How Many Tree Heights Should You Measure for Natural, Atlantic Coastal Plain Loblolly Site Index?

F. Thomas Lloyd

ABSTRACT. Sample size is tabulated for the number of tree heights needed to site-classify plots growing natural, Atlantic coastal plain loblolly pine (Pinus taeda L.). *The size of the sample depends on observed stand age and selected site-class size, index age, and classification success rate. The most important outcome is the relationship of sample size to stand age because putting it into practice results in uniformly reliable site-index estimates.*

Every forester has estimated site index at one time or another. It is easy to do, and the results are meaningful. All you have to do is measure the heights of a few trees, bore them to determine age, and consult some graphs. The result is an indicator of appropriate management actions. The situation is simple—until you start asking questions: What site index curves should I use? How many tree heights must I measure? Does stand age affect the number of sample tree heights measured? What site-index class size should I use? What index age should I use? This paper addresses these questions and more, and provides tables suitable for aiding field crews in making uniformly reliable predictions of site index for natural, Atlantic coastal plain loblolly pine.

We know that local conditions cause aberrations in height growth on individual plots which are impossible to predict, so the best we can expect is for site curves to be correct on the average. However, even this "averaging" argument can not justify the use of some site-index curves. This was the case when Schumacher and Coile's (1960) curves for natural loblolly were compared with height curves from a long-term growth and yield study for natural loblolly pine maintained by the Southeastern Forest Experiment Station. Trousdell et al. (1974) responded by developing new polymorphic site index curves for natural, coastal plain loblolly using stem-analysis data from 50+-year-old trees on plots covering a full range of site quality. These curves are recommended for use in this application.

The way we define a plot determines how these site-index curves are applied. Here, a plot is an area of sufficiently small size to be deemed uniform in productivity. The indexing of larger areas (stands, etc.) that differ in site productivity within their boundaries raises mapping and sampling questions not addressed here.

The familiarity we have with site index can numb our awareness that the values are estimates and not fixed constants. With this in mind, any discussion of the site-index estimation process is impossible without some standard of evaluating the estimates. When we estimate site index, our primary purpose is to place the particular plot into an appropriate site-index or productivity class. Presumably, our success in placing plots into site classes depends on the precision (or variation) of the site-index estimate.

The stem analysis data used by Trousdell et al. (1974) were reanalyzed (Lloyd 1975) to investigate the variance of these site-index predictions. A largely theoretical presentation of this analysis was made in *Forest Science* (Lloyd and Hafley 1977). The primary objective of this paper is to use the equations from their work to present tree-height sample size information in a user-oriented format. However, before doing this an independent check using new data was made on the validity of Lloyd and Hafley's variance prediction equation—the equation used in developing Tables 1 and 2.

VERIFYING THE VARIANCE EQUATION

A validation study was performed in 1978. The approach was to compare *predicted* variance obtained from the Lloyd and Hafley (1977) variance equation (the variance equation is a function of, among other variables, the number of sample tree heights) with *observed* variance computed from repeated site-index estimates on the same plot, using the same sample size for the predicted and observed variances. The site-index estimates were obtained by repeatedly drawing (with replacement between samples) random tree-height samples of the same size from the dominant and codominant trees on a plot.

The validation data set was obtained from 9 plots in natural, even-aged, well-stocked loblolly stands aged 9, 15, 18, 25, 28, 29, 34, 45, and 53 years, located on the Francis Marion National Forest, Berkeley County, South Carolina. The plots were large enough to each contain 30 to 35 dominant and condominant trees, but small enough to be judged uniform in site quality. Tree heights were measured by using a clinometer at a taped distance from the tree. The heights were put on an electronic storage medium and a computer program was written to randomly draw samples of a specified size from each plot. At this point the computer was doing the work, so 100 site-index estimates were made for each sample size of 1, 2, 3, 4, 5, 6, and 10 trees on each plot. In other words, random samples were repeatedly drawn from the 30 to 35 trees on each plot in an effort to mimic the actual variation in site index for that plot. These 100 site-index estimates for the given sample size and plot were used to compute an observed variance.

This resulted in 63 predicted and observed variance points (9 plots × 7 sample sizes) which are plotted in Figure 1 for samples from the

Table 1. Number of tree heights required to attain specified classification success rate for various stand ages and site-index class intervals (index age 50).

