

teristics of that site, the substitute cutting areas available, the population of the market area, and the location of the market area with respect to the cutting site and substitute cutting sites. Because these factors generally vary between cutting sites, the dollar value derived from the application of the model at the Redfeather Lakes site is not appropriate at another cutting site unless the sites are similar in these factors.

The average consumer surplus of \$4.37 per tree implies that total revenue from the Christmas tree sale could be increased by raising the cutting fee above \$5.00 per tree. The question of how high cutting fees can be raised before total revenue starts falling is not definite. Rosenthal et al. (1986) caution that travel cost-based demand curves estimated with primary attention to obtaining the area

under the demand curve may not be highly useful to predict responses to small increases in prices or fees. These curves often estimate large reductions in use with small increases in fees, which may not actually happen. □

LITERATURE CITED

- BOX, G. E. P., AND D. R. COX. 1964. An analysis of transformations. *J. Royal Stat. Soc., Series P.* 26(2):211-243.
- DONNELLY, D. M., AND L. J. NELSON. 1986. Net economic value of deer hunting in Idaho. *USDA For. Serv. Resour. Bull. RM-13.* 27 p.
- DRAPER, N. R., AND H. SMITH. 1966. Applied regression analysis. John Wiley & Sons, Inc., New York. 407 p.
- DWYER, J. F., J. R. KELLY, AND M. D. BOWES. 1977. Improved procedures for valuation of the contribution of recreation to national economic development. *Univ. of Illinois, Water Resour. Cent. Rep.* 128. 218 p.
- JUST, R. E., D. L. HUETH, AND A. SCHMITZ. 1982. Applied welfare economics and public policy. Prentice-Hall, Inc., Englewood Cliffs, NJ. 491 p.

- KMENTA, J. 1971. Elements of econometrics. Macmillan Publishing Co., Inc., New York. 655 p.
- RAO, P., AND R. L. MILLER. 1971. Applied econometrics. Wadsworth Publishing Co., Belmont, CA. 235 p.
- ROSENTHAL, D. H., ET AL. 1986. User's guide to RMTCM: Software for travel cost analysis. *USDA For. Serv. Tech. Rep. RM-132.* 32 p.
- ROSENTHAL, D. H., J. B. LOOMIS, AND G. L. PETERSON. 1984. The travel cost model: Concepts and applications. *USDA For. Serv. Tech. Rep. RM-109.* 10 p.
- STRONG, E. J. 1983. A note on the functional form of travel cost models with zones of unequal populations. *Land Econ.* 59(2):247-254.
- U.S. DEPARTMENT OF COMMERCE. 1982a. County business patterns 1981, Colorado. *CBP-81-7* 82 p.
- U.S. DEPARTMENT OF COMMERCE. 1982b. General population characteristics 1980, Colorado. *PC80-1-B7.* 196 p.
- U.S. DEPARTMENT OF TRANSPORTATION. 1982. Cost of owning and operating automobiles and vans 1982. 20 p.
- ZIEMER, R. R., W. N. MUSSER, AND R. C. HILL. 1980. Recreation demand equations: Functional form and consumer surplus. *Am. J. Agric. Econ.* 62:136-141.

TECHNICAL NOTES

Clinometer Versus Pole Measurement of Tree Heights in Young Douglas-Fir Progeny Tests

Glenn T. Howe and W. Thomas Adams¹

Height measurement in progeny tests plantations with closed canopies is time consuming and costly. Height growth, however, is the major selection criterion for coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) in the Pacific Northwest. More than 500 progeny test plantations involving Douglas-fir progenies from more than 25,000 parent trees have been established in coastal Oregon, Washington, and British Columbia in the past 15 years. Measurement of these plantations represents a large investment of time and money.

Tree breeders are frequently interested in estimating the mean phenotypic value of a tree's progeny. This value, often called the *breeding value*, is useful for making selections among parent trees (Falconer 1981). Breeding

values and genetic gains can be estimated from progeny test information. Genetic gain, the response to selection, is the difference in average breeding value between the selected group of parents and the entire population before selection.

Because only a small sample of a tree's progeny can be included in a progeny test, family mean heights derived from progeny test measurements are not direct measures of parental breeding values. The degree of correspondence between family means and parental breeding values must also be known. This correspondence is measured by the family heritability, and its magnitude is influenced by the amount of microsite variability, the number of progeny measured per family, and measurement error.

