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A photographic technique for use with stem analysis

by

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Abstract

A method for photographing and digitizing radial growth on section rounds from destructively sampled trees for stem analysis was developed and compared in accuracy against hand measurements on those same rounds. Results indicated a high degree of correlation between photographic values and hand values when recording radial growth and total number of rings. Relative merits of this procedure are discussed.

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Introduction

Traditionally whole tree stem analysis has been carried out either to develop a height over age relationship for site quality evaluation (cf. see Curtis, 1964; Monserud, 1975) or to develop growth data essential in situations where extensive remeasurements of permanent plots are not available (see Herman et al, 1975; Turnbull, 1958).

While the most accurate and direct way of investigating the development of a tree is by means of stem analysis (Prodran 1951), it requires intensive labor and is quite expensive. As early as 1926 Reineke introduced a planimeter method to aid in reducing the work of volume determination in the field. Other cost cutting methods include paper rubbings to take ring impressions on paper by application of graphite (Douglass, 1919), or use of plastic overlays to record ring count and growth. Herman et al (1975) selected a representative radius from a transverse section cut for latter laboratory processing. These methods all attempt to reduce the amount of time necessary to take field measurements or to reduce the bulk of material to be transported from the field to the laboratory. To be effective any alternative field procedure must still permit the accurate count of the total number of rings and capture the requisite growth information on section rounds. This paper presents an alternative method of recording the data from tree section rounds based upon photographing section rounds and digitizing the ring locations from the resulting photographs.

Methods and Materials

Data available for this study were from an ongoing cooperative growth and yield project in the mixed conifer region of California combining the efforts of twelve private industry cooperators and the University of California-Berkeley. As part of the overall study trees on thirty clusters of three one-fifth acre plots each and eight clusters of two one-tenth acre plots each were located in Northern California for a stem analysis project. Approximately thirty trees were felled per cluster for a total of more than one thousand trees.

A uniform field procedure was selected to allow for consistent and accurate measurements and simplicity in application by all companies.[1/] Using this procedure, each tree selected for stem analysis was felled and section rounds (1-2" thick) were taken at stump height (1.5'), breast height, and at subsequent log intervals (16.5' or 20.5'). Each section was tagged and photographs were taken for use in further laboratory analysis.

Section Preparation

Each cross-section was tagged and cross-lines were drawn in North-South and East-West directions with a lumber crayon or a felt tip marker. An arrow was drawn to indicate the North direction. A ruler was included in each photo to indicate the scale of the photograph (See Figure 1). Subsequent processing consisted of two components: (A) the section rounds were photographed and (B) the photographic transparencies

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[1/] Initial field testing of procedures was completed by Champion Paper Company in the winter of 1979/80.

were digitized to record the ring widths on magnetic tape for computer analysis.

A. Photographic Procedures

The photographic procedures were designed to maximize the resolution of the photo and the contrast between spring wood and summer wood, while holding costs to a minimum. The film selected for use was Ektachrome ASA 64, a readily available, high-contrast 35mm color film. To further heighten the ring boundary contrasts, photos were taken in direct sunlight whenever possible. To maintain resolution the minimum shutter speed used when the camera was hand-held was $1/250^{th}$ second ($1/60^{th}$ second if the camera was mounted on a tripod). To maintain a minimum depth of field the minimum f-stop was 5.6; the recommended f-stop was 8.0 (or higher). The type of camera used varied among cooperators.

The relationship between distance from the camera to the section and the width of the annual rings was found to be a major factor in the resolution of the rings in the photo. Photos were taken from various heights above sections from test trees felled on the University's Blodgett Experimental Forest. To determine the maximum distance that the camera should be from the round, photos were taken at several distances for rounds with varying numbers of rings per inch. This showed that the maximum distance at which rings could be distinguished conformed to the following relationship:

$$\begin{pmatrix}\text{Maximum camera}\\ \text{distance (feet)}\end{pmatrix} = 10 \times \begin{pmatrix}\text{Minimum 5 year}\\ \text{increment (inches)}\end{pmatrix}$$

For example, if the minimum 5 year increment to be photographed was .25 inches, the maximum height of the camera over the section would be 2.5 feet.

