# Observer Variation in Tree Diameter Measurements

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**ABSTRACT:** *Tree diameter breast height (dbh) was measured on 879 permanently marked trees by two experienced professional foresters. Error rates were approximately equal between observers. Measurement error rates of 5% of tree diameter or greater may be expected in dbh measurements on as many as 5% of measured trees.* *West. J. Appl. For. 20(2):134–137.*

**Key Words:** Diameter breast height, measurement error, subalpine fir, spruce, western larch, Douglas-fir.

Tree diameter measured outside bark at a standard 1.37 m above the ground is defined as diameter at breast height (dbh) and is used as a standard tree metric for inventory, management, monitoring, and research. For example, the measure helps estimate the volume or mass (weight) of products from standing trees (Young and Giese 1990). It is also used to identify size class distribution of trees in a stand during the development of a management prescription and, in a repeated measures design, to measure periodic annual volume growth of individual trees and quantify dynamic changes in forest stands occurring over time.

Measurement errors or differences in the measurement of dbh will result from:

(1) recording errors (either in reading the tape or recording)

(2) divergences in tape placement from the plane perpendicular to the tree axis

(3) placement of the tape above or below the specified 1.3-m height

(4) differences in tape tension.

While these errors can be minimized with training, they cannot be eliminated. Even experienced observers will return variable dbh measurements. Information about the size and extent of this variation is limited. The literature concerning rates of field errors in measuring dbh is comprised of a few studies with small sample sizes (about 200 trees or fewer). McRoberts et al. (1994) measured 61 trees with eight or nine field crews. They found measurements of dbh were typically within 0.75 cm of each other if mistakes were excluded. When individual crew measurements were compared to the mean dbh, 60% were found to be within 0.13 cm of the mean, and 90% within 0.38 cm of the mean. The incidence of mistakes was 1.78%. Nester (1981) used four teams to measure 210 trees, and found that about 95% of all trees were measured to within 0.3 cm of their true dbh (as measured by a "careful, unhurried, experienced operator"). Myers (1961) reported that 93% of dbh measurements made by 49 forestry students on 50 trees were within 2.54 cm of the mode. Johnson and Haag (1985) investigated observer differences in diameter measurement of seedlings using calipers and found differences between observers were small when seedlings were marked at the point of measurement.

We compare dbh measured by two observers on 879 tagged trees in the summer of 2000. These data were collected during remeasurements of eight permanent 0.1-ha plots in the Coram Research Natural Area established as part of a long-term ecological monitoring project (Elzinga and Shearer 1997, Elzinga 2001). The purpose of this report was to evaluate (1) the rate of error made by observers and (2) the amount of consistent bias that may exist between observers. Both questions have implications for long-term monitoring projects, especially for accuracy of inventory and research data.

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## Methods

### Site Description

The 340-ha Coram Research Natural Area (CRNA) occupies the southeast corner of Coram Experimental Forest on the Flathead National Forest near Martin City in northwest Montana (Shearer and Kempf 1999). Approximately 80% of the CRNA is forested with old-growth stands of mixed western larch (*Larix occidentalis*) and Douglas-fir (*Pseudotsuga menziesii*) over 200 years old. About three-fourths of these stands are Society of American Foresters (SAF) western larch cover type 212 (Eyre 1980) and contain nearly equal volumes of western larch and Douglas-fir. About 10% of the CRNA is a younger mixed western larch/Douglas-fir stand that established after a burn in 1890 (Sneck 1977). Most of the CRNA is classified in the subalpine fir (*Abies lasiocarpa*) climax series or habitat type, with patches of western hemlock (*Tsuga heterophylla*) and Douglas-fir habitat types (Pfister et al. 1977). Other common trees in the CRNA are an Engelmann/white spruce hybrid (*Picea engelmannii* × *P. glauca* [Habeck and Weaver 1969], hereafter called spruce), western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta*), and western redcedar (*Thuja plicata*). Paper birch (*Betula papyrifera*) occurs on most plots.

