65	82	98
45	37	55	73	91	110
50	40	60	80	100	120
55	43	65	87	108	130
60	45	69	92	118	139
65	48	73	98	124	148
70	50	76	103	131	157
75	51	79	108	138	165
80	52	82	112	143	171

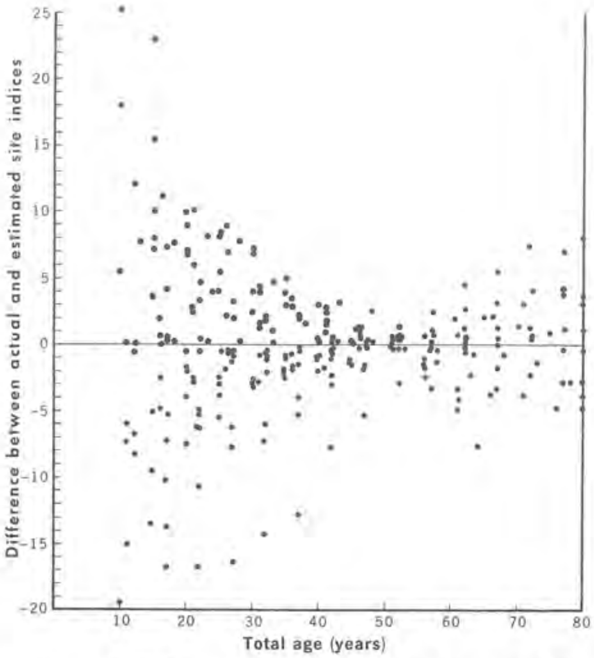


Figure 5—Differences between actual and estimated site indices decrease as index age is approached. From age 20 onward, errors in predicted site index generally are less than 10 feet at 50 years.

and poor sites produce trends differing slightly from those found on better sites. To compensate for this, growth trends were curved by hand for the ages of 10 to 20 and 60 to 80 years. Dominant heights for 20-foot (6-m) site index classes were taken both from freehand curves and regression equations at 5-year intervals between 10 and 80 years total age (*table 2*).

Data points in *table 2* were plotted to develop the site index curves shown in *figure 4*. Patterns of height growth for trees younger than age 30 were compared with height data from 21 check plots in eight plantations too young to be used in the main study. Dominants on check plots ranged from 16 to 29 years in age and from 37 to 120 feet (11 to 37 m) in estimated site index. Check data generally supported the height growth trends we had described for trees below age 30. Some erratic patterns of height growth appeared; we attributed these to soil characteristics or brush competition. Few moderately stocked stands at advanced ages were available for checking the accuracy of our curves. Those that we were able to find did not conflict clearly or consistently with the trends shown in *figure 4*. Inspection of the deviations of estimated dominant heights from those actually attained (*fig. 5*) reveals no consistent bias.

We developed a five-parameter growth function for describing the curves in *figure 4*. The following equation estimates curve values of height within 2.3 feet (0.7 m) for site indices 40 through 120 and ages 10 through 80 years.

$$H = (1.88s - 7.178)\,(1 - e^{-0.025A})^{(0.001S + 1.640)}$$

where

S = site index in feet at base age 50 years
A = total age in years
$R^2 = 0.999$

SITE INDEX IN YOUNGER STANDS

Estimating site index in very young stands is a problem persisting in forestry. Oliver (1972) has shown that height intercept—the relation of the length of the first four internodes above breast height to site index—can be used in predicting site index either at base age 50 or 100 years. We reexamined Oliver's data by (1) calibrating height intercept against the new site index curves; and (2) stratifying data by soil parent material classes (*fig. 6*). In all, over 200 dominant trees were examined over a site index range of 31 to 124. A general linear model described adequately the height-intercept—site-index relationship for all parent material classes except schist inceptisols (poorly developed metasedimentary soils lacking definite zones of accumulation). Analysis of covariance helps confirm that trees growing on skeletal schists have lower site indices for a given height intercept than do trees on all other soils we studied. Predictive models describe these relationships:

For schist inceptisols (model I)

$$S = 17.57 + 6.75\ HI$$
$$r^2 = 0.79$$
$$s_{y.x} = 8.78$$

For soils other than schist inceptisols (model II)

$$S = 21.94 + 8.68\ HI$$
$$r^2 = 0.73$$
$$s_{y.x} = 11.08$$

where

S = site index (height in feet at 50 years)
HI = height intercept (length in feet of the first four internodes above breast height) Multiply intercept coefficients by 0.305 if HI is measured in meters.
r^2 = coefficient of determination
$s_{y.x}$ = standard deviation from regression