Because of variations in saw sharpness and the handling of the rounds prior to the photography, photographers were advised to check the resolution in the view finder and to reduce the distance if necessary.

Depending on the diameter of the sections and the width of the annual rings, one photo may not include the entire section. Provisions for dividing a section into two or more photos were devised (refer to figure 1). A common reference point, marked on the previously drawn cross lines, was included in every pair of photos. Photographs were taken from appropriate heights depending on the area of the section to be covered in the photo and the width of the annual rings in the area. Finally a photo of the entire section was taken to help piece the larger scale photos together.

B. Digitizing

The total number of rings and yearly radial increments were measured and recorded using the digitizing function of a scanning microdensitometer built by the Space Sciences Laboratory at the University of California-Berkeley. This machine is capable of manually or automatically scanning photographic transparencies (up to a 4" square image) and has a geometric resolution of 0.0005 inches. The unit includes an automatic 35mm film advance mechanism for transporting the film across the scanning stage. Output from the microdensitometer is to a 9-track 800 bits per inch magnetic tape drive for subsequent data processing.

In this procedure a photographic frame is projected onto a screen at a scale of about 20X. A cursor is used to locate points along a straight line from the pith to the outer edge of the round for each annual ring. The cartesian coordinates of these points are then recorded on magnetic tape. In addition, two points along the scale, seen in the photo, are used to determine photo scale. This effectively avoids taking photographs at fixed distances as used in a similar procedure by Thies and Harvey (1979) in estimating area of defect on rounds.

Comparison with Hand measurement

A. Selection of test rounds

Seventy breast height sections were selected for analysis of the accuracy of the photographic interpretation techniques. Six classes were formed to test for differences in ability to delineate annual rings dependent upon species and rate of radial growth. These six species growth rate classes are given in Table 1. The species tested include ponderosa pine (*Pinus ponderosa*), Douglas Fir (*Psuedotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl. (Iowiana [Gord.])), red fir (*Abies magnifica* A. Murr.), sugar pine (*Pinus lambertina* Dougl.) and incense cedar (*Libocedrus decurrens* Torr.).

Species Classes

Table 1. Number of rounds by species and growth classes.

Growth Rate	Firs (white,red,Douglas)	Pines (ponderosa,jeffrey,sugar)	Incense cedar
Slow[1/]	15	15	10
Fast[2/]	15	15	-

[1/] If any of the six most current five year radial increments were between 0.15 and 0.5 inches the round was classified as slow growing.

[2/] If all of the six most current five year radial increments were greater than 0.5 inches the round was classified as fast growing.

Because of the paucity of incense cedar rounds growing radially more than 0.5" in five years this class was dropped from consideration. As sections became available in the stem analysis project they were chosen to fill the remaining 5 classes (see Table 1). The photo positive transparencies were then visually scanned to ensure that they could be digitized, i.e. the rings were visible and distinct in at least one quadrant of the photograph delineated every 45° from north (see figure 2).

B. Hand measurements

DBH sections selected for this study were measured in one quadrant of the round of several typically identified as being suitable for digitizing (see figure 2). In the quadrant selected, the disk was sanded

using a hand-held disk sander primarily to remove mold and debris. The total number of rings were counted and recorded. Additionally, five year radial increments (RI_5, RI_{10},..., RI_{30})[1/] inside bark were measured to the nearest one-fiftieth of an inch and recorded.

C. Test Procedures

Two sets of measurements were taken -- total number of rings and current five year radial increment for the last six five-year periods. Tests were undertaken to compare the tree ages and radial increments using the hand and photographic methods. If both methods produce the same or similar results we can conclude that both are accurate. If there are significant differences we will hold that the hand measurements are the standard by which to judge the accuracy of the photographic technique. However, the effort expended on obtaining hand measurements is far too great to allow us to measure all rounds in this way.