Annual precipitation in the CRNA averages 89 cm at the lower elevations and over 102 cm along the upper boundary (Farnes et al. 1995). About 70% of the precipitation falls as snow from Nov. through Apr. Temperature averages 16° C during the summer months. In 2000, much of the Inland Mountain West, including the Coram Experimental Forest, experienced unusually hot and droughty conditions. Based on data from the nearby Hungry Horse Dam climatic station (WRCC 2002a), precipitation within the CRNA averaged about 95 mm less from May through Aug. 2000 than the 53-year average (Table 1). Mean daily high temperature ranged from 1 to 3° C greater from June through Aug. 2000 (WRCC 2002b) (Table 1). Daily mean temperature for the same period ranged from −0.1 to 1.1° C greater than the 53-year average (WRCC 2002c) (Table 1).

### Measurements

During establishment of the eight permanent plots (four in 1985 and four in 1993), all trees were marked at approximately breast height using aluminum tags hung on aluminum nails. Each tree was measured for diameter above the nail, estimated to the nearest hundredths of an inch using standard metal diameter tapes graduated into 0.1-in. diameter equivalents based on tree diameter. Plots established in 1985 were remeasured in 1993, and all plots were remeasured during the summer of 2000. Two professional foresters, each with at least 18 years of field experience, measured all tree diameters. The first, assisted by a recorder, measured the trees June 27–30; the second, who worked alone, remeasured the trees Aug. 15–23.

### Analysis

The measured English units were converted to metric for analysis and rounded to the nearest hundredth centimeter. Data were treated as paired samples, i.e., the June measurement was compared with the Aug. measurement, with the Aug. measurement used as the standard. Although the data were collected in eight plots, each paired measurement was considered an independent sample. While autocorrelation exists in the measurement of dbh within each plot, no autocorrelation in the differences between the two diameter measures are expected because the same two observers measured all eight plots.

Live and dead trees were analyzed separately. Live trees were grouped by species and size classes. Dead trees were separated into standing dead and dead/down classes. A paired *t*-test was used to evaluate the significance of the difference between the two diameter measurements. Analysis was completed using Systat version 7.0 (SPSS 1997).

## Results and Discussion

The mean difference in measured diameters of the 730 live tree observations was −0.003 ± 0.034 cm (95% confidence interval; $P = 0.885$) (mean diameter was slightly, but not significantly, smaller at the second measurement). This difference represents only 1.6% of the average tree diameter of 18.59 cm. The mean difference in measured diameter between all dead standing trees (97 trees) was −0.072 ± 0.091 cm ($P = 0.122$). The mean difference between diameter measurements on dead and down trees (51 trees) was −0.143 ± 0.185 cm ($P = 0.127$).

Variation was much higher in the measurement of dead and dead and down trees compared to live trees. This is reasonable because many dead trees lacked tags, making exact relocation of the tape more difficult compared to tagged live trees. Both measures were negative, with fairly

**Table 1. Comparison of mean monthly precipitation (mm) and average maximum and mean temperature (°C) for May through Aug. 2000 to the 53-year average, Hungry Horse Dam climatic station, 3 km from the western boundary of the CRNA.**

| Event | May | June | July | Aug. |
|---|---|---|---|---|
| Mean precipitation (1948–2001) | 72.1 | 87.9 | 46.2 | 48.0 |
| Mean precipitation (2000) | 61.0 | 73.4 | 18.3 | 6.4 |
| Deviation from 53-year mean | –11.1 | –14.5 | –27.9 | –41.6 |
| Mean maximum temperature (1948–2001) | 17.7 | 21.9 | 26.7 | 26.3 |
| Mean maximum temperature (2000) | 17.2 | 23.0 | 28.6 | 29.3 |
| Deviation from 53-year mean | –0.5 | +1.1 | +1.9 | +3.0 |
| Mean temperature (1948–2001) | 10.8 | 14.7 | 18.4 | 18.0 |
| Mean temperature (2000) | 10.6 | 14.6 | 19.5 | 19.1 |
| Deviation from 53-year mean | –0.2 | –0.1 | +1.1 | +1.1 |

low *P*-values, suggesting the difference between the two measures may have been due to shrinkage rather than random observer errors.

