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ESTIMATING SITE INDEX OF PONDEROSA PINE IN NORTHERN CALIFORNIA...standard curves, soil series, stem analysis

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USDA Forest Service
Research Note PSW-265
1972

Abstract: Four sets of standard site index curves based on statewide or regionwide averages were compared with data on natural growth from nine young stands of ponderosa pine in northern California. The curves tested were by Meyer; Dunning; Dunning and Reineke; and Arvanitis, Lindquist, and Palley. The effects of soils on height growth were also studied. Among the curves tested, those by Dunning and Reineke seem superior in describing height growth trends of dominant trees in the first 50 to 60 years of stand development. Forest managers can estimate site index more accurately by applying a set of adjustment factors.

Oxford: 174.7 *Pinus ponderosa*:522.31:181.2:561.1.
Retrieval Terms: Pinus ponderosa; California; height increment; natural growth; site classification; site index curves.

Site index—the height of the tallest trees at an arbitrarily chosen age—is a proven and practical means of estimating site productivity. But if site index curves fail to represent the actual growth trend of trees, large errors in expected yield can result, and management programs will be adversely affected.

The concept of tree height as an index of site quality evolved from Huber's work in the forests of Germany in the 1820's. By 1918 site index became the standard means of forecasting forest productivity in the United States. Curves of height over age now exist for most commercial timber species.

Techniques for constructing such curves are varied. Sampling only dominant trees[1] and considering age at breast-height rather than total age,[2] generally increases accuracy. And though most early curves were developed from mean guide trends with harmonic departures (anamorphosis), such curves risk many inaccuracies.[3] Polymorphic site index curves based on stem analyses or long-term measurements on permanent sample plots more closely describe the actual growth pattern of trees.[4] Height curves based both on anamorphosis and polymorphosis have been compared.[3,5] Without exception, the latter have shown clear and consistent superiority, especially in the younger age classes.

Site classification problems are manifold in California. Climate, geology, and time have induced such racial and edaphic variability that reliance on any single set of site index curves for a particular species seems tenuous. And since site index should be flexible enough to meet changing forest management objectives, curves based on index ages of 100 years or more may need revision in anticipating shorter rotations.

This note reports a test of four sets of standard site index curves in describing the natural height growth pattern of even-aged ponderosa pine *(Pinus ponderosa* Laws.*)* to index age 50 in northern California. Growth trends on differing soil series and depth classes were compared. Of the four sets of curves that I tested, those by Dunning and Reineke seem best in describing height growth trends of dominant trees during the first 50 to 60 years of stand development.

METHODS

Samples were drawn from nine even-aged pine stands on gentle slopes bordering the Sacramento Valley *(fig. 1)*. Stands were at least 50 years old at breast height,[6] with complete or nearly complete crown closure. Stand density was estimated about each sample tree by point sampling in five of the nine stands *(table 1)*. Five of the tallest well-formed dominants lacking signs of past damage and with visible progressions of branch whorls were selected from small, homogeneous units within each stand. Increment cores were extracted from each tree and breast-height age determined. Trees with annual ring patterns suggesting past injury or suppression were rejected. Heights were measured at five-whorl intervals from the fifth whorl above breast height through the 50th and to the top of the tree. Heights were measured to the nearest 0.1 foot by using a telescoping pole for the first 42 feet and an engineer's transit thereafter.

Soil descriptions were taken from California State Cooperative Soil-Vegetation Survey maps[7] for samples within mapped areas. Otherwise, soil samples were collected and identified later by a soil scientist.[8] Seven distinct soil series were sampled *(table 1)*.