Analysis

Analysis of the data was undertaken to assess the accuracy of the photographic procedures as compared with the hand measurements on the same rounds. If both methods prove accurate we would expect that a line representing the relationship between these two measurements would have an intercept (b_0) of zero and a slope (b_1) of one. Subsequently it will be tested whether the regressions can be considered to be through the origin with slope coefficient near one. Since the quality of digitizing

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[1/] Radial increment is denoted RI. Radial increment between the current year and five years prior is denoted RI_5, similarly RI_{30} denotes the five year radial increment between years 26 and 30.

and hence accuracy may depend upon species and growth classes tests will be undertaken to examine whether the regressions are different for the classes presented in Table 1.

A. Total number of rings To investigate whether or not the regression model relating photo to hand measurements for total number of tree rings goes through the origin two models were postulated:

$$HA_{ij} = b_{oj} + b_{1j} PA_{ij} + e_{ij} \qquad (1a)$$

$$HA_{ij} = b_{1j} PA_{ij} + e_{ij} \qquad (1b)$$

where HA_{ij} is the age as measured by hand for the ith section and jth class

PA_{ij} is the age as measured by photographic techniques for the ith section and the jth class.

To test the significance of the classes in Table 1, Models (1a and 1b) were compared against the following models:

$$HA_i = b_o + b_1 PA_i + e_i \qquad (1c)$$

$$HA_i = b_1 PA_i + e_i \qquad (1d)$$

where HA and PA are defined as in model (1a) except all classes are combined

If both methods are accurate we would expect an intercept (b_o) of zero and a slope (b_1) of one. Regressions for model (1a and 1c) were performed and the hypothesis that b_o was equal to zero was tested for both models. For all groups, excluding slow growing firs (Model 1a), we could not reject the hypothesis (at $\alpha = 0.05$) that b_o was equal to zero. For slow growing firs b_o was computed as 5.83 (S.E = 2.08). Even though

b_o is significant for this group the ages of the rounds were 47 to 83 years. Thus when extrapolating to the origin it is not unexpected that b_1 may not be zero since the sample for this group included no trees at young ages. This test was repeated for model (1c). Similarly for all classes we could not reject the hypothesis that b_o was equal to zero. Thus the models (1a and 1c) were refit while constraining them to go through the origin (Model 1b and 1d). The resulting coefficients and fit statistics are given in table 2a. The coefficients (b_1) in table 2a for each class were all near one with each being greater than 0.97, but less than 1.00. Therefore it appeared that the ability to count number of rings was the same for all classes. Hence a test was formulated to investigate whether the regression coefficients for the individual classes (Model 1b) were significantly different from one another. Table 2b provides the values for the computed F. Based upon the sample data we could not reject the hypothesis at $\alpha = 0.05$ of equality of regression[1,2/] Thus there is no evidence to indicate that there was differential ability in counting total number of rings based upon the designated species and growth classes. Therefore as judged overall or by individual classes total number of rings measured by hand correlated quite highly with the number of rings discerned via photographic techniques. Additionally, all standard errors of regression were less than 2 years with the exception of incense cedar. For the combined model the standard error of regression was 1.7 years and coefficient of variation of 3

1/ See, eg., J. Johnson, Econometric Methods (New York: McGraw-Hill, 1963) pp. 192-207.

2/ The power of the F-test was greater than .95 for this and all subsequent F-tests.

percent. Thus for every 2 of 3 measurements we can except an accuracy of within 3 years for 100 rings.

B. Five year radial growth As for the total number of rings, a simple linear regression model was postulated and run for each of the five classes to associate hand measured five year radial increment values with those measured using photographic techniques. First, however, hand measures required a correction factor to account for shrinkage since sections were not stored under controlled conditions. MacLean (1945) showed that shrinkage of section rounds is due to only radial shrinkage if checking is disregarded. In essence the diameter after seasoning (D_a) is equal to diameter before seasoning (D_b) times a correction factor. This correction factor is: $1-P_r(1 - M/30)$ where P_r is the unit radial shrinkage for a species and M is the moisture content to which wood is seasoned.