We were concerned the 7-week growing season between measurements introduced a consistent bias caused by tree growth. We explored this potential for bias in two ways. First, we compared the fastest growing trees (top 10%) with the slowest growing trees (bottom 10%), classed based on percent change in diameter in the previous decade. If growth were an important source of bias, the difference between the two measurements would have been positive and larger in the fast-growing trees compared to the slow-growing trees. Mean difference between the two measurements was higher for the fast-growing group (mean of +0.061 cm), but not significantly higher than the slow-growing group (mean of +0.047 cm; $P = 0.841$). Second, we compared the wettest plot with the driest plot in the study to evaluate potential bias caused by shrinkage. We found the dbh measurement difference between the two observers similar (mean of +0.010 cm for the wet plot and +0.019 for the dry plot) and not significantly different between the two plots ($P = 0.895$).

The number of trees measured larger at the second measurement was about the same as the number measured smaller (342 versus 346) suggesting no consistent difference in methodology occurred between the two observers. Some errors, however, were clearly measurement mistakes. In 15 cases an inch was added to the correct measurement. Surprisingly, no errors involved subtracting an inch. Recording mistakes (e.g., transposed numbers) also occurred. Most of these errors, however, were only obvious when compared with previous diameter measurements made during plot establishment 7–10 years earlier.

Overall, approximately 2% of the measurements differed between observers by more than 10% of the measured diameter, 5% of the measured trees differed by 5% or more of the measured diameter, and 12% of the measurements differed by 3% or more (Table 2). Differences are most pronounced in the smaller size classes (Figure 1).

## Conclusions

Based on these data, errors of 5% of the diameter or greater may be expected in dbh measurements on as many as 5% of measured trees. Error rates, as expressed as a percentage of tree diameter, of 5% or greater occurred in nearly 12% of the trees <7 cm in diameter, but in only 3–5% of the larger-diameter trees (>20 cm). We suspect our error rate may be smaller than the rate that occurs in

**Table 2. Differences in dbh measurements of live trees on Coram Research Natural Area made by two observers in 2000. Size classes are: 1, <7 cm; 2, 7–9.9 cm; 3, 10–14.99 cm; 4, 15–19.99 cm; 5, 20–29.99 cm; 6, 30–40 cm; 7, >40 cm. The last three columns show the percentage of trees differing in diameter between the two measurements by a given percentage.**