In 1984, the Pacific Northwest Tree Improvement Research Cooperative at Oregon State University began an investigation into measurement strategies for young Douglas-fir progeny tests, including strategies of height-measurement. Crown closure of Douglas-fir progeny test plantations usually occurs when trees are 10 to 15 years old. Because height-pole measurements become difficult and time

consuming at this stage, tree breeders in some tree-improvement programs have begun measuring tree heights with a clinometer. In this study, we evaluated the use of height-poles and clinometers for height measurement of progeny test plantations. The information should be useful to tree breeders for improving the efficiency of genetic selection.

TEST PLANTATIONS

Two series of height measurements of Douglas-fir were made in three progeny test plantations that were established by the Umpqua Tree Improvement Cooperative near Eugene, OR. The progeny were derived from wind-pollinated seed collected from 90 parents located in wild stands in the central part of the Oregon Coast Range (Silen and Wheat 1979). All parents are in the Noti Breeding Unit of the Douglas-fir Progressive Tree Improvement Program. The progeny were divided into three sets of 30 families that were planted in adjacent experiments at each of the three planting sites. At each site, a randomized complete-block design experiment with four blocks was used for each set. Four 1-0 plug seedlings per family were randomly planted in each block at 3.05 × 3.05 m spacing.

The plantations were fenced to exclude large browsing animals. Survival in each was greater than 76%. Trees were replanted for 3 years after the initial planting, making current survival 84%, but replacements were not used in the analyses. Trees in two of the plantations were 12 years old from seed when measured in November 1984; those in the third plantation were 13 years old. All trees were about 8 m tall, and crowns were

¹ Department of Forest Science, College of Forestry, Oregon State University, Corvallis, OR 97331. The authors thank members of the Pacific Northwest Tree Improvement Research Cooperative for support and technical assistance. This is Paper 2180, Forest Research Laboratory, Oregon State University, Corvallis. The mention of trade names or commercial products does not constitute endorsement or recommendation for use by Oregon State University.

sufficiently closed that branches at breast height were beginning to senesce.

HEIGHT MEASUREMENTS

The first series of height measurements was made with a 15 m bottom-reading measuring pole. One person operated the pole and another recorded height. Measurements to the nearest decimeter were made of all trees in each plantation. Crown closure made it necessary to low the pole before moving from tree to tree. However, while the pole operator was moving the pole, the observer had time to find a good vantage point for viewing the top of the next tree.

The second series of measurements was made on a single set of 30 families with a Suunto clinometer. Trees from this set of families were measured in two blocks in two plantations and in a single block in the third plantation, resulting in an average 15.3 trees per family (range = 11–18). Readings, in percent, were made at breast height (1.37 m) and at the top of a tree by an observer who also recorded the data. An assistant held a rope and a flashlight at breast height on each tree in order to position the observer 10 m away and to help locate breast height. Both the observer and assistant remained within rows when taking the readings, traveling through the plantation systematically. Because the observer remained within rows, he generally had a poorer view of the treetop than was possible when measuring trees with a pole. Tree height to the nearest decimeter was estimated from clinometer readings after measurements were completed. Values for trees measured with both height-pole and clinometer comprise the data hereafter referred to as the "subset."

In order to obtain information on relative costs, the elapsed times for measuring each of six blocks with the height pole and each of five blocks with the clinometer were recorded.

ANALYSIS OF RELATIVE EFFICIENCY

Height-pole and clinometer estimates of tree height can be thought of as separate "traits." Because height-pole measurement is generally more reliable than clinometer measurement, we considered pole-height to be the trait with the least measurement error. Therefore, the use of height-pole measurements can be thought of as "direct" selection and the use of clinometer estimates as "indirect" selection. The percentage of genetic gain from indirect versus direct selection is the relative efficiency (RE). If we assume equal selection intensities for both traits, the efficiency of indirect

selection (clinometer) in comparison with direct selection (height-pole) is

$$RE = [h_c/h_p] r_a \times 100,$$

where h_c and h_p are the square roots of the family heritabilities for clinometer and pole measurements, respectively, and r_a is the genetic correlation between the traits (Falconer 1981). Genetic parameters, including h_c , h_p , and r_a , were estimated from analyses of variance and covariance of both traits in the subset data (Zobel and Talbert 1984).