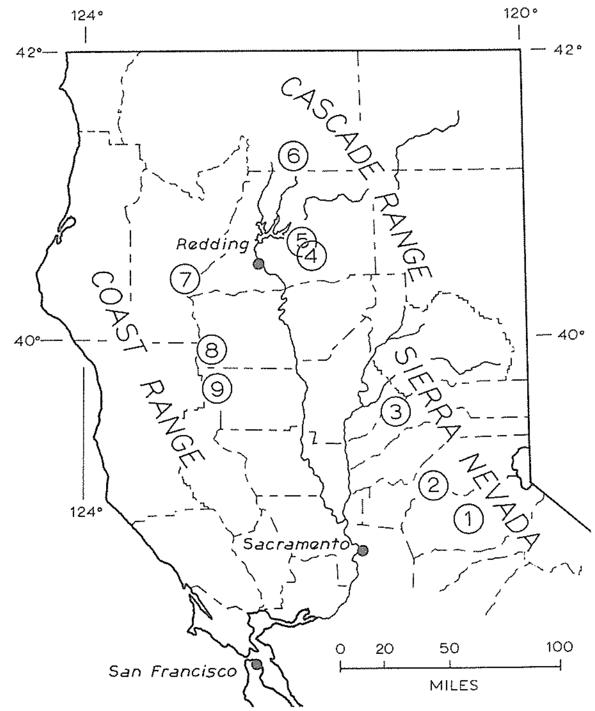

Figure 1—Sample stands of ponderosa pine on slopes bordering the Sacramento Valley of California were selected for the study of site index curves. Numbers refer to stands described in *table 1*.

Heights at 5-year intervals were averaged for each five-tree sample. Site index curves were chosen from each of four standard sources that intersected average sample tree heights at breast-height age 50 (site $index_{50}$) for each sample stand. The curves tested were those by Meyer,[9] Dunning,[10] Dunning and

Table 1—*Characteristics of nine sample stands, in northern California, selected to test site index curves and effects of soils on height growth of ponderosa pine*

Stand name & Map No.[1]	Mean breast height age of dominants	Basal area normality[2]	California county	Elevation	Annual precipitation	Parent material	Soil series	Soil depths
	Years	*Pct.*		*Feet*	*Inches*			*Feet*
Sly Park (1)	41	–	Eldorado	3,850	48	Basalt	Cohasset	>4
Foresthill (2)	55	–	Placer	2,950	47	Schist	Sites	>4
Forbestown (3)	91	71	Butte	2,700	62	Greenstone	Challenge	>4
Tamarack (4)	81	–	Shasta	2,650	45	Basalt	Aiken	>4
Buckhorn (5)	58	93	Shasta	2,750	47	Basalt	Cohasset	>4
Show (6)	50	131	Siskiyou	3,900	54	Basaltic alluvium	Elam	>4
Chanchelulla (7)	96	60	Trinity	3,350	44	Gabbro	Tish tang-like	3-4
Pollard Corral (8)	59	–	Tehama	4,150	38	Schist	Sheetiron	1-2
Alder Springs (9)	63	71	Glenn	3,350	58	Schist	Sheetiron	2-3

[1]See Figure 1.
[2]Expressed as percent of normal yield data.[9] Although not measured at all sites, stand densities tended toward lower basal area stocking levels more appropriate for young-growth management than those reported in "normal" stands.

Table 2—*Mean and standard deviation of sample tree heights of ponderosa pine at index age, and the departure of sample means from standard curve values averaged over seven 5-year intervals between 15 and 45 years, breast-height age*

Sample stand	Mean height at age 50	Standard deviation in height at age 50	Mean departure from curves of . . .[1]			
			Dunning and Reineke	Arvanitis, Lindquist, and Palley	Dunning	Meyer
	Feet					
Sly Park	127	6.0	5.5	-4.1	-8.3	-5.8
Foresthill	111	6.9	4.8	-3.3	-6.2	-6.7
Buckhorn	105	4.4	3.8	-2.6	-5.0	-5.1
Tamarack	103	8.4	2.4	-4.1	-6.3	-6.6
Forbestown	102	5.4	1.7	-4.8	-7.0	-7.3
Chanchelulla	99	5.3	-1.1	-7.6	-9.2	-9.5
Show	92	3.0	1.4	-4.1	-5.5	-5.6
Alder Springs	91	1.5	1.1	-4.4	-5.5	-5.9
Pollard Corral	79	5.1	5.5	- .7	- .2	-1.4

[1]Negative departures indicate that: (a) average sample tree heights are below standard curve values at ages younger than 50 years, and (b) sample curves are rising to intersect the standard curves at index age. Standard curves therefore tend to underestimate or overestimate actual site index roughly in proportion to the magnitude of the negative or positive departure, respectively.