| | | | Difference | | | | Percent of trees differing by | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Size class | *n* | Average (cm) | SD | Positive (cm) | Negative (cm) | ≥3.0–4.9% | ≥5.0–9.9% | ≥10.0% |
| Subalpine fir | 1 | 92 | –0.05 | 0.530 | 2.06 | –2.59 | 22.8 | 5.4 | 5.4 |
| | 2 | 60 | 0.01 | 0.238 | 0.48 | –1.09 | 8.3 | 5.0 | 1.7 |
| | 3 | 61 | 0.07 | 0.451 | 2.49 | –0.38 | 1.6 | | 3.3 |
| | 4 | 29 | 0.00 | 0.153 | 0.30 | –0.25 | | | |
| | 5 | 17 | 0.11 | 0.644 | 2.54 | –0.36 | | | 5.9 |
| | 7 | 1 | –0.05 | | | –0.05 | | | |
| | | 260 | 0.01 | 0.436 | 2.54 | –2.59 | 10.4 | 3.1 | 3.5 |
| Douglas-fir | 1 | 11 | –0.03 | 0.169 | 0.23 | –0.41 | 18.2 | 18.2 | |
| | 2 | 9 | –0.02 | 0.143 | 0.15 | –0.33 | 11.1 | | |
| | 3 | 15 | 0.00 | 0.198 | 0.46 | –0.28 | 7.4 | | |
| | 4 | 28 | 0.12 | 0.468 | 2.46 | –0.13 | | | 3.6 |
| | 5 | 41 | 0.06 | 0.497 | 2.18 | –1.78 | 2.4 | 4.9 | |
| | 6 | 24 | 0.00 | 0.822 | 2.72 | –2.74 | | 8.3 | |
| | 7 | 32 | 0.00 | 0.598 | 2.49 | –1.14 | | 3.1 | |
| | | 160 | 0.03 | 0.525 | 2.72 | –2.74 | 3.1 | 4.4 | 0.6 |
| Spruce | 1 | 11 | 0.00 | 0.222 | 0.43 | –0.30 | 54.5 | | 9.1 |
| | 2 | 17 | –0.04 | 0.225 | 0.30 | –0.46 | 17.6 | 5.9 | |
| | 3 | 26 | –0.01 | 0.151 | 0.30 | –0.38 | 3.8 | | |
| | 4 | 17 | 0.33 | 0.868 | 2.59 | –0.33 | | | 11.8 |
| | 5 | 18 | –0.18 | 0.547 | 0.30 | –1.85 | | 11.1 | |
| | 6 | 15 | –0.30 | 0.669 | 0.23 | –2.41 | | 6.7 | |
| | 7 | 9 | 0.40 | 0.976 | 2.66 | –0.43 | | 11.1 | |
| | | 113 | 0.00 | 0.584 | 2.66 | –2.41 | 8.8 | 4.4 | 2.7 |
| Western larch | 1 | 10 | –0.09 | 0.133 | 0.05 | –0.36 | | 10.0 | |
| | 2 | 15 | 0.09* | 0.106 | 0.28 | –0.05 | 6.7 | | |
| | 3 | 31 | 0.00 | 0.124 | 0.20 | –0.30 | | | |
| | 4 | 12 | 0.04 | 0.123 | 0.25 | –0.10 | | | |
| | 5 | 3 | –0.01 | 0.330 | 0.33 | –0.33 | | | |
| | 6 | 5 | 0.11 | 0.140 | 0.23 | –0.10 | | | |
| | 7 | 28 | –0.07 | 0.701 | 0.69 | –3.35 | | 3.6 | |
| | | 104 | 0.00 | 0.380 | 0.69 | –3.35 | 1.0 | 2.0 | |
| Grand total | | 730 | 0.00 | 0.471 | 2.72 | –3.35 | 7.1 | 3.0 | 1.9 |

NOTE: Grand total also includes 15 western white pines, 22 western hemlocks, 10 lodgepole pines, and 46 paper birches.

