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DRAFT

SITE INDEX EQUATIONS FOR YOUNG-GROWTH MIXED CONIFERS OF NORTHERN CALIFORNIA

by

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Abstract

This paper presents site index equations and graphs developed to describe height growth development of dominant and co-dominant trees of the mixed conifer forests in Northern California based upon stem analysis data collected by the Northern California Forest Yield Cooperative (NCFYC). The site indicies presented have a base age of 50 years at breast height and results are presented for all species combined (ponderosa pine, sugar pine, white fir and Douglas-fir). Since the majority of the data used are between 60 and 80 years of age at breast height, extrapolation of the curves beyond age 100 is not recommended. The results presented herein superceed the curves presented on June 27, 1983.

INTRODUCTION

This report describes the height development of dominant and co-dominant trees of the mixed conifer species of Northern California. These species include ponderosa pine (PP), sugar pine (SP), Douglas-fir (DF) and white fir (WF). The height development of each individual tree is modelled using a sigmoidal model. A weighted least squares technique is then employed to combine these individual estimates to form a mean estimate of the parameters of a sigmoidal height growth model. These parameters are then used to predict the height development of trees for the determination of site index. The techniques used herein are described in detail by Biging (1984).

DATA SOURCES

Data for this study were provided by the Northern California Forest Yield Cooperative growth and yield project. This study, in the mixed conifer region of California, combines efforts of twelve private companies and the University of California, Berkeley. In the stem analysis portion of the Coop study, thirty clusters containing 3 one-fifth acre plots and eight clusters containing two one-tenth acres plots were located in northern California (see Biging (1983) for a description of the data collected and location of the study plots).

On each plot, four to six dominants (two to three for each of the two most prevalent species in the overstory) were chosen randomly and felled as site index trees for stem analysis. Section rounds (1-2 in. thick) were taken at stump height (1.5'), breast height and subsequent log lengths (16.5' or 20.5'). Additionally, three sections were cut in the non-merchantable section of the tip. These sections corresponded to the three most recent 5 year height growth intervals. Each section was tagged and photographed. Laboratory analysis to determine age and annual radial growth from the photographs followed a procedure given by Biging and Wensel (1984) in which a digitizer was used to record the Cartesian coordinates of annual ring boundaries from the pith to the outer edge of a section.

Site trees chosen for felling were healthy dominants receiving full light from above and partly from the sides. They had well-developed crowns, but they could be somewhat crowded on the sides. In all-aged stands, site trees needed to extend above the general level of their group, but not necessarily above the general level of the stand to be dominant.

Additionally, site trees had minimal past damage to tops and minimal height-growth reduction due to extremes in density. Increment borings were taken to inspect the pattern of past radial growth which provided information on past stand density effects. In cases where no dominants could be found that displayed unsuppressed radial growth, the following types of trees were selected in decreasing order of preference: co-dominants showing no signs of suppression, dominants displaying moderate radial suppression or co-dominants that have undergone moderate radial suppression. There were 198 site trees available for analysis in the mixed conifer forest type. However, eleven trees were dropped from analysis because their breast height ages were less than 40 years. This was done to avoid long extrapolations when estimating height at age 50. This left 187 trees for analysis of which 172 were dominants and 15 were codominants. Of the 172 dominant trees selected, 21 displayed some past radial suppression and of the 15 co-dominants selected, 6 displayed some past radial suppression. Table 1 summarizes the sizes of trees and site indices for the mixed conifer site tree data. For these 187 site trees, there was a total of 1551 individual measurements of diamter inside bark, age and height above ground. Thus there was an average of about 8 measurements per tree.

Table 1. Summary statistics for the 187 site trees in the mixed conifer forest type.

Variable	Mean	Standard Deviation	Min.	Max.
DBH(in.)	21.5	5.4	9.4	35.5
HT (ft)	101.1	20.3	39.4	148.9
Site (ft) Index at age 50	80.2	20.3	35.0	130.5

The mixed conifer data was supplemented with data collected in the ponderosa pine type (26 trees), the Douglas-fir type (28 trees) and the true fir type (102 trees) to increase the number of sampled site trees (see Table 2). The grand total of trees used in analysis was 343. The results presented in the next section are based upon all 343 trees. Though not presented here, the curves generated solely from the mixed conifer data are virtually identical to those generated from all data combined and are less than two feet different at age 100 on the highest sites.

Table 2. Numbers of trees over 40 years breast height age by species and forest type.

