vicultural system and 498 bf/ac/yr under clearcutting This 20% reduction approximates the long-term reduction in growth, and thus future harvest levels, that may result from such an alternative silvicultural system.

Reduction in MAI is about 20%, but the reduction in yield for the first rotation may be somewhat greater. While standing volumes at the end of rotation are comparable for the two systems (Table 3), this is primarily due to the large volume contained in the overstory trees (Figure 2). If the alternative system is continued beyond the first rotation, some of the overstory trees and some of the mature understory trees, will need to be retained on site for coarse woody debris and second-rotation green tree reserves.

For our example, PROGNOSIS predicted that 16 of the original 20 overstory trees remained after 100 years. Four of the original reserve trees either died or were removed in the commercial thinning. We assumed that four of the 16 remaining would be killed and left standing as snags and future downed woody material. Four others, along with 16 mature understory trees, were designated for "green retention" for the next rotation. Therefore, about 13,700 bf/ac was retained on site, representing nearly 33% of the standing volume at the end of the first rotation (Table 3).

SUMMARY

We believe that the development of alternative silvicultural systems, including those associated with "new forestry" can yield considerable benefits. Such systems can combine the inherent advantages of even-aged and uneven-aged management, e.g., greater structural diversity than strictly even-aged stands, and reduced management complexity compared with classic uneven-aged systems. Silvicultural prescriptions must, of course, be executed properly to capture potential benefits and minimize potential risks. Green tree retention carries with it risks and tradeoffs. For example, adverse effects related to windfirmness and future stand health may make the system illustrated in our discussion inappropriate in some stands.

The associated reductions in growth and yield are not trivial. Actual reductions in growth, yield, and value will depend on such factors as the level of residual growing stock and species mix. In our example, current and first rotation harvest levels were about one-third lower than in the clearcutting system. Smaller tree size due to overstory competition may further reduce the value of future harvests. As a first approximation, our analysis suggests that this type of alternative silvicultural system may result in a 20% reduction in long-term growth, and thus future harvest levels, compared to traditional even-aged systems.

An important point to emphasize is that many of the potential disadvantages of such alternative silvicultural systems are only negative in relation to some other system, e.g., clearcutting or single-tree selection. As priorities change so do the objectives of forest management; when management objectives and constraints do not allow either classic even-aged or uneven-aged systems, a thoughtfully designed and carefully executed alternative silvicultural system may be a viable option. □

LITERATURE CITED

Daniel, T.W., J.A. Helms, and F.S. Baker. 1979. Principles of silviculture. Ed. 2. McGraw-Hill, New York. 500 p.

Franklin, J.F. 1989. Toward a new forestry. Am. For. 95:37–44.

Leak, W.B., and J.H. Gottsacker. 1985. New approaches to uneven-aged management in New England. North. J. Appl. For. 2:28–31.

Matthews, J.D. 1989. Silvicultural systems. Oxford Science Publications, Clarendon Press, Oxford, 284 p.

Orians, G.H. 1990. "New Forestry" and the Old-Growth Forests of Northwestern North America. A conversation with Jerry F. Franklin. Northwest Environ. J. 6:445–461.

Salwasser, H. 1990. Gaining perspective: Forestry for the future. J. For. 88(11):32–38.

Smith, D.M. 1986. The practice of silviculture. Ed. 8. Wiley, New York. 527 p.

Wycoff, W.R., N.L. Crookston, and A.R. Stage. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. 112 p.

Site Index and Height Growth Curves for Ponderosa Pine, Western Larch, Lodgepole Pine, and Douglas-Fir in Western Montana

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ABSTRACT. Height growth patterns from several published site curve sytems for ponderosa pine (Pinus ponderosa), *Douglas-fir* (Pseudotsuga menziesii *var* glauca), *western larch* (Larix occidentalis) *and lodgepole pine* (Pinus contorta *var* latifolia) *were compared to stem analysis data from western Montana. Most of the published curves had height growth patterns that differed significantly from those in the data. The magnitude of the deviations often varied by level of site index; this appeared to be related to differences in the range of site qualities sampled. Those curves constructed from stem analysis data from geographically similar populations compared most closely. Curves constructed using guide curve techniques showed a consistent tendency to underpredict heights at greater ages. New site index and height growth curves are presented for each species.*

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Site index and dominant height growth curves are commonly used to identify the potential height-growth pattern that individuals of a given species might be expected to achieve in a particular place. This potential height growth curve may then be used as the site quality "driver" in a yield prediction system. Identification of the appropriate potential curve is essential for reliable predictions of future growth and yield by such systems.