Thus $D_a = D_b\ (1-P_r(1-M/30))$

and hence $D_b = D_a\ (1-P_r(1-M/30))^{-1}$

Values for P_r, which are species dependent, are compiled from MacLean (1945) and presented in Table 3. The postulated regression models for growth were:

$$HG_{ij}^{(c)} = b_{oj} + b_{1j}PG_{ij} + e_{ij} \qquad (2a)$$

$$HG_{ij}^{(c)} = b_{1j}\ PG_{ij} + e_{ij} \qquad (2b)$$

where $HG_{ij}^{(c)}$ is the 5 year radial growth as measured by hand and corrected for shrinkage for the ith section and jth class

PG_{ij} is the 5 year radial growth as measured by photographic techniques for the ith section and jth class

$$HG_i^{(c)} = b_o + b_1 PG_i + e_i \qquad (2c)$$

$$HG_i^{(c)} = b_1 \; PG_i + e_i \qquad (2d)$$

where $HG^{(c)}$ and PG are defined as in model (2a) except that all classes are combined

As for total number of rings if this method of measuring growth is accurate we would expect an intercept (b_o) of zero and a slope (b_1) of one. Regressions for model (2a and 2c) were performed and the hypothesis that b_o was equal to zero was tested for both models. For all groups (Model 2a) we could not reject the hypothesis (at $\alpha = 0.05$) that b_o was equal to zero. This test was repeated for model 2c in which all classes are combined. Similarly we could not reject the hypothesis that b_o was not different from zero. Thus the models (2a and 2c) were refit while constraining them to go through the origin (Models 2b and 2d). The resulting coefficients and fit statistics are given in table 4a. The coefficients in table 4a for each class were all near one with each being between 0.97 and 0.98 except for slow growing pines which had a slope coefficient of 1.01. Therefore as was found for total number of rings it appeared that there was an essentially equal ability to measure radial growth among all five classes. To test this hypothesis an analysis of covariance was undertaken and Table 4b provides the values of the computed F. Based upon the sample data we could not reject the hypothesis of equality of regressions at $\alpha = 0.05$. This demonstrates an

equal ability to digitize annual rings for growth between the five classes. Thus we conclude that the five year radial increments were measured equally well by hand as those measured by photographic techniques. Also, all standard errors of regression were less than 0.125 inches. The standard error of regression for the combined model was less than 0.10 inches which corresponded to a value of 15% of the mean 5 year growth of 0.658 inches.

Evaluation of the digitizing system

The analysis of number of rings and growth indicated that there was a high degree of correlation between photographic and hand measurement techniques and that the photographic technique is essentially unbiased. To evaluate its accuracy several comparisons can be made. One comparison is of the photographic techniques against repeated hand measurements on sanded disks which represents the best alternative laboratory procedure. Another comparison is against the accuracy of repeated hand measurements on unsanded disks which more closely approximates the original field conditions under which measurements can be taken.

A. Repeated measurements on sanded disks

Forty disks were selected for hand measurements to be taken by two separate technicians in the same 45° quadrant (see figure 2) from north on sanded disks. A simple linear regression was postulated for each species and growth class to relate total number of rings as measured by one technician to total number of rings as recorded by the second technician. Next the regression was run with all classes combined. Similarly regression models were postulated for radial growth. (For model form see equations 1a, 1b, 2a and 2b.) As in the prior investigation an

analysis of covariance was undertaken to test the hypothesis of equality of regressions for both total number of rings and radial growth for each of the five growth and species classes. As previously, no evidence existed to reject the hypothesis of equality of regressions at $\alpha = 0.05$. The regression coefficients and fit statistics are presented in Tables 5a and 5b only for the model with all classes combined. For the regression of total number of rings the standard error of regression was 0.57 years. This compares with a standard error of 1.71 years obtained when number of rings via hand measurements is regressed upon number of rings via photographic techniques. While larger, the standard error for the photographic technique represents a coefficient of variation of only 3 percent. Thus no further analysis of ring counts was made.