Species	Mixed Conifer type	Ponderosa Pine type	Douglas-Fir type	True Fir Type
PP	65	26	-	6
SP	25	-	-	12
IC	2	-	-	-
DF	40	-	28	-
WF	55	-	-	69
RF	0	-	-	15
Total	187	26	28	102

Grand Total 343 trees

RESULTS

Site index model:

The following model was fit to the data:

$$h = 4.5 + Bo\,(S^{d1})\,[\,1.0 - \exp(\,-d2 * t\,)]^{B1} \qquad [1]$$

where h = height of site trees at breast height age (t)

d1= 0.89

d2= -0.024

Bo= 2.93243

B1= 1.81845

To constrain the model to predict site when breast height age is 50, the value of B1 was calculated as:

$$B1 = -2.790315 * \ln[\,(S-4.5)/\,(\,Bo\,(S^{d1}))] \qquad [2]$$

and substituted into equation [1].

The curves generated and presented in Figure 1 besides being constrained to predict the site index value at age 50 are formulated to predict 4.5 feet in height when breast height age is zero. Table 3 gives the average total heights of dominant and co-dominat mixed conifers by breast height age and site index.

Dunning and Reineke's curves

The curves generated with model [1] were compared with Dunning and Reineke's (1933) young-growth curves (see Figure 2). Since Dunning and Reineke's curves are for total age, not breast height age the following conversions was implemented (personal communication with John Fiske, U.S.F.S, and John Helms, Univ. Calif.):

Base age 50 curves (breast height)	Years to reach breast height
120	4
110	4
100	5
90	5
80	6
70	6
60	7
50	7
40	8
<40	10

This represents an optimistic forecast and assumes that the deer and brush do not cause special problems in establishment. There could be significant variation from these age adjustments, especially with white fir owing to its shade tolerance. Nonetheless, this demonstrates the differences between the different site curves.

In Figure 2, it can be seen that the two curves are similar especially on the higher sites. However, the new curves (denoted by dashed lines) are lower than the Dunning and Reineke curves beyond age 70 on the higher sites (100 and above). If the Dunning and Reineke curves project too high at advanced ages, then the earlier levelling off in the new curves is warranted. At ages below index age, it appears that the new curves predict lower than Dunning and Reineke's curves especially on lower sites (less than 60).

King's curves

The curves generated with model [1] were compared with King's (1966) site index curves for Douglas-fir. This comparison is particularly significant in that Wensel and Krumland (1984) found King's curves to be appropriate for Douglas-fir on California's north coast. The new and King's curves are presented in Figure 3. It is evident that there are substantive differences between the new curves and King's curves. In every case, the new curves predict higher heights beyond index age (50) than do King's curves. This is most notable on the lower and medium sites (less than 120) where at age 100 there are differences of 10 feet or more. As site index increases these differences decrease. For predictions less than index age (50) the new curves show substantially less height for a given age than do King's curves.

This same trend was seen on the comparison between the Dunning and Reineke curves, but to a much lesser extent.

Powers and Oliver's curves:

In Figure 4, a comparison of the new curves and those of Powers and Oliver (1978) is presented. Since Powers and Oliver's curves are for total age, the conversions between breast height age and total age (given above) were used for this comparison. For the higher sites (100 and above) there is fairly close agreement between the curves. On the site below 100, the new curves project higher values at age 80 (approximately 10 feet higher) than given by Powers and Oliver. On all sites, the new curves show lower heights below base age than their counterpart in Powers and Oliver's curves. This effect was more dramatic on the lower sites and parallels trends found in comparison of the new curves to Dunning and Reineke's and King's curves.

Conclusions

The young-growth site index curves presented herein differ from other published curves including Dunning and Reineke (1933), King (1966) and Powers and Oliver (1978) and thus, lead to differing estimates of productivity. After study, the new curves appear to better reflect young-growth managed stand productivity than prior published curves and thus, should be used in place of other curves. It should be noted that the majority of the data used in development of the mixed conifer site curves are between 60 and 80 years of age at breast height (as was Dunning and Reineke's data), and thus, extrapolation of the curves beyond age 100 is not recommended.

The new curves are also being used in version 1.0 of CACTOS (California Coniferous Timber Output Simulator) (see Wensel, 1984) to predict potential height growth with good results.

Literature cited:

Biging, G.S., and L.C. Wensel. 1983. A photographic technique for use with stem analysis. Accepted for publication in **Forest Science**. September, 1983. Ms. 20 pgs.