Traditional site curve systems summarize the relationships between height, age (either breast height or total), and height at some index age (SI), for some specified set of trees belonging to a defined population. For a given species, the summarization will show different height-growth patterns depending on the population definitions, sampling procedures, and construction methodology used. Any one

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of these factors could cause a particular site curve system to be suboptimal in estimating potential height-growth patterns for a particular site. In recognition of this fact, there has been continual regional activity aimed at assessing the appropriateness of particular site curve systems to a specific area, and at developing new curves where necessary (Monserud 1984, Vander Ploeg and Moore 1989, Means and Sabin 1989). In addition to providing a closer match to populations, the new curves often utilize methodology and data that provide improved estimates of potential height growth patterns.

Due to its ubiquitous distribution and substantial economic value, Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) has received most of the attention in such research in the Inland Empire. There is little information on the appropriateness of existing site curve systems for western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), or lodgepole pine (*Pinus contorta* var. *latifolia*). The purposes of this paper are to compare several site curve systems for these species to data collected in western Montana, and to provide a new set of height growth and site index curves for each species.

METHODS

Data Collection

These data were collected as part of a general investigation into sources of variation in dominant tree height growth patterns (Milner 1987). The study area was western Montana, defined as the area bounded by Missoula in the south, Libby to the north, the Montana/Idaho border on the west, and Helena to the east. Sites were selected according to levels of precipitation, temperature, solar insolation, and the presence of suitable site trees. Since values for the stratification variables were not available at the time of field sampling, slope, aspect, elevation, and geographic location were used as initial proxies. Ponderosa pine was sampled at 31 locations, Douglas-fir at 46, western larch at 37, and lodgepole pine at 39. The means and ranges of site and stand characteristics for the sample are given in Table 1.

Site trees, which were selected in a fashion similar to that described by Monserud (1984), had the following characteristics: (1) dominant crown class in the sense of receiving light from above and from all sides (thus, trees growing in openings in cutover or unevenaged stands were potential candidates), (2) no substantial top damage, (3) healthy crowns of at least 40% of total height, (4) no substantial periods of suppression, based on increment cores taken at breast height (BH), and (5) potentially repeatable on the site. That is, wolf trees or trees growing on microsites obviously different from the general conditions were avoided.

Three trees on roughly a half-acre area were selected and felled for measurement of "actual" site index (defined to be the total height corresponding to a ring count of 50 at 4.5 ft). Because of time and money constraints it was assumed that the pattern of height-growth for the tree of median site index, of the three felled, would represent the average potential for that location. This assumption appeared reasonable at six sites where stem analysis was performed on all three site trees.

The tree of median site index was sectioned at ground level, breast height, and at intervals of one-tenth of tree height above 4.5 ft, for a total of 12 sections per tree. Annual rings were counted at the top of each section. The ring count at each section was subtracted from that at breast height to obtain the BH age of the tree corresponding to the height of that section above 4.5 ft. Assuming that, on the average, section cuts (including that at BH) were made at internode midpoints (see discussion by Dyer and Bailey 1987), the resulting height data are unbiased with respect to "true" BH age (ring count—0.5 yr), for all points except the tip, which will be underestimated by a half-year's growth. The effect of 1 point in 11 was considered trivial and no correction was made to the data.

Table 1. Means and ranges of stand and site characteristics, by species, for the western Montana site index study sites.

	Species			
	Ponderosa pine	Douglas-fir	Western larch	Lodgepole pine
Number of sites	31	46	37	39
Site Index (ft)	60	59	71	60
	(41–84)	(27–91)	(50–97)	(31–86)
Elevation (100 ft)	39	46	42	48
	(28–57)	(24–66)	(24–59)	(20–64)
Slope (degrees)	14	20	17	14
	(0–32)	(1–36)	(1–33)	(0–31)
Aspect (degrees)	(0–350)	(36–350)	(0–352)	(0–360)
Precipitation (in.)	27	30	35	37
	(15–50)	(16–55)	(15–60)	(15–60)

Evaluation of Existing Site Curves

For each species the observed height:BH age patterns for a given site index level were compared with those predicted by various published site curve systems. The published curves compared to the data were as follows *ponderosa pine*—Tesch 1980, Lynch 1958 as adjusted by Brickell 1970, Summerfield 1980, and Barrett 1978; *Douglas-fir*—Monserud 1984, Cochran 1979, Summerfield 1980, and Vander Ploeg 1989; *western larch*—Schmidt 1976; and *lodgepole pine*—Alexander 1967.