Reineke,[11] and Arvanitis, Lindquist, and Palley.[12] Codominant heights were estimated and integrated for the Meyer curves[9] by using an equation from another study.[13] Three of the site index curves are on a total age basis, requiring an adjustment to breast-height age. The Dunning curves[10] were adjusted by a constant 10 years, and the Meyer curves by a site-dependent variable, as suggested by their respective authors. Dunning and Reineke[11] offered no age adjustment factor, so a site-dependent variable[13] was used.

Differences between mean heights of sample trees and corresponding site index curve values were calculated at 5-year intervals from the youngest curve values to 45 years, breast-height age. Graphical techniques were used for all but the Arvanitis, Lindquist, and Palley curves, where mathematical solutions were possible. The magnitude of mean difference *(table 2)* shows the average 5-year departure of each sample growth trend from its corresponding standard curve.

RESULTS AND DISCUSSION

Comparison of Site Index Curves

None of the standard curves matched the sample data precisely, but some had a consistently poor fit. Stand growth trends differed more from the Meyer site index curves than from the others *(table 2)*. Deviations of sample heights from standard curve

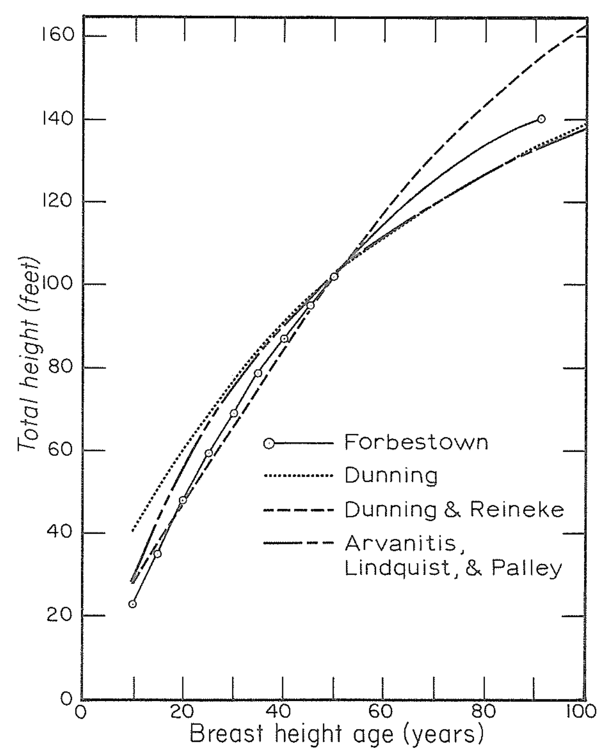

Figure 2—Height growth trend at Forbestown, in Butte County, California, compared with standard site index curves adjusted to intersect at 50 years, breast-height age. The Meyer curve based on dominant and codominant tree heights is not shown, but would approximate the Dunning curve.

values were consistently negative, except for the Dunning and Reineke curves, from which positive deviations predominated *(table 2; fig. 2).*

Dunning—The Dunning curves had the poorest fit for one stand and the second poorest on seven others *(table 2).* At 10 years, curve heights exceeded sample heights by an average of 66 percent. Despite their initial elevation, Dunning growth rates were less than sample rates from 10 years through index age, except for the Pollard Corral stand in Tehama County. The Dunning curves underestimated site index at all ages below index age 50, with the greatest error in the