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Dunning, Duncan and L.H. Reineke. 1933. Preliminary yield tables for second growth stands in the California pine region. USDA Tech. Bulletin No. 354. 23 pgs.

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

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Wensel, L.C. 1984. CACTOS User's Guide, California Conifer Timber Output Simulator. Research Note no. 10, Department of Forestry and Resource Management, Univ. Calif. Berkeley (mimeo).

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FIGURE 1. MIXED CONIFER SITE INDEX CURVES-ALL DATA 5/23/84 (NCFYC)

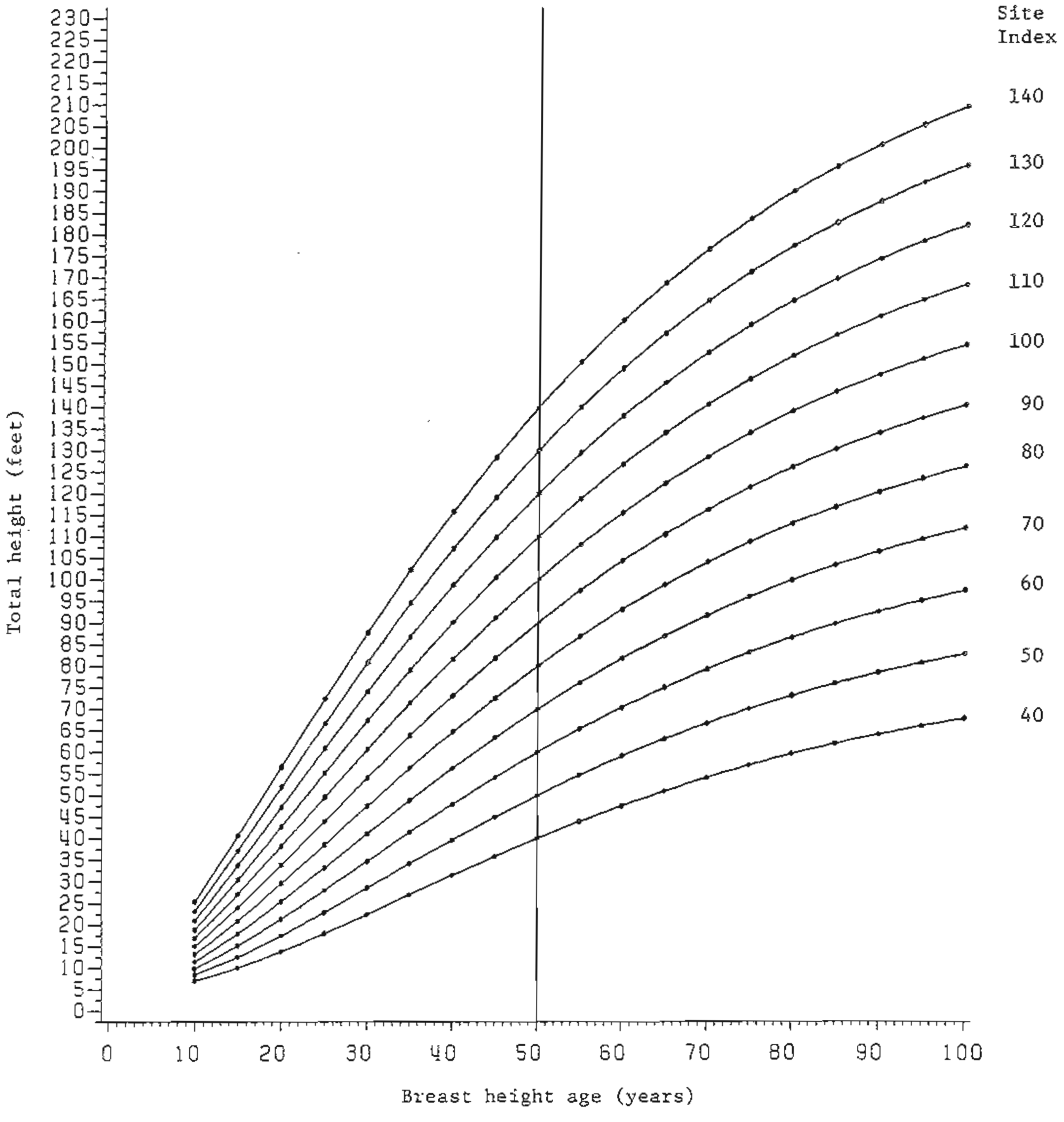

Figure 2. Dunning and Reineke's site curves for mixed conifers with the new site curves superimposed.