To compare height growth patterns in the data to those in the published curves, a site index had to be obtained for each sample tree that was consistent with the various index ages used in the published site curves. The study data were appropriate for the BH-age 50-yr base curves of Monserud (1984), Cochran (1979), and Summerfield (1980). For those curves indexed by total age, 50-yr base (Tesch 1980, Lynch 1958, and Schmidt 1976), a compatible value was estimated from the data via linear interpolation between the height:total age pairs bracketing total age 50. However, for those curves that were total age-base 100 yr (Alexander 1967), no observations were available Therefore, a regression equation was first developed from the published height growth curves that converted height at total age 50 to height at total age 100. This equation was then used to convert the SI base 50-total age observations in the data to a SI base 100-total age basis. For those curves that were base 100-BH age (Barrett 1978) a similar regression equation was developed from the published curves that converted the SI base 50-BH age values to SI base 100-BH age values. Use of these conversion equations means that the published height growth curves are accessed according to height at 50 years of age rather than 100. Thus, conclusions regarding adequacy of the published curves are only relevant to applications consistent with this modification. Had observations of height at age 100 been available, different results might have been evident. The regression equations used were:

$$\text{Alexander (LPP) } SI100 = -2.99666 + 1.6129 * SI50$$

$$\text{Barrett (PP) } SI100 = -2.64174 + 0.6853 * SI50$$

For each (SI, Age, Height) triplet contained in the stem analysis data, a predicted height was obtained from the

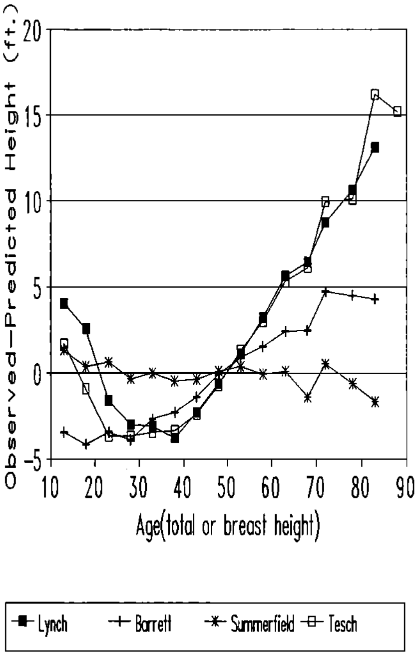

Figure 1. Mean height residuals for ponderosa pine height growth curves by Lynch, Barrett, Summerfield, and Tesch.

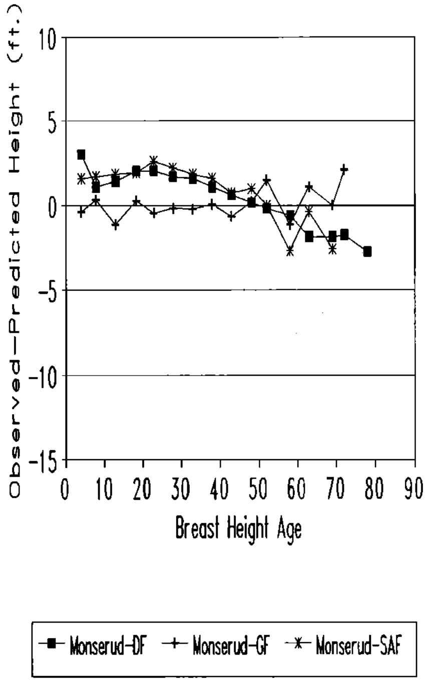

Figure 3. Mean height residuals for Douglas-fir height growth curves by Monserud (by habitat type series).

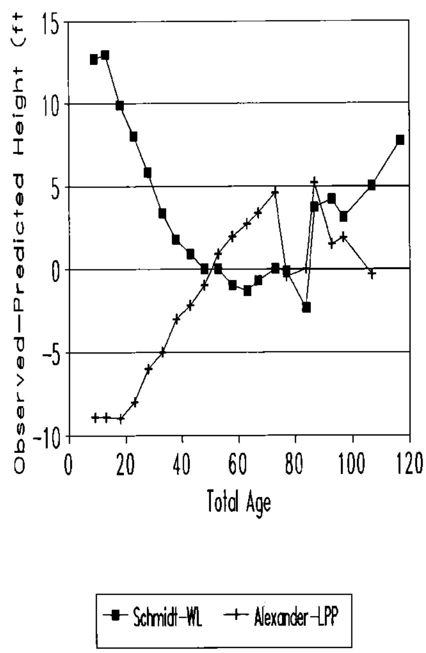

Figure 4. Mean height residuals for lodgepole pine and western larch height growth curves by Alexander and Schmidt, respectively.

appropriate published $H = f$ (SI, Age) equation. The residual, (observed-predicted height), was formed for each SI and Age pair and plotted against age (total or breast height depending on the site curve). To aid in detection of age-related bias the residuals were grouped by 5-yr age classes and the means, standard deviations, and standard errors calculated for each class. The residuals were also examined at various levels of site index, since age-related trends could vary by level of site index.