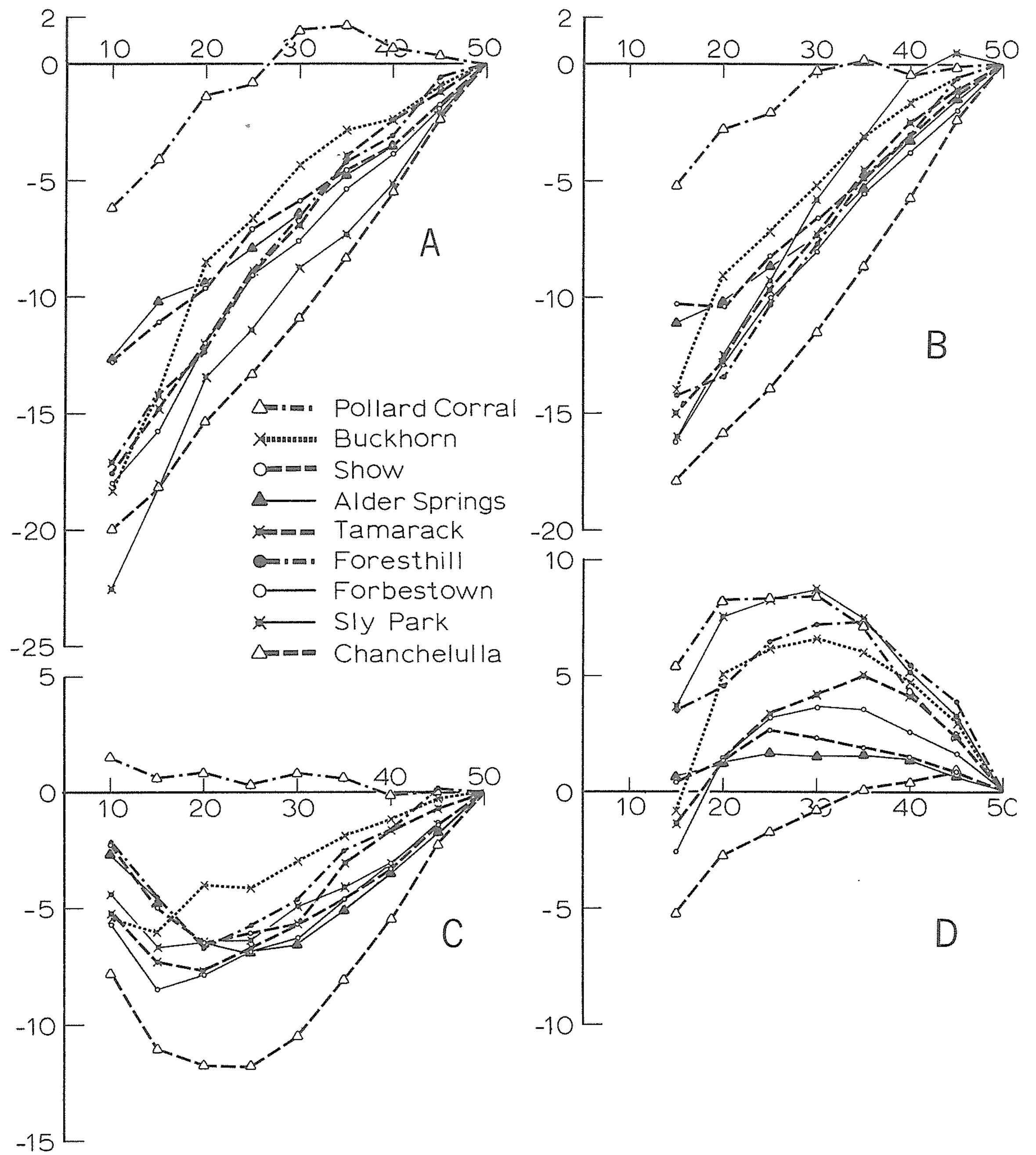

Figure 3—Relation of height of sample plot trees to their respective site index curves at 50 years intersection age. Horizontal axis: breast-height age in years; vertical axis: departure in feet of sample plot tree heights from site index curves of (A) Dunning, (B) Meyer, (C) Arvanitis, Lindquist, and Palley, (D) Dunning and Reineke.

youngest classes *(fig. 3A)*. Curve values beyond 30 years were nearly identical with those of Arvanitis, Lindquist, and Palley *(fig. 2)*.

Though containing some young-growth data, Dunning's study was directed primarily toward evaluating site in old-growth mixed-conifer stands comprised of small even-aged groups. Of his 3,047-tree sample, only 6 percent were younger than 100 years. And since no trees were younger than age 40,[10] curve values for earlier ages must have been extrapolated.

Meyer—The Meyer curves had the poorest fit of all those tested. They consistently underestimated site index to a high degree *(fig. 3B)*. Curve heights exceeded sample tree heights an average of 40 percent at 15 years. Meyer's data reflected region-wide averages under growing conditions of high stand density. Therefore it seems unlikely that they depict ponderosa pine growth in California.