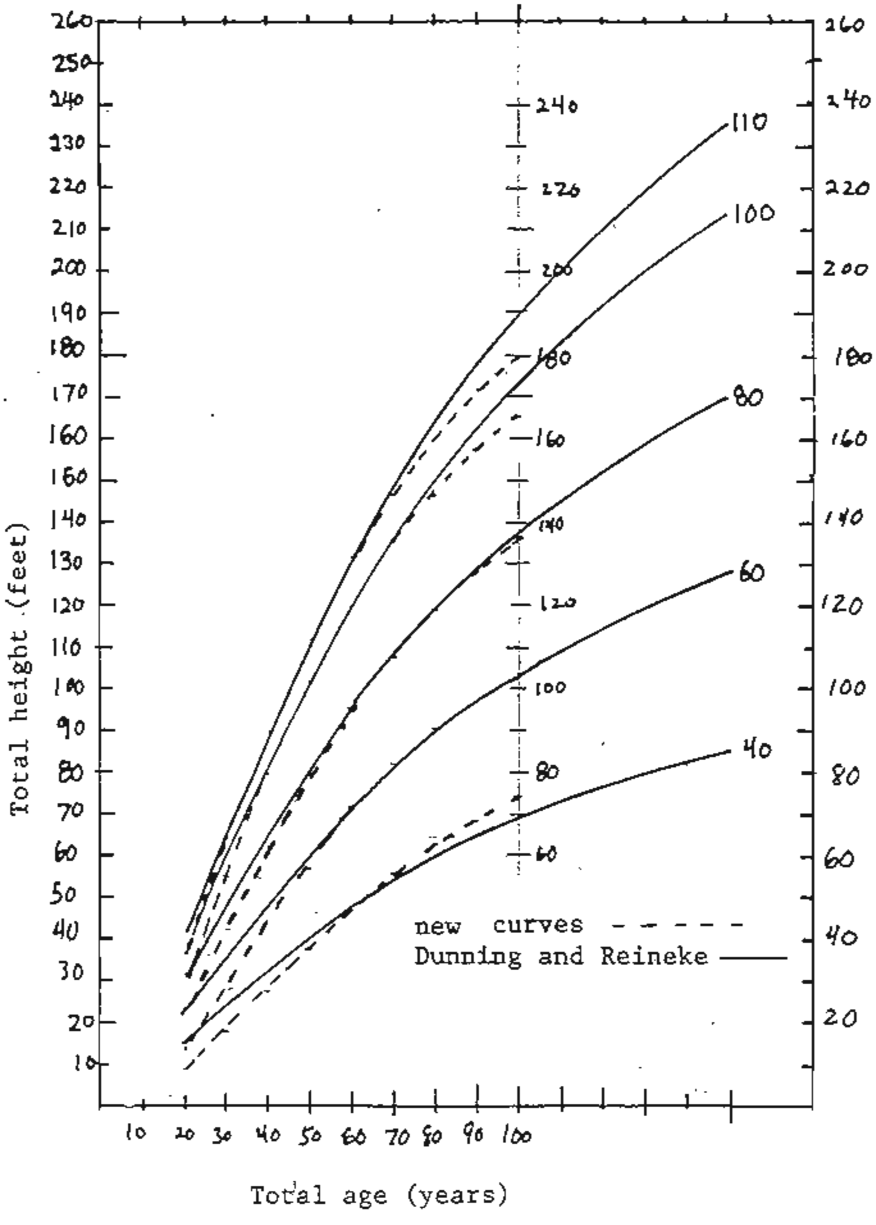

Figure 3. King's (1966) site index curves for Douglas-fir with the new site curves superimposed.