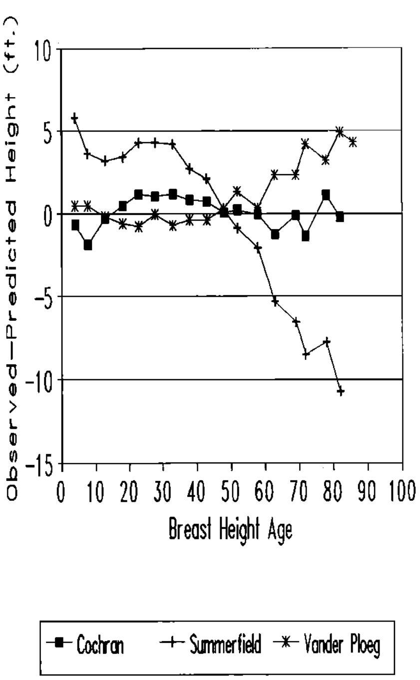

Figure 2. Mean height residuals for Douglas-fir height growth curves by Cochran, Summerfield, and Vander Ploeg.

Site Curve Construction

Site index and height growth equations were developed from the data using procedures described by Heger (1968), Dahms (1973), and many others. The procedures involve first fitting simple, linear models to the decadal height and site index data and then predicting the regression coefficients of these equations as functions of age. Final models are obtained by substituting the latter equations for the appropriate coefficients in the former. Though the resulting equations are over-parameterized, they fit the data quite well and were judged to satisfactorily represent the patterns of height-growth in the sample. No attempt was made to refine or advance site curve construction methodology in this study.

RESULTS

Residuals Analyses

Figures 1–4 show the mean height residuals (observed–predicted) by age class. Positive values indicate underpredictions; negative values indicate overpredictions. The associated site index curves will give overestimates of site index where the height growth curve underestimates, and underesti-

Table 2. Site index and height growth equations for ponderosa pine (PP), Douglas-fir (DF), western larch (WL), and lodgepole pine (LPP).

Site Index Equations:

$$\text{PP } SI = 59.6 + (4.787 + 0.012544 \ast A - 1.141 \ast \text{Ln}A + 11.44/A^2) \ast (H\text{-}4.5 - 121.4 \ast [1\text{-EXP}(-0.01756 \ast A)] \ast\ast 1.483)$$

$$\text{DF } SI = 57.3 + (7.06 + 0.02275 \ast A - 1.858 \ast \text{Ln}A + 5.496/A^2) \ast (H\text{-}4.5 - 114.6 \ast [1\text{-EXP}(-0.01462 \ast A)] \ast\ast 1.179)$$

$$\text{WL } SI = 69.0 + (-0.8019 + 17.06/A + 0.4268 \ast \text{Ln}A - .00009635 \ast A^2) \ast (H\text{-}4.5 - 127.8 \ast [1\text{-EXP}(-0.01655 \ast A)] \ast\ast 1.196)$$

$$\text{LP } SI = 59.6 + (1.055 - 0.006344 \ast A + 14.82/A - 5.212/A^2) \ast (H\text{-}4.5 - 96.93 \ast [1\text{-EXP}(-0.01955 \ast A)] \ast\ast 1.216)$$

Height Growth Equations:

$$\text{PP } H = 4.5 + 121.4 \ast [1\text{-EXP}(-0.01756 \ast A)] \ast\ast 1.483 + (1.189 \ast [1\text{-EXP}(-0.05799 \ast A)] \ast\ast 2.63) \ast (SI - 59.6)$$

$$\text{DF } H = 4.5 + 114.6 \ast [1\text{-EXP}(-0.01462 \ast A)] \ast\ast 1.179 + (1.703 \ast [1\text{-EXP}(-0.02214 \ast A)] \ast\ast 1.321) \ast (\text{SI} - 57.3)$$

$$\text{WL } H = 4.5 + 127.8 \ast [1\text{-EXP}(-0.01655 \ast A)] \ast\ast 1.196 + (1.289 \ast [1\text{-EXP}(-0.03211 \ast A)] \ast\ast 1.047) \ast (SI - 69.0)$$

$$\text{LP } H = 4.5 + 96.93 \ast [1\text{-EXP}(-0.01955 \ast A)] \ast\ast 1.216 + (1.410 \ast [1\text{-EXP}(-0.02656 \ast A)] \ast\ast 1.297) \ast (SI - 59.6)$$

where

SI = site index, breast height age 50 yr base

H = total height; Ln = natural logarithm

A = breast height age; EXP = exponential function, base e

Table 3. Mean height residuals (observed-predicted), *R*, and associated standard errors, SE, for new height growth curves.