For purposes of illustration, we also estimated the gain in height in progeny from a wind-pollinated clonal seed orchard. Height gain at 12 to 13 years of age was estimated with the assumption that the top 20% of the parent trees from each set would be included in the orchard and that inbreeding would be negligible. Although relative efficiency was calculated from the "subset" data, the estimates of absolute height gain were calculated with the complete height-pole information from all three sets of families. Height gain in seed orchard progeny from parents selected on the basis of height-pole information (G_p) was estimated as

$$G_p = 1.5 \times [ih_p \sigma_a]$$

where h = the square root of the family heritability, σ_a = the square

root of the additive genetic variance estimated from the complete data set, and i , the intensity of selection, equals 1.354 when the best 6 parents are chosen from each set of 30 (Falconer 1981). The multiplier (1.5) is based on an assumed coefficient of relationship among open-pollinated progeny of $1/2$. Genetic gains in height for selections based on clinometer measurements (G_c) were estimated by multiplying the height-pole estimates of gain by the relative efficiency (in fractional form):

$$G_c = G_p \times [RE/100].$$

In addition to calculating relative efficiency, we calculated family mean heights from the subset height-pole and clinometer measurements. Families were ranked on the basis of these means so that differences in decisions on parental selection could be judged.

RESULTS

Results of analysis of the complete height-pole data from all three sets of families support the hypothesis that there is significant family variation in height at the 0.005 level of probability. When we used the subset data, family heritabilities for the height-pole ($h^2 = 0.34$) and clinometer ($h^2 = 0.33$) were nearly identical, showing that height-breeding values can be estimated with nearly equal precision with either

Table 1. Family height rankings of 12- to 13-year-old Douglas-fir in an open-pollinated progeny test, as measured with a pole and a clinometer.

Noti Breeding Unit parental genotype number	Mean height (m) and family rank (in parentheses)	
	Height-pole	Clinometer
1692	8.54 (1)	8.39 (1)
1672	8.48 (2)	8.16 (2)
1673	8.45 (3)	8.09 (3)
1650	8.41 (4)	8.03 (5)
1691	8.40 (5)	8.06 (4)
1669	8.39 (6)	8.01 (6)
1690	8.33 (7)	7.98 (7)
1682	8.27 (8)	7.97 (8)
1656	8.19 (9)	7.83 (12)
1663	8.18 (10)	7.72 (16)
1655	8.16 (11)	7.87 (10)
1671	8.07 (12)	7.58 (20)
1685	8.03 (13)	7.66 (18)
1683	8.02 (15)	7.89 (9)
1664	8.02 (15)	7.86 (11)
1676	8.02 (15)	7.52 (22)
1687	7.99 (17)	7.75 (14)
1670	7.98 (18.5)	7.55 (21)
1667	7.98 (18.5)	7.74 (15)
1658	7.97 (20)	7.80 (13)
1653	7.91 (21)	7.67 (17)
1688	7.78 (22)	7.61 (19)
1662	7.68 (23)	7.28 (25.5)
1660	7.66 (24)	7.27 (27)
1665	7.64 (25)	7.40 (24)
1659	7.63 (26)	7.47 (23)
1675	7.49 (27)	7.14 (28)
1666	7.46 (28)	7.28 (25.5)
1684	7.36 (29)	7.01 (29)
1657	7.13 (30)	6.85 (30)

measurement technique. Because of the closeness in heritability estimates and the high genetic correlation ($r_a = 0.96$), the relative efficiency of using the clinometer versus the height-pole was 94% for parental selection. Gain in height from a clonal seed orchard of the best 20% of parents was estimated at 4.54% from height-pole data from the complete test. If clinometer measurements are used for selection, genetic gain is expected to be 4.27%.

Because progeny-test information can also be used to select among progeny in test plantations, we estimated the relative efficiency of this approach as well. In this case, we assumed that index selection would be made on the basis of family means and individual-tree values, called combined selection (Falconer 1981). The relative efficiency for combined progeny selection (0.95) was nearly identical to that for parental selection (0.94). This indicates that the relative gain obtained through use of the clinometer is nearly the same regardless of whether selections are made among parents or among progeny.

The similarity of height-gain estimates for selections based on clino-

meter and height-pole data is reflected in the agreement of family rankings (Table 1), which were particularly close for fastest and slowest growing families. Clinometer estimates of height were consistently lower than height-pole estimates. The subset mean was 7.68 m with the clinometer, 7.99 m with the height-pole.

On average, the two-person crews took only 60% as long to measure height with a clinometer as with a pole. In three of the four blocks where both measurement techniques were used on the same trees, clinometer measurements were faster, but in the fourth block, clinometer measurements took 15% longer than measurements with a pole.