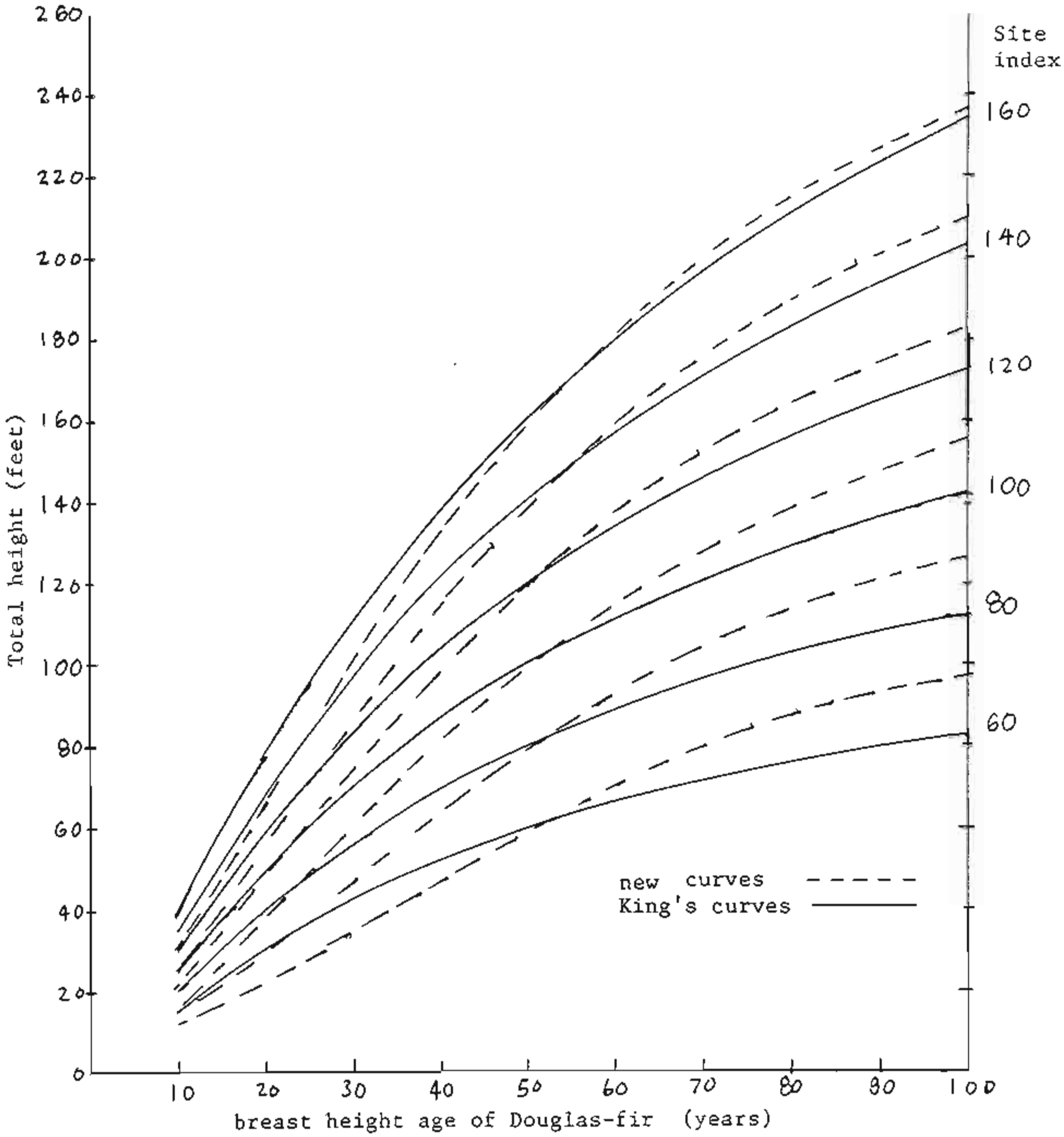

Figure 4. Powers and Oliver's (1978) site index curves for plantations and young natural stands of ponderosa pine with the new site curves superimposed.