	Species											
	PP			DF			WL			LP		
Age	*n*	*R*	SE	*n*	*R*	SE	*n*	*R*	SE	*n*	*R*	SE
10	26	2.1	0.41	51	−0.3	0.29	31	−0.3	0.48	37	0.2	0.41
20	29	−0.8	0.66	44	−0.2	0.39	32	−0.3	0.66	33	−0.1	0.55
30	30	−1.1	0.59	46	0.1	0.44	29	−0.2	0.65	30	−0.4	0.67
40	36	−0.7	0.43	35	0.3	0.30	29	−0.7	0.40	27	−1.0	0.51
50	31	0.4	0.22	33	−0.1	0.23	24	0.1	0.30	22	0.1	0.41
60	22	0.7	0.44	23	0.3	0.49	18	−0.5	0.49	17	1.5	0.45
70	9	−0.1	0.75	14	−0.5	1.16	14	−0.7	1.05	12	0.6	0.94
80	4	1.7	4.46	8	1.1	1.92	8	1.4	1.67	10	−2.3	1.77

mates of site index where the height growth curves overestimate. Trends of residuals by age class for levels of site index are discussed but not shown.

Figure 1 shows the results for the ponderosa pine height growth curves by Tesch (1980), Lynch (1958), Summerfield (1980), and Barrett (1978). Tesch's, Lynch's, and Barrett's curves show similar trends: an overprediction of height between 20 and 50 years and an underprediction of height at older ages. This pattern is evident across all levels of site index but becomes more pronounced as site index decreases. Tesch's and Lynch's curves also show a tendency to underpredict height at very young ages. Summerfield's curves fit the data quite well; they could be applied to the study population without incurring any substantial bias. The results for the Douglas-fir site curves by Cochran, Summerfield, and Vander Ploeg are shown in Figure 2; those for Monserud's curves are given in Figure 3. Cochran's curves and Monserud's curves for the grand fir habitat type series fit the data well, but Summerfield's curves and Monserud's curves for the Douglas-fir and subalpine fir habitat type series, all show various degrees of departure from the height growth patterns in the data. All three curves tend to underpredict height for young ages and overpredict height at older ages. This pattern of residuals is most evident at low site index levels (<60 ft) and tends to become less pronounced as site index increases. Vander Ploeg's curves agree well with the test data at young ages but there is a clear trend toward underprediction at older ages. This pattern is strongly present at site indexes below 55 ft but virtually disappears at site indexes above 60 ft.

The results for Schmidt's (1976) western larch curves and Alexander's (1967) curves for lodgepole pine (as reindexed for use with these data) are given in Figure 4. Neither set of curves appears to fit the data particularly well. Schmidt's curves underestimate heights at ages less than 40 years and at ages greater than 80. The pattern intensifies as site index increases. Alexander's curves overestimate heights at young ages, but may be adequate for ages above index age. The pattern of residuals is similar across all levels of site index.

Site Curves

Table 2 gives the site index and height-growth equations, developed from the study data, for ponderosa pine, Douglas-fir, western larch and lodgepole pine. Graphs of the height growth equations are shown in Figures 7–10.

As a basis for assessing reliability of the new curves, the residuals (observed–predicted) of SI and height were obtained by using the present stem analysis data as inputs to the site index and height growth equations. Means, standard deviations, and standard errors for the residuals were then calculated for 5-yr age classes. The degree of bias in the new equations may be assessed in Tables 3 and 4, which give the mean residuals, along with the associated standard errors, for the site index and height growth equations by age class for each set of curves. There does not appear to be any significant bias.

Figures 5 and 6 show the standard deviations of the height and SI residuals, respectively, plotted against age. The standard deviation is a measure of the variation remaining after the relationships between height, SI, and age have been modelled. This variation consists of two orthogonal components (Monserud 1984); within plot variability associated with the sample based mean; and variability of the plot means about the model. The error due to the within-plot variability can be reduced by increasing the sample size of site trees on a plot. The "plot about the model" error cannot be reduced.

It is tempting to use these standard deviations of residuals to calculate the number of site trees of a given age needed to obtain estimates of site index and/or height to some statistical standard (Monserud 1984). However, due to the sampling scheme used in the study (one tree per plot), these components cannot be separated. Thus, precision curves are not possible. Moreover, the tree selected was the one with median site index from a sample of three. Thus, it is likely that the within plot component of the variance is seriously under represented. If this is the case, then the standard de-

Table 4. Mean site index residuals (observed-predicted), *R*, and associated standard errors, SE, for new site index curves.