Arvanitis, Lindquist, and Palley—These curves were best in representing tree growth for three of the nine stands. Excluding the Pollard Corral stand where curve fit was nearly exact, curve values always exceeded sample heights, averaging 16 percent high at 10 years and reaching a maximum difference between 20 and 25 years *(fig. 3C)*. Sample growth rates exceeded curve rates by 25 years and continued through and beyond index age *(fig. 2)*. The Arvanitis, Lindquist, and Palley curves underestimated site index for eight of the nine sample stands at all ages less than index age, reaching a maximum error between 10 and 15 years.

Dunning and Reineke—Although based on data from mixed-conifer species, the Dunning and Reineke curves were the most accurate in describing actual height growth in five of the nine stands *(table 2)*—yet only 6 percent of their 311 sample plots were younger than 50 years,[11] and none were younger than 40. Standard curve heights differed from sample heights an average of only -0.6 percent at breast-height age 15, but sample heights moved above standard curve heights by 20 years and reached a peak elevation above the curves around breast-height age 30 *(fig. 3D)*. After 35 years, sample growth rates fell behind the Dunning and Reineke rates and remained behind thereafter. The Dunning and Reineke curves overestimated site index between about 20 years and index age, with a maximum error near 25 years.

Effects of Soils

Soil Series—Of those soils examined, height growth was best on the Cohasset series, followed in order by Sites, Aiken, Challenge, Tish tang, Elam, and Sheet-

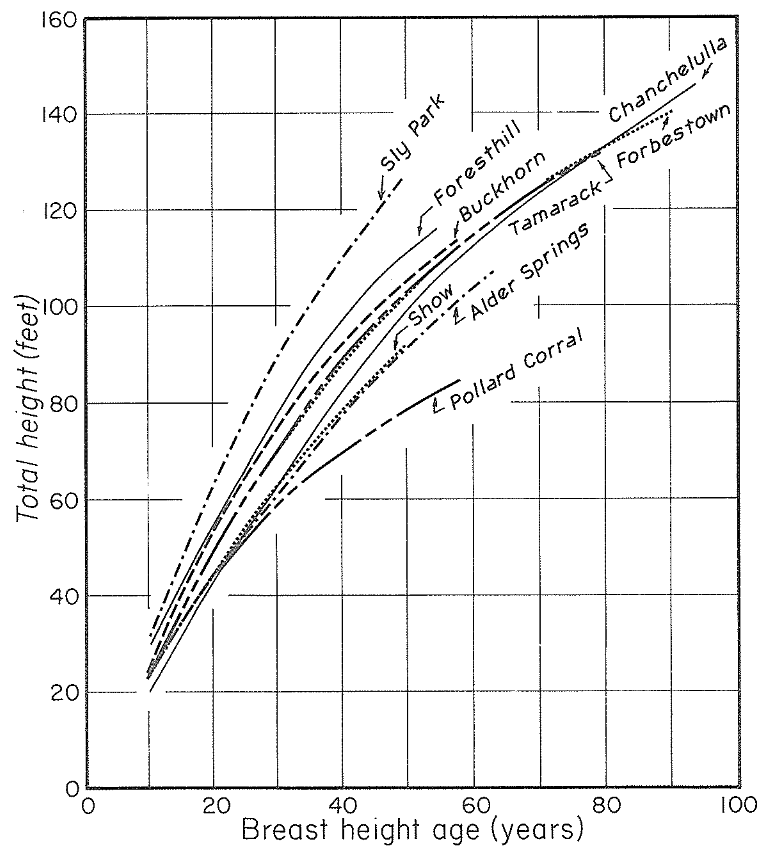

Figure 4—Height growth trends for all sample plots. Values between 50 years and total age are interpolated.

iron *(fig. 4; table 1).* Height growth in the Forbestown stand on the Challenge series was comparable to growth in the Tamarack stand on Aiken. Growth in the Show stand on the Elam series closely matched growth in the Alder Springs stand on Sheetiron. Except for the Tish tang-like series and the shallower Sheetiron, the basic form of the growth trend seems similar on all soils, varying only in general magnitude.

Growth in the Chanchelulla stand on the Tish tang-like series appears significantly different from the other plots *(fig. 4).* At 10 years Chanchelulla ranked lowest in height of all samples. By index age it ranked 6th. And at 96 years it appears at least fourth best, judging from the two plots of similar age. Derived from gabbro, the soil profile shows a well-weathered gravelly loam overlaying small, scattered fragments of weathered parent material at a depth of 3 to 4 feet. Clay content is relatively low compared with soils derived from basalt, schist, and greenstone. The Tish tang series is known to produce better growth than most gabbro soils,[14] but the cause is not known.