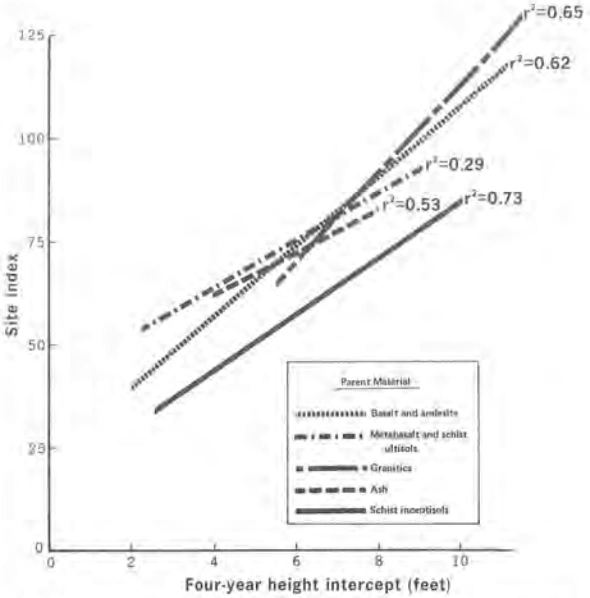


Figure 6—Site index can be predicted from the length of the first four branch internodes above breast height (height intercept). Trends are similar for trees growing on four classes of parent material, but are significantly different for those growing on schist inceptisols. Coefficients of determinations are shown for the trends in each parent material class.

DISCUSSION

Height Growth Patterns

The site index curves shown in *figure 3* are polymorphic—that is, their forms are dissimilar. Growth of trees on medium and poorer sites is disproportionally slower during the first 15 years of stand development than that on the best sites. Growth rates are proportional between 20 and 60 years. But by 65 years, growth slows disproportionally on poorer sites.

As shown by Curtis and others (1974) and Dahms (1975), differing systems of height-over-age curves can develop, depending on whether height or site index is the dependent variable in the basic regression equation. Strictly speaking, trends shown in *figure 4* (and most existing site index curves, for that matter) are more properly termed "height growth curves" because of the statistical treatment of the data. Although we recognize the distinction between site index and height growth curves, we believe that in this case the differences are unimportant. Differences between the two curve types are reduced if dominant trees, rather than dominants and codominants, are the basis for site curve construction, and if the relative crown positions of sample trees remain fairly stable over time.

At ages near zero, neither height growth nor site index estimating curves give very reliable estimates of site index. True site index estimating curves generally do not pass through the origin, and often describe heights that are not biologically possible at early ages on the best and poorest sites (Curtis and others 1974). Conventional height-over-age curves do pass through the origin, but users may develop a false confidence in their precision for estimating site index in young stands. The scatter of points in *figure 5* indicates the confidence that can be placed on site index estimates using very young trees. For example, estimates of site index for sample stands from heights attained by trees aged 10 through 15 years showed an error of 10 or more site index units in 39 percent of the cases. Differences dropped rapidly with age, however, when height of older trees were taken as the base. Only 11 percent of the sample stands in the 21- through 25-year age class differed by 10 or more site index units in their estimated and actual values.

Soil and Stand Effects on Height Growth

Estimates of site index in young stands may be biased because of certain soil characteristics controlling height development. For example, trees growing on ridge tops, on midslope benches, and on shallow or skeletal soils often gave lower site indices than indicated by early height growth. Generally, the reverse was true for trees growing on deep alluvial soils. Young plantations used as check stands showed similar growth patterns. Competitive vegetation is another factor in unusually slow early growth rates on poorer sites. For example, brush usually develops in young stands of widely spaced trees before crown closure. Our experience shows that for a given density of brush, the poorer the site the greater the competitive effect on tree growth. Until they reach dominant positions, trees on poorer sites have disproportionally greater competition from brush.

Trends indicated in *figure 3* show that rapid height growth can be sustained beyond 50 years on good sites, providing stand density remains moderate. Stands with rapidly decreasing rates of height growth tended to have basal area stand densities approaching normal stocking (Meyer 1938). Plot 8 in the Show 1 natural stand was an exception. There, height growth continued at a rapid pace although stand basal area was 131 percent of normal. This may be explained by the deep alluvial soil profile in that area, which seems free of horizons restricting root development.