	Species											
	PP			DF			WL			LP		
Age	*n*	*R*	SE	*n*	*R*	SE	*n*	*R*	SE	*n*	*R*	SE
10	26	−1.25	2.28	46	1.90	1.33	31	1.29	1.21	37	0.28	1.44
20	38	1.01	1.09	44	0.81	0.92	32	1.05	1.04	33	−0.68	1.15
30	31	0.54	0.71	46	0.00	0.67	24	0.02	0.87	30	0.77	1.04
40	36	0.77	0.50	31	0.17	0.57	29	0.78	0.44	27	1.35	0.62
50	31	−0.36	0.23	33	0.22	0.27	18	−0.03	0.35	22	−0.05	0.40
60	22	−0.72	0.39	23	−0.90	0.45	18	0.57	0.46	17	−1.36	0.41
70	9	−0.50	0.69	14	0.30	0.91	14	0.21	0.83	12	−0.64	0.81
80	6	−0.47	2.15	8	−0.78	1.40	6	−0.19	1.61	10	1.31	1.57

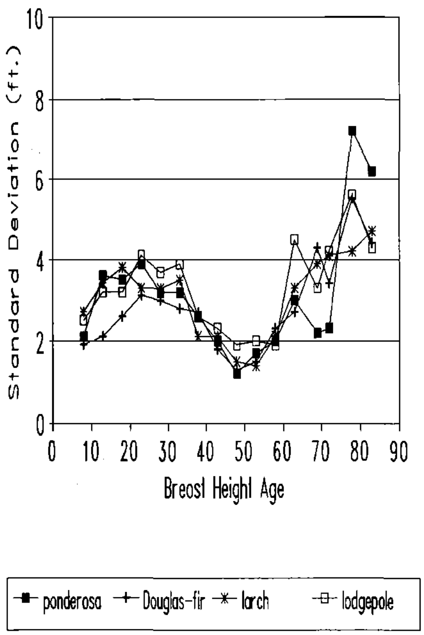

Figure 5. Standard devition of height residuals *vs.* age for new height growth curves.

viation of residuals approximates the between-plot variation only, and represents the best precision possible. Indeed, the plots in Figures 5 and 6 resemble those presented by Monserud (1984) for his Douglas-fir curves, both in shape and magnitude, for large ($n >$ 10) within-plot sample sizes. Assuming similar amounts of variability, approximately 10 trees per site would be required to achieve the levels of precision indicated.

Of course, it is also true that by increasing the within-site sample size one may be significantly changing the population of site trees used to estimate site index, relative to that specified in the sampling design. Depending on the underlying distribution of tree heights and ages, greater sampling intensity on a fixed area can substantially reduce the estimate of SI. For the present site curves, plot size is not specified, and considerable responsibility is placed with the user to select individual trees that (1) exhibit height growth patterns at or near the potential for the site, and (2) are potentially repeatable across the site. If care is taken to ensure that all site trees fully meet the criteria specified, a larger number of trees would be taken on a larger area, the sampling intensity relative to the underlying distribution would remain constant, and no bias would result.

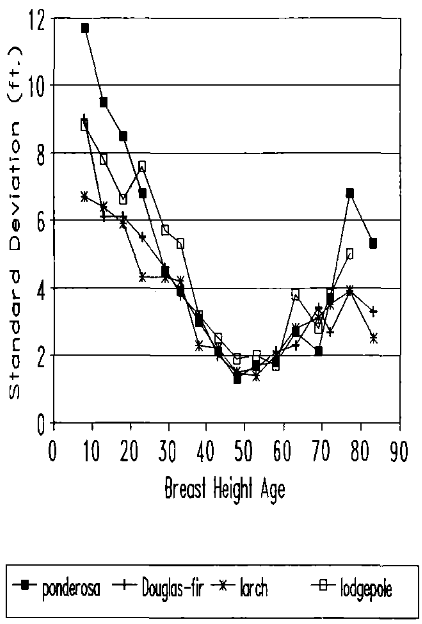

Figure 6. Standard deviation of site index residuals *vs.* age for new site index curves.

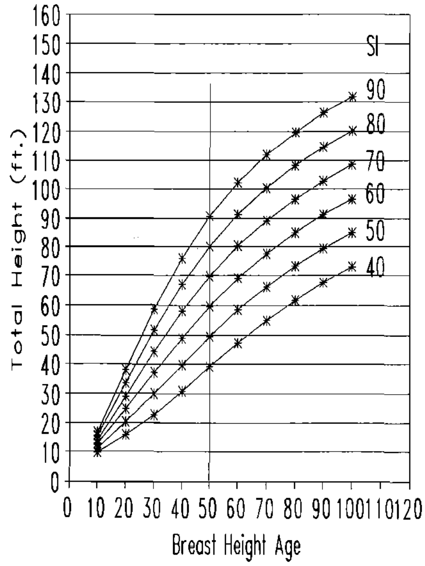

Figure 7. New height growth curves for ponderosa pine.

DISCUSSION

With a few exceptions, the published curves did not accurately portray the height growth patterns contained in the study data. These results were not unexpected; they reflect the differences in populations, definitions, sampling procedures, and curve construction methodologies used by the various authors, relative to the sample to which they were compared.