Soil Depth—Soils averaged 2 to 3 feet deep at Alder Springs and 1 to 2 feet deep at Pollard Corral *(fig. 5).* And while growth rates are nearly identical through 20 years, they differ considerably thereafter, probably reflecting a longer period of available soil moisture at Alder Springs. Higher precipitation rates and greater rooting depth would favor growth at Alder Springs as tree size increases and total water need mounts. Judging from annual ring and internode patterns, shrub competition had never been a problem in the early development of the trees in either stand. And assuming no major genetic differences between the two stands, soil depth and precipitation differences seem the main causes of height growth variability. Zinke[15] found a major increase in site index at depths greater than 2.5 feet in his Coast Range study. The result from this single comparison is similar to his findings.

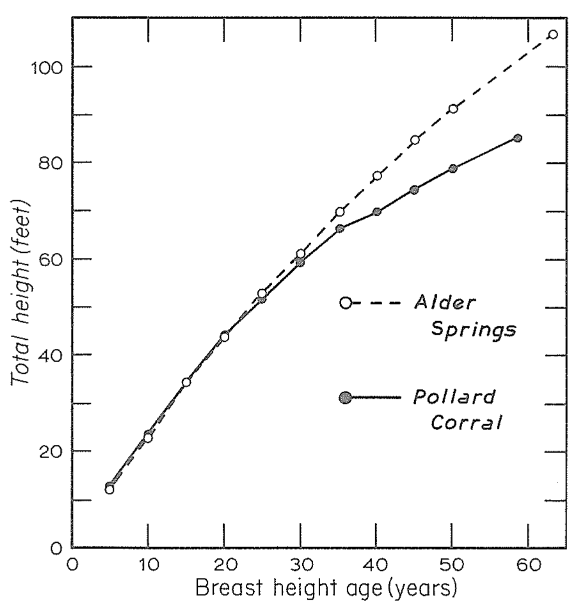

Figure 5—Effect of soil depth on height growth on Sheetiron soil series. Depths average 2 to 3 feet at Alder Springs in Glenn County, Calif., and 1 to 2 feet at Pollard Corral, in Tehama County.

SITE INDEX ADJUSTMENT

Of the standard curves tested, those by Dunning and Reineke and by Arvanitis, Lindquist, and Palley best described the sample growth data. Furthermore, stem analysis means deviated from standard curve values in a predictable pattern. Assuming (a) that the standard curves may contain distortions inherent in their construction methods, (b) that stem analysis describes the true growth trend of trees, and (c) that stand and site factors sampled are typical of the pine belt bordering California's Great Valley, then the standard curves may be adjusted for more accuracy by using factors based on the average deviation of standard curve values from stem analysis means.

Variation is minimal when stands growing on soils derived from extrusive volcanic rocks are combined with those on soils formed from deeper schists *(fig. 6).* Stands on Tish tang-like and shallow Sheetiron soil series show considerable deviation and require much more study, but the central curves should provide more accurate estimates of site $index_{50}$ for pine stands younger than 50 years and growing on similar soils. To apply adjustment factors to such curves,

1. Select at least five well-formed trees showing no sign of previous suppression from the tallest dominants and determine their heights and breast-height ages.
2. Determine the projected height of each sample tree at breast-height age 50, using either the Dunning and Reineke, or the Arvanitis, Lindquist, and Palley standard curves.
3. Average these heights for a mean estimate of site index.
4. Using the appropriate curve in *figure 6,* multiply the estimated site $index_{50}$ by the adjustment factor corresponding to the average breast-height age of the trees you have measured. This results in an adjusted estimate of site $index_{50}$.