For the regression of radial increment on repeated measurements of sanded rounds (increment measured by one observer as a function of increment measured by another observer) the standard error of regression was 0.055 inches with a coefficient of variation of 8%. This compares with a standard error of regression of 0.099 inches and a coefficient of variation of 15% for the regression of radial increment as measured by hand on radial increment as measured photographically. This indicates that under ideal circumstances, i.e. having a sanded disk to measure, one could expect a standard error of regression roughly one-half as large as that obtained using photographic techniques.

B. Repeated measurements on unsanded disks

To approximate field conditions forty recently cut disks were hand measured for radial increment by two independent observers in the same 45° quadrant (see figure 2). Disks were brushed to remove debris but

were not sanded. As in model 2b, a simple linear regression model for all species and growth classes combined was postulated to correlate radial growth as measured by one technician to radial growth as measured by the second technician. Regression coefficients and fit statistics are presented in Table 5c for radial increment for all classes combined. The standard error of the regression was 0.082 inches with a coefficient of variation of 22.8 percent. This result is quite similar to that obtained via digitizing techniques ($S_{y.x}$ = 0.099; CV = 15%). One would expect, however, that a value of 0.082 inches would underestimate the standard error obtainable in the field since in this laboratory test lighting and other factors were favorably controlled.

Results and Conclusions

A technique for photographing and digitizing section rounds was presented as an alternative to traditional field measurement techniques for stem analysis procedures. Five categories of species groups and growth classes were analyzed for accuracy of measurement of five year radial increments and total number of rings. Results showed that there was essentially an equal accuracy and precision for digitizing annual growth and counting rings in all five classes considered.

Total number of rings was accurately estimated by both digitizing techniques and by hand measurements under laboratory conditions. The standard errors of regression were 1.7 and 0.6 years, respectively. This represents a coefficient of variation of 3 percent or less which is adequate for most applications.

The digitized values for 5 year radial increments were correlated with values achieved by sanding and measuring test rounds. A simple linear model was fitted to predict hand measured values as a function of digitized values. The resulting standard error of regression was 0.099 inches. This is considerably larger than can be obtained with repeated hand measures on sanded rounds for which a standard error of regression of 0.055 inches was obtained. However, in an attempt to more closely approximate field conditions repeated measurements on unsanded rounds were taken with a resulting standard error of estimate of 0.082 inches. In probability this underestimates the standard error that would be obtained under actual field conditions. Thus the digitizing procedure produces 5 year radial increment values similar in precision to those that could be obtained via field measurement techniques.

Ancillary benefits include dramatic reductions in the time for field data collection, elimination of bulk transfer of wood to the laboratory and associated problems of shrinkage and molding. Too, the photographic transparencies provide a long term record that is readily accessed should the section require reanalysis.

Drawbacks, however, of this procedure include requisite access to a digitizer and accompanying computer software. Additionally, high resolution photographs are necessary to delineate springwood and summerwood borders. Thus rounds need to be retained until the film is developed and inspected for quality of image to determine whether rephotographing is mandated. Should a section need rephotographing it may require sanding to remove mold and to improve the photographic image. None-the-less, this method provides a viable alternative to the extensive time

required to undertake field measurements of number of rings and radial growth in traditional stem analysis while providing the same data precision.

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Thies, Walter G. and Robert D. Harvey, Jr. 1979. A photographic method for measuring tree defect. Can. Jour. For. Res. 9(4):541-543.

Turnbull, Kenneth J. 1958. Stem analysis techniques and applications, and some studies of second-growth Douglas fir in western Washington. Unpub. M.F. thesis, Univ. Washington.