Generally, the results agree with Monserud's (1985) conclusions regarding similarity in shape of Douglas-fir site index and height growth curves in the Pacific Northwest. Curves constructed from stem analysis based methodologies applied to data from populations reasonably close to the study area agreed most closely with the test data. These included Monserud's and Cochran's Douglas-fir curves and Summerfield's ponderosa pine curves. Site curves that utilized cross-sectional data and guide curve techniques (Tesch 1980, Lynch 1958,

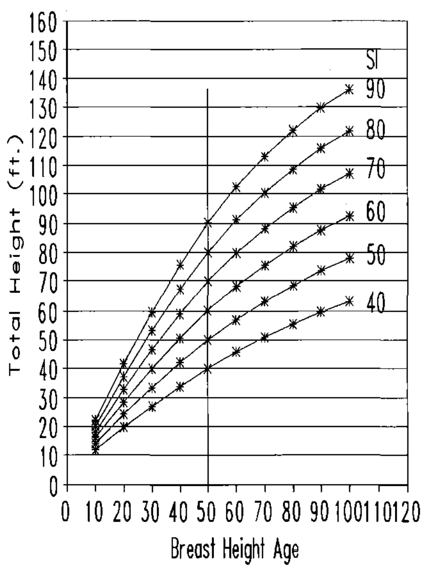

Figure 8. New height growth curves for Douglas-fir.

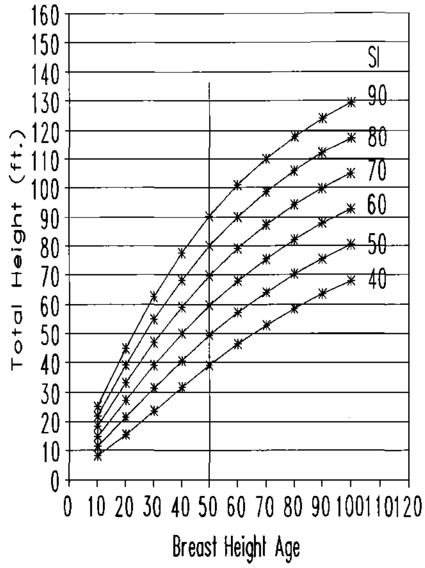

Figure 9. New height growth curves for western larch.

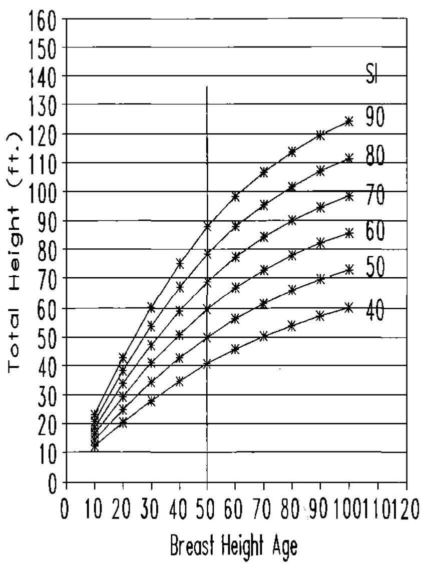

Figure 10. New height growth curves for lodgepole pine.

Schmidt 1976), on the other hand, showed a distinct and consistent underestimation of height at older ages, suggesting that the assumption of equal site quality representation across all levels of age was not met. Alexander's curves for lodgepole pine were derived from a sample that encompassed the Rocky Mountain, Intermountain, and Pacific Northwest regions. It is not surprising that their comparison to a small, geographically and genetically compact population should show differences. It was also noted that the pattern of over and under predictions in height relative to the study data was completely consistent with the age-related pattern of predicted site index noted by Alexander in the presentation of his final curves. Thus, the differences might be both methodological and genetic in nature.

Stem analysis based curves from reasonably close geographic regions did not always correspond well with the test data. The study area for Vander Ploeg's Douglas-fir curves for western Montana had considerable overlap with the current study area and yet substantial underestimates of height were noted at older ages. Also, Barrett's ponderosa pine curves and Summerfield's Douglas-fir curves, both from east of the Cascade crest (similar to Cochran's Douglas-fir and Summerfield's ponderosa pine curves), showed different height growth patterns from those in the study data. The cause of the differences for Vander Ploeg's curves is likely related to the absence of plots with site indexes below 55 ft in his sample. In the current study, the daa show a distinct change in curve shape at low site indexes; Vander Ploeg's sample would not have contained this change For the Summerfield and Barrett curves, it is unclear to what extent the causes of the differences are primarily genetic, methodological or sample based in origin.