Classification success rate	Stand age 10	15	20	25	30	35	40	45	50	55
					5-Foot class					
2-out-of-3	22	10	6	4	3	3	2	2	2	2
3-out-of-4	62	22	11	7	6	5	4	4	4	4
4-out-of-5	100+	50	21	13	9	7	6	6	6	6
9-out-of-10	100+	100+	100+	100+	65	38	28	24	22	26
19-out-of-20	100+	100+	100+	100+	100+	100+	100+	100+	89	100+
					10-Foot class					
2-out-of-3	4	2	1	1	1	1	1	1	1	1
3-out-of-4	8	4	2	2	1	1	1	1	1	1
4-out-of-5	14	6	4	3	2	2	2	2	2	2
9-out-of-10	100+	51	21	13	9	7	6	6	6	6
19-out-of-20	100+	100+	100+	100+	65	38	28	24	22	26
					20-Foot class					
2-out-of-3	1	1	1	1	1	1	1	1	1	1
3-out-of-4	2	1	1	1	1	1	1	1	1	1
4-out-of-5	3	2	1	1	1	1	1	1	1	1
9-out-of-10	14	6	4	3	2	2	2	2	2	2
19-out-of-20	100+	51	21	13	9	7	6	6	6	8

Table 2. Number of tree heights required to attain specified classification success rate for various stand ages and site-index class intervals (index age 25).

Classification success rate	Stand age									
	10	15	20	25	30	35	40	45	50	55
					3.75-Foot class					
2-out-of-3	17	8	5	4	3	3	2	2	2	2
3-out-of-4	33	15	9	6	5	5	4	4	4	4
4-out-of-5	59	24	14	10	8	7	7	7	7	8
9-out-of-19	100+	100+	60	39	34	37	47	76	100+	100+
19-out-of-20	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
					7.5-Foot class					
2-out-of-3	4	2	1	1	1	1	1	1	1	1
3-out-of-4	7	4	2	2	1	1	1	1	1	1
4-out-of-5	12	6	6	3	2	2	2	2	2	2
9-out-of-10	59	24	14	10	8	7	7	7	7	8
19-out-of-20	100+	100+	61	40	34	37	48	76	100+	100+
					15-Foot class					
2-out-of-3	1	1	1	1	1	1	1	1	1	1
3-out-of-4	2	1	1	1	1	1	1	1	1	1
4-out-of-5	3	1	1	1	1	1	1	1	1	1
9-out-of-10	12	6	3	3	2	2	2	2	2	2
19-out-of-20	60	24	14	10	8	7	7	7	7	8

dominant-codominant stand and from only the dominant stand, respectively. In both cases the variance prediction equation proved acceptable, although it did underestimate observed variance obtained when sampling tree heights from the dominant-codominant crown class. I attribute this in part to measurement error resulting from having measured the standing trees in this validation study with a clinometer, while the original heights used in development of the variance equation were taped to the nearest tenth of a foot on felled trees. Although this bias is not large, those inclined to adjust for it can do so by restricting site indexing to the less variable dominant tree heights.

This validation study confirms Lloyd and Hafley's variance equation, which, in addition to being a function of sample size, is a function of stand age and index age. The validated equation is then used to evaluate the effects on sample size of stand

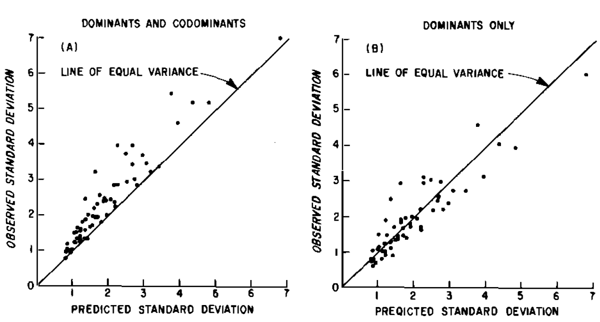

Figure 1. Observed standard errors computed from repeated estimates of site index vs corresponding predicted standard errors (Lloyd and Hafley 1977) for 9 stands aged 9, 15, 18, 25, 28, 29, 34, 45, and 53 years and sample sizes 1, 2, 3, 4, 5, 6, and 10 tree heights.

age and index age. Recalling that the ultimate goal is to place plots into site-index classes, Lloyd (1975) defined a measure of the classification success rate that is a function of both the variance equation and the size of the site class (*i.e.*, the length of the interval: 5 feet, 10 feet, etc.). By holding classification success rate (expressed as percent) constant, the effect on sample size of stand age, site-class size, and index age can be examined. The results are tabulated in Tables 1 and 2.