Figure 1. Labelling a section for photographing

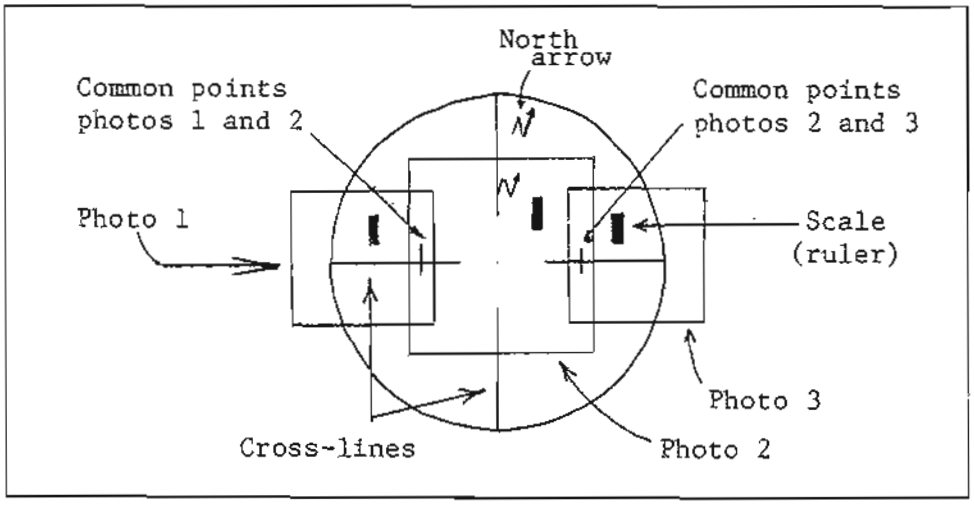

Figure 2. Delineation of quadrant in which the photograph was digitized

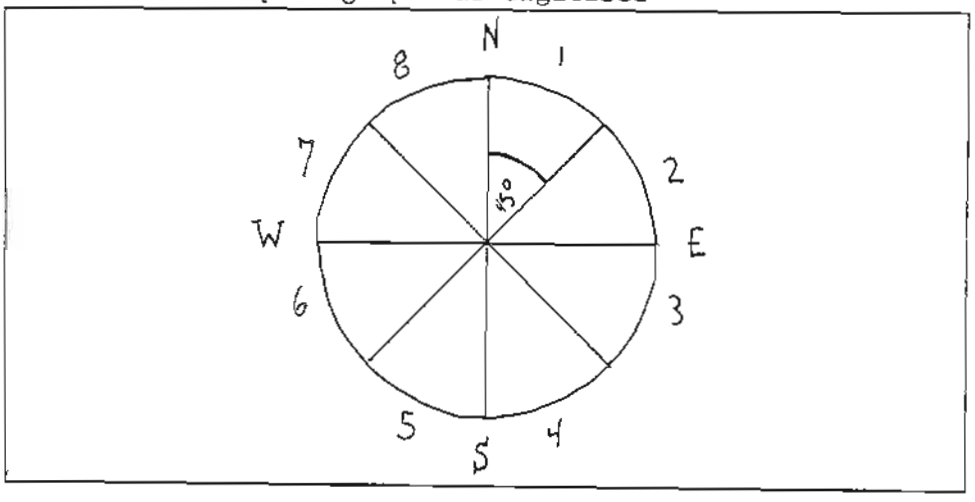

Table 2a. Number of rings regression. Model [1a]

	Pines		Firs		Cedar	All Classes
	slow	rapid	slow	rapid	slow	Combined
b_1	.996	.979	.990	.981	.983	.986
$S_{y.x}$	1.945	1.536	1.253	1.317	2.627	1.71
R^2	.987	.983	.973	.980	.989	.986
$\bar{y}$ 1/	63.467	60.200	62.293	55.667	53.600	59.571
range in y	26-90	39-86	47-83	34-68	23-99	23-99
S_y	17.365	11.779	7.669	9.348	25.110	14.682
CV 2/	3	3	2	2	5	3
n 3/	15	15	15	15	10	70

1/ $\bar{y} = \overline{HA}$ = average age as measured by hand

2/ $CV = (S_{y.x}/\bar{y}) \times 100$

3/ Number of rounds in sample

Table 2b. Analysis of Covariance for Model [1b] and Model [1d].