The new site curves provide an unbiased summarization of the relationships between "true" age (as distinct from ring count) at BH, total tree height corresponding to that age, and SI (total height at a BH ring count of 50). This configuration is most appropriate for simulation models, which use true age (trees are assumed to reach 4.5 ft at the end of a growing season). Since ring count at BH overestimates true BH age by a half year, field estimates of SI will be biased downward slightly unless 0.5 is subtracted from the ring count prior to using the site index equation. It is interesting to note that were the raw height data adjusted to the ring count data (by adding a half years growth), the bias in field estimation of SI would disappear; only to reappear as an overestimation of height for the true ages assumed in model applications.

The site curve system developed in this study provides the user with the means to identify potential height growth patterns for ponderosa pine, Douglas-fir, western larch, and lodgepole pine in Western Montana. Any polymorphism in curve shape is reflected only to the extent that it is associated with levels of site index. □

LITERATURE CITED

ALEXANDER, R.R., D. TACKLE, AND W.G. DAHMS. 1967. Site indexes for lodgepole pine, with corrections for stand density. USDA For. Serv. Res. Pap. RM-29. 18 p.

BARRETT, J.W. 1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232. 14 p.

COCHRAN, P H 1979 Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap PNW-251. 16 p.

DAHMS, W.G. 1973. Gross yield of central Oregon lodgepole pine. Wash. State Univ., Proc. symp Management of lodgepole pine ecosystems.

DYER, M.E., AND R.L. BAILEY. 1987. A test of six methods for estimating tree heights from stem analysis data. For. Sci. 33(1):3–13.

HEGER, L. 1968. A method of constructing site index curves from stem analysis. For. Chron 44:11–15.

LYNCH, D.W. 1958. Effects of stocking on site measurement and yield of second-growth ponderosa pine in the Inland Empire. USDA For Serv. Res. Pap. INT-56. 36 p.

MEANS, J.E., AND T.E. SABIN. 1989. Height growth and site index curves for Douglas-fir in the Siuslaw National Forest, Oregon. West. J Appl. For. 4(4):136–142.

MILNER, K.S. 1987. The development of site specific height growth curves for four conifers in western Montana. Ph.D diss., University of Montana, Missoula.

MONSERUD, R.A. 1984. Height growth and site index curves for inland Douglas-fir based on stem analysis data and forest habitat type. For Sci. 30:943–965.

MONSERUD, R.A. 1985. Comparison of Douglas-fir site index and height growth curves in the northwest. Can. J. For. Res. 15(4):673–679.

SCHMIDT, W.C., R.C. SHEARER, AND A.L. ROE 1976. Ecology and silviculture of western larch forests. USDA For. Serv. Tech. Bul. INT-1520 96 p.

SUMMERFIELD, E.R. 1980a. Site index and height growth of Douglas-fir in eastern Washington Oper. Res. Intern. Rep. No. 80-12. Oper. Res Sec., Div. of Manage. Serv, DNR, State of Washington. 34 p.

SUMMERFIELD, E.R. 1980b. Site index and height growth of ponderosa pine in eastern Washington. Oper. Res. Intern. Rep. No. 80-14. Oper Res. Sect., Div. of Manage. Serv., DNR, State of Washington. 34 p.

TESCH, S.D., H.R. ZUURING, AND J.L. FAUROT 1980. Ponderosa pine site curves for the Blackfoot River drainage, Montana. Res. note no. 15, Mont. For. & Cons. Exp. Stn., School of For., Univ. of Mont., Missoula, MT.

VANDER PLOEG, J.L., AND J.A. MOORE. 1989 Comparison and development of height growth and site index curves for Douglas-fir in the Inland Northwest. West. J. Appl. For 4(3):85–88.

Establishment of Jeffrey Pine Seedlings from Animal Caches

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*ABSTRACT. Jeffrey pine (*Pinus jeffreyi*) seeds have large wings and are effectively dispersed by wind, but 37% of the seedling emergence sites in spring 1989 in the Sierra Nevada of western Nevada consisted of tight clumps of seedlings. By fall 1989, 41% of all emergence sites where seedlings survived had resulted from what were originally clumps of seedlings. As Jeffrey pines aged, clumps became smaller, and the frequency of clumps decreased. These seedling clumps and many single seedlings emerged from the scattered caches of seed-hoarding rodents and corvids, and the activities of these animals in the study area were sufficient to account for most of the Jeffrey pine seedling establishment observed. Cached seeds may gain important advantages over uncached seeds in the semiarid habitat occupied by this pine.*

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Food-hoarding animals are known to disperse the seeds of many plants These animals cache seeds or nuts under a layer of soil or plant litter, and the propagules germinate in spring if not recovered. Most attention has been directed toward corvids (jays and nutcrackers) and rodents that store large nuts. Relatively little is known concerning the influence of rodents as dispersers of the seeds of conifers, shrubs, and grasses (see Price and Jenkins 1986 for a review). Among pines, interest has focused on the wingless-seeded species of the soft pines (subgenus *Strobus*), which are dispersed