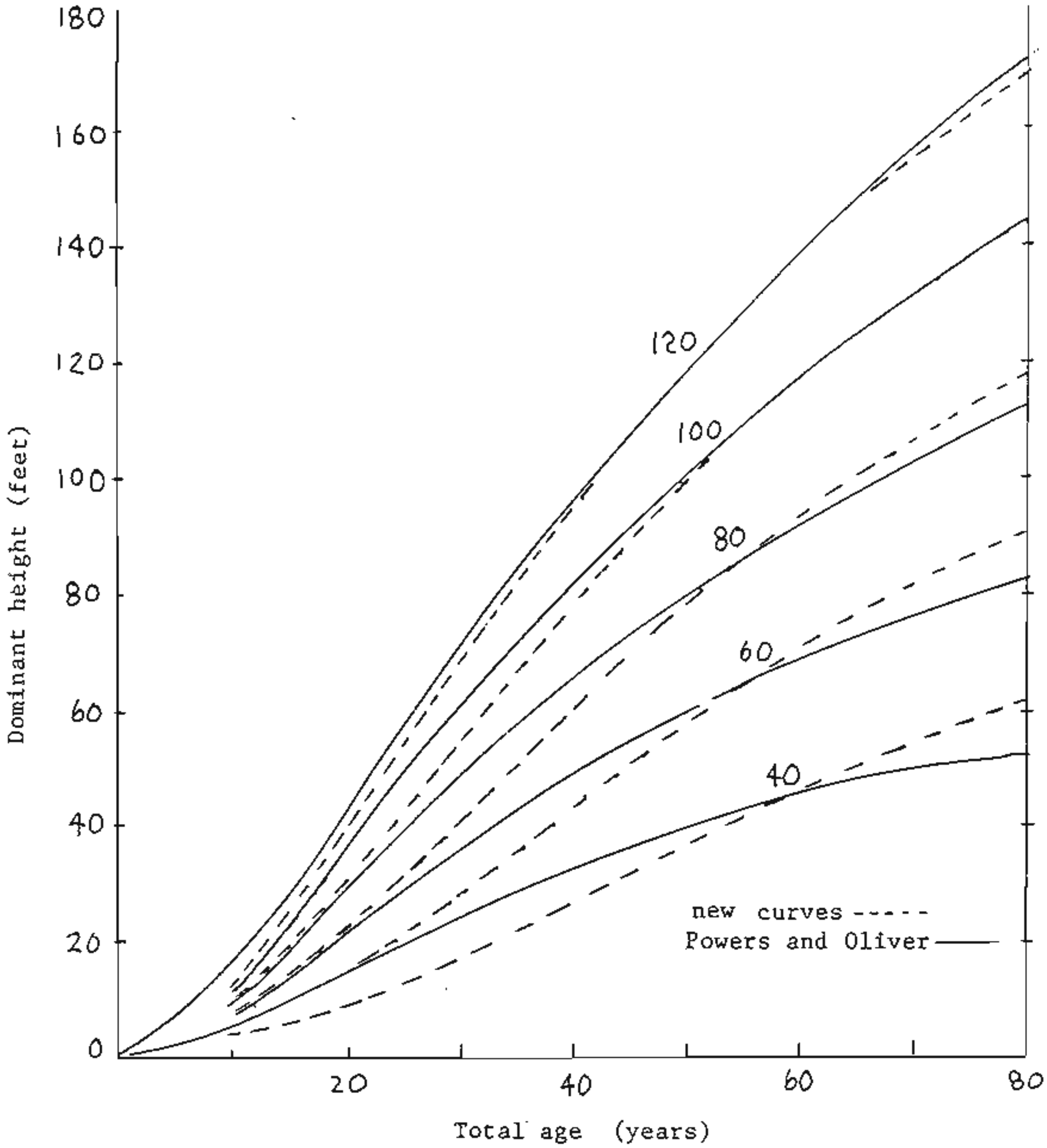

Table 3. The average total height of dominant and co-dominant mixed conifers by breast height age and site index.