DISCUSSION

Height estimation by means of a clinometer can be an effective basis for genetic selection. Although the gain may be slightly less than that obtained with a height-pole, trees can be measured in considerably less time. This may be an acceptable trade-off for tree-improvement programs in which resources saved can be allocated to other tree-improvement activities. In

such cases, it might be wiser to devote the extra resources to measurement of additional traits such as stem diameter, tree form, or wood quality.

Results from this study apply to plantations where the trees are 10 to 15 years old and crown closure is such that branches are beginning to senesce at breast-height. In younger plantations, where the height-pole can be moved readily from tree to tree without lowering and raising the pole, the time advantage of the clinometer would not be as great. In older plantations, where it is possible to use a height-pole but where tree-tops are difficult to see, clinometer height estimates may not have an adequate level of precision because the fixed viewing distance and angle required for readings may prevent the observer from gaining a good vantage point for each tree. □

LITERATURE CITED

- FALCONER, D. S. 1981. Introduction to quantitative genetics. Longman Inc., New York. 340 p.
- SILEN, R. R., AND J. G. WHEAT. 1979. Progressive tree improvement program in coastal Douglas-fir. J. For. 77:78-83.
- ZOBEL, B., AND J. TALBERT. 1984. Applied forest tree improvement. John Wiley & Sons, New York. 505 p.

A Modified Density Management Diagram for Coastal Douglas-Fir

James N. Long, James B. McCarter, and Steven B. Jack¹

Density management diagrams (DMD) of the type pioneered by Japanese foresters (Ando 1968) were introduced to North American forestry when Drew and Flewelling (1979) published a diagram for coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). DMDs are essentially models of stand average dimensional relationships. Foresters have used simple two-parameter stocking guides for years (Reineke 1933, Gingrich 1967, Wilson 1979), but the inclusion of additional size parameters, particularly height, greatly improves the utility of these charts.

The format of a DMD depends largely on personal preference. For example, the Douglas-fir DMD of Drew and Flewelling (1979) has mean volume and trees per acre (TPA) on the major axes, and additional curves

correspond to quadratic mean diameter (Dq) and average height of the site trees. "Relative density," based on mean volume and TPA, is used as the index of stocking in their DMD.

A different format was used in McCarter and Long's (1986) lodgepole pine (*Pinus contorta*) DMD. Dq and TPA were represented on the major axes, and additional lines corresponded to total stand volume and height of site trees. McCarter and Long (1986) preferred Dq as the principal size variable because it is more commonly used, and easier to estimate in the field, than is mean volume. Their choice of axes influenced the decision to use SDI, a function of Dq and TPA, as the index of stand density on the lodgepole pine DMD.

We used the regression equations presented by Drew and Flewelling (1979) to construct a new DMD for coast Douglas-fir (Figure 1). Essentially we have merely reformatted their original DMD, but believe that foresters will find the new format substantially easier to understand and use.

As is the case in the lodgepole pine

DMD, Dq and TPA are plotted on the major, logarithmic, axes. Growing stock levels, the diagonal parallel lines, are derived from Reineke's (1933) Stand Density Index:

$$SDI = TPA (Dq/10)^{1.6} \quad (1)$$

SDI is one of a number of size-density indexes that are particularly useful to silviculturists because they are independent of site quality and stand age (Curtis 1982, Daniel et al. 1979, Long 1985). The uppermost SDI line (Figure 1), corresponding to $SDI = 600$, is quite similar to the maximum relative density relation that Drew and Flewelling (1979) found for coast Douglas-fir. This SDI also closely approximates the maximum SDI value (595) for Douglas-fir suggested by Reineke (1933). The two families of curves, representing average site tree height and total volume (ft^3/ac), were derived from Drew and Flewelling's (1979) original regression equations. The range of heights and volumes displayed approximate the range of data used in the original regression analyses.

The density management diagram is particularly useful in planning for, and evaluating the consequences of, alternative density management regimes. The diagram will help resource specialists involved in the management of coast Douglas-fir prescribe and evaluate stand density manipula-

¹ Department of Forest Resources and Ecology Center, Utah State University, Logan, UT 84322-5200; and McCarter is with the Department of Biology and Ecology Center, Utah State University, Logan, UT 84322-5200. This is Journal paper No. 3501, Utah Agricultural Experiment Station.