Height Growth Patterns Compared with Standard Curves

Results gained with our system support conclusions of an earlier study (Powers 1972) that the systems of both Meyer (1938) and Arvanitis and others (1964) generate curves that underestimate later height growth in even-aged stands of ponderosa pine. Meyer's regional data came from unmanaged stands developing under strong competition. In fact, basal areas in the California stands he sampled exceeded normality by over 7 percent. Furthermore, less than 3 percent of his samples were from stands younger than 30 years. We do not believe the Meyer curves reflect accurately the height growth patterns of young, moderately stocked, west-side ponderosa pine.

Adjusting the curves of Arvanitis and others (1964) for total age (*fig. 2*) and comparing them with *figure 4* showed comparable trends only for site index 40. We conclude that either their curves are distorted because of a sampling imbalance in age classes and site qualities, or that the higher stand densities in the unmanaged stands they sampled may have depressed height growth in older trees.

In our study, the Dunning and Reineke (1933) curves came closest of all published standards in describing height growth patterns for individual stands. Growth trends in the 1933 curves are far more linear, however, than growth patterns found in our study. We conclude that the Dunning and Reineke curves generally overestimate growth of trees younger than index age, particularly on medium and poorer sites.

Because suitable stands were not found on that parent material, the accuracy of the site index curves shown in *figure 4* for stands on granitic soils is unknown. Data from the height intercept study (*fig. 6*) suggests that early height-growth—site-index patterns for trees on granitics are indistinguishable from those on soils developed from different parent materials (other than schist). Still, trends on granitic soils should be compared against our curves when suitable stands are found.

Restricted rooting space probably is the primary reason trees on schist inceptisols give low site indices for given height intercepts (*fig. 6*). Schist inceptisols generally are skeletal—that is, at least 35 percent of the soil volume is composed of rock. The limited rooting space restricts growth severely as stands develop and stand densities increase. Stands growing on nonskeletal schists probably will develop according to model II, the general height intercept equation.

Applying Results in Field Practice

By the time dominant trees have reached heights of 20 to 30 feet (6 to 9 m) most seem to express site potential accurately (*figs. 3, 4*). To use the site classification system in *figure 4*, select an average of 15 dominant trees per acre (37/ha) from stand units that seem homogeneous, physically. Sample trees must show no sign of past suppression or injury above breast height. For natural stands, estimate total age of each tree by adjusting breast height age using *figure 2* and the length of the first four internodes above breast height. Be alert for annual ring patterns showing abrupt changes between periods of slow and rapid growth. These indicate past suppression and release. For plantations, determine the total number of growing seasons from planting. Measure total height of each tree to the nearest foot (0.3 m). Finally, figure site index independently for each tree, using *figure 4*, and average these values to establish one site index for the stand unit.

For dominant trees that are less than 20 feet (6 m) tall, but have reached a breast-height age of at least 4 years, we recommend the height intercept method. Depending on the precision desired, select the appropriate number of the tallest trees per acre, as follows:

	Number of sample trees per acre (ha) to estimate site index within...		
	±20 ft	± 10 ft	± 5 ft
Soil parent material:			
Schist inceptisols	16 (40)	24 (60)	60 (150)
Other soils	16 (40)	28 (70)	88 (220)

Avoid trees showing any top damage and stand units showing obvious site changes. For each tree, measure the length of the first four internodes above breast height and estimate site index using regression model I or II, depending on soil type. Then average site indices for all sample trees to obtain a single estimate of site index for the stand unit.

Although no single set of idealized curves can account fully for the variety of growth patterns found in nature, we believe the system described in this paper reflects the patterns found on most sites under moderate stocking control. We recommend that the classification system described in *table 2* and *figure 4* be adopted as the standard site index reference for managed stands of ponderosa pine west of the Sierra Nevada crest and in the Warner Mountains of California. Yield tables based on this site index system have been developed for plantations of ponderosa pine and will be published separately.

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The Pacific Southwest Forest and Range Experiment Station

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Powers, Robert F., and William W. Oliver
1978. **Site classification of ponderosa pine stands under stocking control in California**. Res. Paper PSW-128, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

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Oxford: (794): 174.7 *Pinus ponderosa* — 114.7 [541 + 542].
Retrieval Terms: stocking density; soil productivity; *Pinus ponderosa*; site class assessment.

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