bh age	Mixed Conifer Site Index 40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
10	7	8	8	9	10	11	12	12	13	14	15	16	17	18	19	20	21	22	23
12	8	9	10	11	12	13	14	15	16	17	18	20	21	22	23	25	26	27	29
14	9	11	12	13	14	15	17	18	19	21	22	24	25	27	28	30	31	33	34
16	11	12	14	15	16	18	19	21	23	24	26	28	29	31	33	35	36	38	40
18	12	14	15	17	19	21	22	24	26	28	30	32	34	36	38	40	42	44	46
20	14	16	18	19	21	23	25	27	30	32	34	36	38	40	43	45	47	50	52
22	15	18	20	22	24	26	29	31	33	36	38	40	43	45	48	50	53	55	58
24	17	19	22	24	27	29	32	34	37	39	42	45	47	50	53	55	58	61	64
26	19	21	24	27	29	32	35	38	40	43	46	49	52	55	58	61	64	67	70
28	21	23	26	29	32	35	38	41	44	47	50	53	56	59	63	66	69	72	75
30	22	26	29	32	35	38	41	44	48	51	54	57	61	64	67	71	74	78	81
32	24	28	31	34	37	41	44	48	51	55	58	62	65	69	72	76	79	83	86
34	26	30	33	37	40	44	47	51	55	58	62	66	69	73	77	81	84	88	92
36	28	32	35	39	43	47	50	54	58	62	66	70	74	77	81	85	89	93	97
38	30	34	38	41	45	49	53	57	61	65	70	74	78	82	86	90	94	98	102
40	31	36	40	44	48	52	56	61	65	69	73	77	82	86	90	94	99	103	107
42	33	38	42	46	50	55	59	64	68	72	77	81	86	90	94	99	103	108	112
44	35	39	44	48	53	57	62	67	71	76	80	85	89	94	98	103	108	112	117
46	37	41	46	51	55	60	65	69	74	79	84	88	93	98	102	107	112	117	121
48	38	43	48	53	58	63	67	72	77	82	87	92	97	101	106	111	116	121	126
50	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
52	42	47	52	57	62	67	73	78	83	88	93	98	103	108	114	119	124	129	134
54	43	48	54	59	64	70	75	80	86	91	96	101	107	112	117	122	128	133	138
56	45	50	56	61	66	72	77	83	88	94	99	104	110	115	120	126	131	137	142
58	46	52	57	63	68	74	80	85	91	96	102	107	113	118	124	129	135	140	146
60	48	53	59	65	70	76	82	87	93	99	104	110	116	121	127	132	138	143	149
62	49	55	61	67	72	78	84	90	95	101	107	113	118	124	130	135	141	147	152
64	50	56	62	68	74	80	86	92	98	104	109	115	121	127	133	138	144	150	156
66	52	58	64	70	76	82	88	94	100	106	112	118	124	130	135	141	147	153	159
68	53	59	65	72	78	84	90	96	102	108	114	120	126	132	138	144	150	156	162
70	54	60	67	73	79	86	92	98	104	110	116	122	129	135	141	147	153	159	165
72	55	62	68	75	81	87	94	100	106	112	118	125	131	137	143	149	155	161	168
74	56	63	70	76	82	89	95	102	108	114	120	127	133	139	145	152	158	164	170
76	58	64	71	77	84	90	97	103	110	116	122	129	135	141	148	154	160	166	173
78	59	65	72	79	85	92	98	105	111	118	124	131	137	144	150	156	163	169	175
80	60	66	73	80	87	93	100	107	113	120	126	133	139	146	152	158	165	171	178
82	61	68	74	81	88	95	101	108	115	121	128	134	141	147	154	160	167	173	180
84	62	69	75	82	89	96	103	110	116	123	130	136	143	149	156	162	169	175	182
86	62	70	77	84	90	97	104	111	118	124	131	138	144	151	158	164	171	177	184
88	63	70	78	85	92	99	105	112	119	126	133	139	146	153	159	166	173	179	186
90	64	71	79	86	93	100	107	114	120	127	134	141	148	154	161	168	175	181	188
92	65	72	79	87	94	101	108	115	122	129	136	142	149	156	163	169	176	183	190
94	66	73	80	88	95	102	109	116	123	130	137	144	151	157	164	171	178	185	191
96	67	74	81	89	96	103	110	117	124	131	138	145	152	159	166	173	179	186	193
98	67	75	82	89	97	104	111	118	125	132	139	146	153	160	167	174	181	188	195
100	68	75	83	90	98	105	112	119	126	133	141	148	155	162	169	175	182	189	196

This is a basic program to calculate site given height and age using an iterative algorithm. It will ask for age (enter zero to quit) and height. It takes an initial guess of site as s1= ht/age*50 and then solves for s2. It iterates until s1 and s2 are within .1 feet of each other and then prints s2 as the answer.

```
10 d1= .89 : d2=.024 : b0= 2.93243
20 input  "Enter age: " ; age
30 if  age=0 goto 140
40 input "Enter height: " ; ht
50 s1= ht / age * 50  :  rem initial guess.
60 ht= ht - 4.5
70 b1= -2.790315 * log( (s1 - 4.5) / (b0*s1^d1) )
80 s2= ( ht / (b0 * ( 1 - exp(-d2 * age) ) ^ b1 ) ) ^ (1/d1)
90 if abs( s2 - s1 ) < .1  goto 120
100 s1 =  (s1 + s2 ) / 2
110 goto  70
120 print " site= "; s2
130  goto 20
140  end
```

CAUTION: This algorithm may not solve for some ages and heights (extreme values) on small computers due to round off error. A counter placed between lines 70 and 110 to check for excessive iterations is advisable.