USE OF THE TABLES

Learning how to use these tables can best be done by following an example. Keep in mind when doing this that we never know the exact site index of a plot, but can only estimate it (remember that all dominant and codominant trees on a plot are only a sample of an infinite number of trees that could have been there). Now suppose the goal is to classify plots into 10-foot site classes at index age 50. This means that we use the data in the middle section of Table 1. The last step is to choose the classification success rate. The x-out-of-y success rate means that on the average (x/y)100 percent of the plots are correctly placed into the classes to which they correctly belong. If, for example, we choose a 9-out-of-10 success rate, then sample 100+, 51, 21, 13, 9, 7, 6, 6, 6, and 6 sample tree heights (see ninth row in Table 1) at the corresponding stand ages of 10, 15, 20, 25, 30, 35, 40, 45, 50, and 55 years. If stands younger than age 20 are expected in this sample problem, then either the success rate, site-class size, or index age must be changed because 20+ tree heights per plot would be prohibitively large for most applications.

A possible alternative for this example would be to retain the age 50 index age and 9-out-of-10 success rate, but use a 20-foot site class. In this case, the recommended sample sizes are 14, 6, 4, 3, 2, 2, 2, 2, 2, and 2 tree heights (see fourteenth row of Table 1) for the respective stand ages listed in the table. It is easy to envision other combinations of classification success rate, expected stand age range, site-class size, and index age that could tailor the application to your particular needs.

The choice of 100 trees as the maximum reported sample size was arbitrary. It is based on the premise that it would be rare for someone to want to sample that many tree heights for one plot. Also, it is unlikely that one would find plots of uniform site quality containing that many dominant and codominant trees.

Several reviewers of this work have questioned why minimum sample size does not always occur when index age equals stand age. This outcome is most clearly demonstrated in Table 2 for index age 25. The reason is best envisioned by considering the combined effects of converging site curves as stand age decreases and equal variation in tree heights over the observed range of 10 to 55 years. It follows that projecting backward to a younger index age will result in less variation of the projected heights than the actual variation in height at the observed age. Actually, the location of minimum sample size relative to stand age results from the interaction of these factors plus others addressed in more detail in the discussion section of Lloyd and Hafley (1977).

The unusual site-class sizes for index age 25 (Table 2) are equal to 75 percent of the size of the corresponding index age 50 classes (Table 1). Seventy-five percent was chosen because the distance between any 2 of Trousdell's site curves at age 25 was 70 to 80 percent of the distance between these curves at age 50. Choosing site-class size this way made it possible to isolate the effect on sample size of changing index age.

If this example satisfies no other purpose, it serves to accentuate an element of arbitrariness in the process it describes. This is primarily due to a lack of explicitness in our choice of the success rate. It also results from a lack of understanding the effects site-class size and index age have on the classification success rate. This all works to emphasize the most important outcome of these results—how tree-height sample size changes with stand age. No matter what success rate, site-class size, or index age is finally decided on, it is the relation of sample size to stand age found in Tables 1 and 2 that makes uniformly reliable site-index classification possible.

Literature Cited

LLOYD, F. T. 1975. An estimator of variance for a site index predictor using a family of cumulative total height growth curves as the model. Ph.D. Thesis. N.C. State Univ. 73 p. University Microfilms, Ann Arbor, MI (Diss. Abstr. 75-17, 103).

LLOYD, F. T., and W. L. HAFLEY. 1977. Precision and the probability of misclassification in site index estimation. For. Sci. 23:493–499.

SCHUMACHER, F. X., and T. S. COILE. 1960. Growth and yields of natural stands of the southern pines. 115 p. T. S. Coile, Inc., Durham, NC.

TROUSDELL, K. B., D. E. BECK, and F. T. LLOYD. 1974. Site index for loblolly pine in the Atlantic Coastal Plain of the Carolinas and Virginia. Southeast. For. Exp. Stn., USDA For. Serv. Res. Pap. SE-115, 11 p.

F. Thomas Lloyd is research forester, Southeastern Forest Experiment Station, USDA Forest Service, Forestry Sciences Laboratory, Charleston, South Carolina.