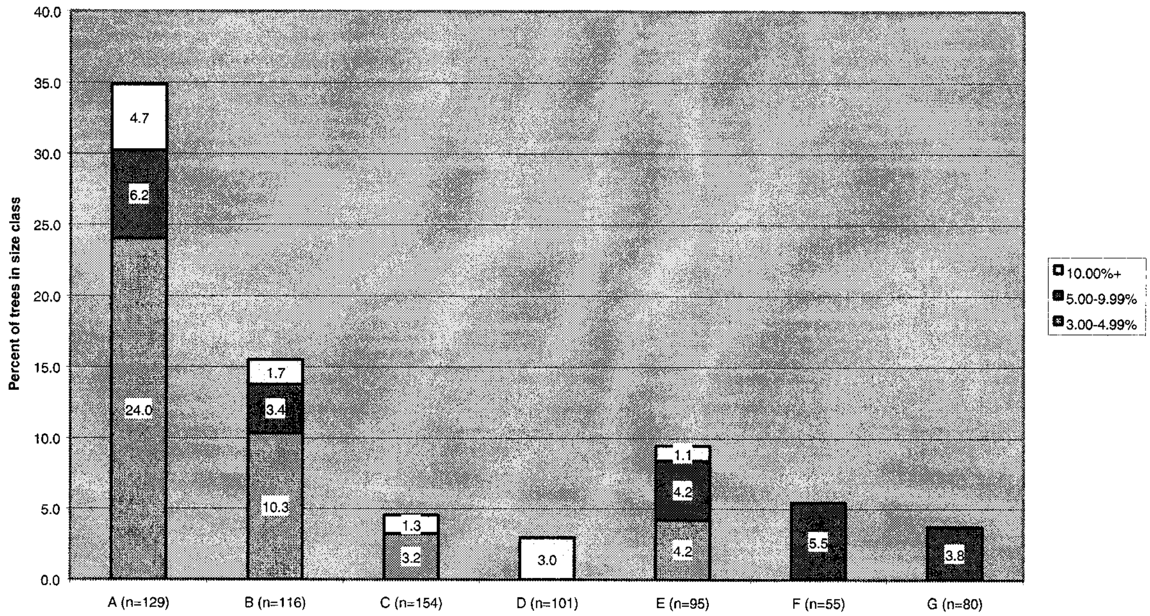


**Figure 1. Difference in dbh measurement (expressed as a percentage of tree diameter) determined by two observers summarized for all species of living trees. The difference in dbh measurement is given in the percentage of trees within a given size class with one of three levels of error (10.00%+, 5.00–9.99%, and 3.00–4.99%). Tree size classes are: A, <7.00 cm dbh; B, 7.00–9.99 cm; C, 10.00–14.99 cm; D, 15.00–19.99 cm; E, 20.00–29.99 cm; F, 30.00–39.99 cm; G, >40 cm.**

many studies because both workers were highly skilled and experienced and were motivated to make careful measurements because of personal interest in the study.

## Literature Cited


Elzinga, C.L. 2001. Results of 15 years of monitoring in the Coram Research Natural Area, Montana. USDA For. Serv. unpublished rep., Forestry Sciences Laboratory, Missoula, MT.

Elzinga, C.L., and R.C. Shearer. 1997. Vegetation structure in old-growth stands in the Coram Research Natural Area in northwestern Montana. USDA For. Serv. Gen. Tech. Rep. INT-GTR-364. 22 p.

Eyre, F.H. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC. 148 p.

Farnes, P.E., R.C. Shearer, and K.J. Hansen. 1995. Hydrologic and precipitation characterization of Coram Experimental Forest, Montana. USDA For. Serv. Final Rep. RJVA-INT-92734. 19 p.

Habeck, J.R., and T.W. Weaver. 1969. A chemosystematic analysis of some hybrid spruce (*Picea*) populations in Montana. Can. J. Bot. 47(10):1565–1570.

Johnson, J.E., and C.L. Haag. 1985. Reliability of height and diameter remeasurements on red pine (*Pinus resinosa* Ait.) seedlings. Tree Planters' Notes 36(2):27–29.

McRoberts, R.E., J.T. Hahn, G.J. Hefty, and J.R. Van Cleve. 1994. Variation in forest inventory field measurements. Can. J. For. Res. 24:1766–1770.

Myers, C.A. 1961. Variation in measuring diameter at breast height of mature ponderosa pine. USDA For. Serv., Rocky Mountain Forest and Range Experiment Station. Research Note 67. 3 p.

Nester, M.R. 1981. Assessment and measurement errors in slash pine research plots. Department of Forestry, Queensland. Technical Paper 26. 10 p.

Pfister, R.D., B.L. Kovalchik, S.F. Arno, and R.C. Presby. 1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34. 174 p.

Shearer, R.C., and M.M. Kempf. 1999. Coram Experimental Forest: 50 years of research in a western larch forest. USDA For. Serv. Gen. Tech. Rep. RMRS GTR-37. 66 p.

Sneck, K.M. Davis. 1977. The fire history of Coram Experimental Forest. M.S. thesis, University of Montana, Missoula, MT. 134 pp.

SPSS, Inc. 1997. SYSTAT 7.0 for Windows. Chicago, IL. Available online at www.fs.fed.us/rm/ogden/manual/pdf/manual_2001_annual.pdf; accessed Nov. 15, 2001.

Western Regional Climatic Center. 2002a. Hungry Horse Dam (244328), Montana, monthly total precipitation (inches). Available online at www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?mthung; accessed Sept. 16, 2002.

Western Regional Climatic Center. 2002b. Hungry Horse Dam (244328), Montana, monthly average maximum temperature (º F). Available online at www.wrcc.dri.edu/cgi-bin/cliMONtmxt.pl?mthung; accessed Sept. 16, 2002.

Western Regional Climatic Center. 2002c. Hungry Horse Dam (244328), Montana, monthly average temperature (º F). Available online at www.wrcc.dri.edu/cgi-bin/cliMONtavt.pl?mthung; accessed Sept. 16, 2002.

Young, R.A., and R.L. Giese. 1990. Introduction to Forest Science, 2nd Ed. John Wiley & Sons, New York, NY. 586 p.