For example, assume in step 1 that five dominant trees 10 years old at breast-height measured 23, 24, 24, 26, and 27 feet tall, respectively. By using the Arvanitis, Lindquist, and Palley curves in step 2, these data produce height estimates of 78, 83, 83, 88, and 96 feet at 50 years, for a mean site index$_{50}$ estimate of 85 (step 3). And multiplying this by 1.16 from *figure 6B,* the adjusted estimate of site index$_{50}$ rounds out to 99 (step 4), or an upward adjustment of nearly a full site class.[10]

This procedure was tested by measuring nodal heights in seven additional stands growing on a variety of soils in Glenn, Shasta, Siskiyou, Placer, Nevada, and Tuolumne counties. Stands were unrelated to those in the original sample. Tree selection and measurement procedures were the same as before. Site index$_{50}$ estimates were made from sample averages at 10-year intervals and compared to actual 50-year heights for each stand using both standard curves and adjustment factors. Adjusted values produced more accurate site index estimates for every stand than did standard curve values using the Arvanitis, Lindquist, and Palley curves, and in six of seven stands when using the Dunning and Reineke curves *(table 3).* The only sample data matching the unadjusted Arvanitis, Lindquist, and Palley curves closely were from an open stand growing on placer mining wastes near Grass Valley.

CONCLUSION

Accurate site index curves are vital in assessing forest productivity and forecasting stand development. Existing anamorphic site index curves developed for long rotations do not closely define the early height growth of ponderosa pine found in this study. The consistent deviation of sample data from standard curve values suggests that errors are inherent in the shape of the standard curves, probably resulting from harmonized construction techniques and preponderance of older age classes.

Results of this study suggest that soils derived from differing parent materials may induce major differences in ponderosa pine height growth. Soil depth seems an important interacting factor. Further stem analyses on replicated soil series are needed to produce separate polymorphic growth curves for the important timber-growing soils of California. But until such a study is complete, existing curves can be adjusted for estimating site index more accurately in young stands on certain soil series and depth classes.

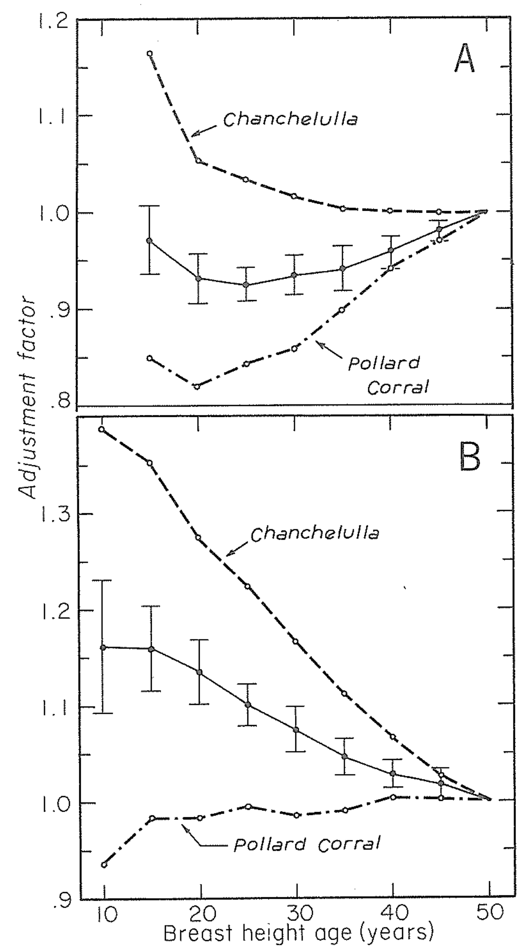

Figure 6—Adjustment factors for estimating height of dominant trees at 50 years breast-height age from the site index curves of (A) Dunning and Reineke, and (B) Arvanitis, Lindquist, and Palley. Central Curves represent seven-stand averages on deep soils derived from extrusive volcanic rocks and schists. Vertical bars represent one standard deviation.

Table 3—*Mean deviations of estimated site index$_{50}$ from actual site index$_{50}$ for even-aged ponderosa pine, using two sets of standard curves and their adjustment factors. Basis: seven stands of ponderosa pine*

Standard curves by . . .	Mean deviation of the estimate from actual site index$_{50}$ at breast-height age . . .			
	10	20	30	40
	Feet			
Arvanitis, Lindquist, and Palley:				
Unadjusted	-15.2	-13.6	-8.7	-4.1
Adjusted	-2.0	-2.8	-2.1	-1.6
Dunning and Reineke:				
Unadjusted	–	5.0	4.9	2.5
Adjusted	–	-1.9	-1.4	-1.4

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