	Pines		Firs		Cedar	All Classes
	slow	rapid	slow	rapid	slow	Combined
residual sum of squares	52.978	33.025	21.981	24.299	62.090	207.079
Total residual SS pines, firs, cedar	194.373					

$$F = \frac{(207.079 - 194.373)/K(p-1)}{194.373/N-Kp} = \frac{12.706/8}{194.373/60} = .490$$

where $N = 70$ = total number of observations

$K = 2$ = number of parameters in model

$p = 5$ = number of classes

$F(8,60,.950) = 2.10$

Table 3. Unit radial shrinkage values.

Species	P_r	M[1/]
Ponderosa pine	0.039	14
Sugar pine	0.029	14
White fir	0.032	14
Douglas fir	0.050	14
Incense cedar	0.033	14

[1/] Average value of moisture content level at storage facilities of the Forest Products Laboratory, Richmond, California in 1981.

Table 4a. Growth regression modell [2b and 2d] coefficients and fit statistics.

	Pines		Firs		Cedar	All Classes
	slow	rapid	slow	rapid	slow	Combined
b_1	0.9720	0.9706	1.011	0.9703	0.9772	0.9759
$S_{y.x}$	0.106	0.123	0.064	0.116	0.056	0.099
R^2	0.738	0.801	0.903	0.863	0.807	0.900
$\bar{y}$ 1/	0.5049	0.8737	0.5341	0.8969	0.8886	0.6579
range y	.16-1.29	.39-1.60	.22-1.17	.34-2.22	.11-.63	.11-2.22
S_y	0.2077	0.2750	0.2051	0.3130	0.1284	0.3143
CV 2/	21.	14.	12.	13.	15.	15.
n	89.	90.	90.	90.	59.	418.

1/ $\bar{y} = \overline{HG}$ = average five year radial growth as measured by hand

2/ $CV = (S_{y.x}/\bar{y}) \times 100$

Table 4b. Analyses of covariance for model [2a] and model [2b].

	Pines		Firs		Cedar	All Classes
	slow	rapid	slow	rapid	slow	Combined
residual sums of squares	0.9914	1.3387	0.3644	1.1949	0.1846	4.11407
total residual SS pines, firs, cedar	4.0740					

$$F = \frac{(4.11407-4.0740)/K(p-1)}{4.11407/N-Kp} = \frac{.071/8}{4.062/408} = 0.890$$

$F(8,408,.950) = 1.96$

where $N = 418$ = total number of observations

$K = 2$ = number of parameters in the model

$p = 5$ = number of classes

Table 5. a,b,c. Regression coefficients and fit statistics for all classes combined.

	5a	5b	5c
	Number of rings- Sanded disks	Growth- Sanded disks	Growth- Unsanded disks
b_o	0.1752	0.0007	0.00684
b_1	0.9978	0.9882	1.01400
$S_{y.x}$	0.5663	0.0553	0.082
R^2	0.9982	0.9732	0.910
$\bar{y}$	57.2564 1/	0.6759 2/	0.3606 3/
S_y	13.2143	0.3375	0.2740
cv 4/	1.0	8.2	22.8
n	39	233	240

1/ $\bar{y} = \Sigma y_i^{(1)}/n$ where $y_i^{(1)}$ = number of rings on 1st hand measurement for round i

2/ $\bar{y} = \Sigma y_i^{(1)}/n$ where $y_i^{(1)}$ = 5 year radial growth on 1st hand measurement for round i

3/ $\bar{y}$ is as defined in 2/

4/ $CV = (S_{y.x}/\bar{y}) \times 100$