#15



# ANALYSIS AND EVALUATION OF THE SOURCES OF VARIATION IN TREE-RINGS FROM MESA VERDE NATIONAL PARK[1]

Harold C. Fritts and David G. Smith
Laboratory of Tree-Ring Research
The University of Arizona

(Progress Report)

The study of tree-ring series, called dendrochronology, was originally conceived by A. E. Douglass as a tool for studying sun-spot cycles. He developed a system of cross-dating which provided for the accurate age determination of rings and this made possible the precise dating of archaeological sites. More recently Edmund Schulman used the width measurements of dated tree-rings as estimates of past climatic and stream-flow patterns. Such applications appeared to have greater precision when the tree-ring samples came from so called "sensitive sites" (i.e., well-drained ridges or exposed slopes). The present study is the first of a series designed to further assess the effect of site and to provide an estimate of the relative magnitude of each of the sources of variation. The study is supported by the National Geographic Society, Wetherill Mesa Project at Mesa Verde National Park.

## Methods

The data for the study were obtained through a designed sampling from 4 microenvironments at Mesa Verde National Park: one located on Chapin Mesa (M2) and the others in Navajo Canyon (C1, C2, C3). The sites are located in an area 3/4 mile wide in the south central portion of the park. The canyon sites were in an area 1/4 mile wide east of the mesa station. Four cores were obtained from each of 5 trees per site. The trees were superficially selected for uniform age, crown form, and competition. The M2 sample consists of pinyon

---

[1]Presented at the annual meeting of the American Institute of Biological Sciences, Corvallis, Oregon, August 30, 1962.

pine (Pinus edulis Engelm.) averaging 227 years while C1 and C3 are canyon-side pinyon pines averaging approximately 180 years and growing on opposing southwest and northeast - facing slopes respectively. All 3 sampled communities are pinyon-juniper stands although juniper (mainly Juniperus osteosperma (Torr.) Little) is less abundant in the canyon areas. Five Douglas fir (Pseudotsuga taxitolia (Poir.) Britt.) averaging 264 years were selected from the west-facing slope of a tributary of Navajo Canyon (C2). This species is generally restricted to only the most protected canyon sites and is often associated with pinyon pine and occasionally juniper.

Each core was selected from cardinal compass directions and its up, down, or side slope orientation in the tree noted. The cores were mounted, dried, and cross dated with the Mesa Verde master chronology. Each ring width was measured to the nearest 0.01 mm for the years 1855-1960. Each series of 106 ring widths was converted to index values which objectively remove the growth function. This computation involves fitting the relation of the logarithm of the tree-ring width on year number with a least squares line having a negative or zero slope. An equation was thus obtained of the form $y = ae^{-bt}$ where y is the growth function with constant a and coefficient b which is a function of the year number in each series. The constant a was chosen so that the area under the curve is equal to the sum of the ring widths. The tree-ring index was defined as the quotient of ring width/ y and the result is a series with a mean of 1.00 and a variance which is independent of time. Additional parameters are calculated for each core, each tree and each group; and the sums and sums of squares are recorded to be used in further analysis. Some of these data are given in Table 1.

## Results

The average ring width for pinyon pine is less than the average for Douglas fir (Table 1). The pine from the southwest-facing site exhibits

Table 1. Averaged Tree-Ring Parameters for the Four Mesa Verde Sites

| | | Pinyon Pine | | | Douglas Fir |
|---|---|---|---|---|---|
| | NE Facing Slope | | SW Facing Slope | Mesa Top | North Facing Slope |
| | C3 | | C1 | M2 | C2 |
| Mean Age in 1960 | 181 | | 180 | 227 | 264 |
| Mean Ring Width | 0.43 | | 0.38 | 0.40 | 0.67 |
| Mean Square of Indices | 0.26 | | 0.35 | 0.20 | 0.29 |
| Mean Index for 7 Lowest Yrs.[1] | 0.14 | | 0.10 | 0.20 | 0.12[2] |
| "Mean Sensitivity" of Indices | 0.56 | | 0.58 | 0.49 | 0.66 |
| Serial Correlation of Indices | 0.31 | | 0.60 | 0.32 | 0.23 |
| Mean Correlation between Indices within Trees | 0.82 | | 0.77 | 0.78 | 0.91 |
| Mean Correlation between Indices among Trees | 0.79 | | 0.82 | 0.66 | 0.88 |
| Correlation between Indices among Groups | C3 | with | 0.93 | 0.87 | 0.81 |
| | C1 | with | -- | 0.84 | 0.78 |
| | M2 | with | -- | -- | 0.81 |

[1] Lowest for pinyon pine - 1861, 1883, 1899, 1902, 1904, 1934, 1951.

[2] Same years averaged but not the lowest indices for Douglas fir series.

the lowest mean growth while the pine on the north-east facing site has the highest mean growth. The mean square or variance of indices is greatest on the southwest-facing slope and least on the mesa top. The same relationship can be noted in the mean of indices for the seven lowest years where the most variable southwest-facing trees have a mean of 0.10 and the least variable mesa top trees have the highest mean of 0.20.

The first order serial correlation (Table 1) is a parameter of considerable import in quantitative evaluation as it is a measure of the lag effect or average dependence of each year's growth on the growth of the preceding season. Figure 1 illustrates the phenomenon. The upper series is the chronology for the C2 Douglas fir group and the lower an equivalent Douglas fir series from near Flagstaff, Arizona. The serial correlation in the upper series amounts to 0.23 (Table 1) which indicates that only 5% of the total variance may be attributed to lag. In the lower series the serial correlation is 0.66 which indicates that 44% of the variance may be due to lag. The variance component in each series which is not a result of lag amounts to 0.27 for the upper series and 0.06 in the lower. Such differences between related series will effectively lower the cross correlation and reduce the common variance. Likewise, high serial correlation in two related series will increase the apparent cross correlation and common variance.

The chronology for group C1 which exhibited a high variance also had a high serial correlation (Table 1). However, the Douglas fir chronology, with a relatively high variance, exhibited a low serial correlation.

Cross correlations were made among the 4 chronologies within each tree, among the 5 chronologies for trees in groups, and among the chronologies for each group (Table 1). If we assume no serial correlation, the means within and among pine trees can be shown to be significantly different, but with the high

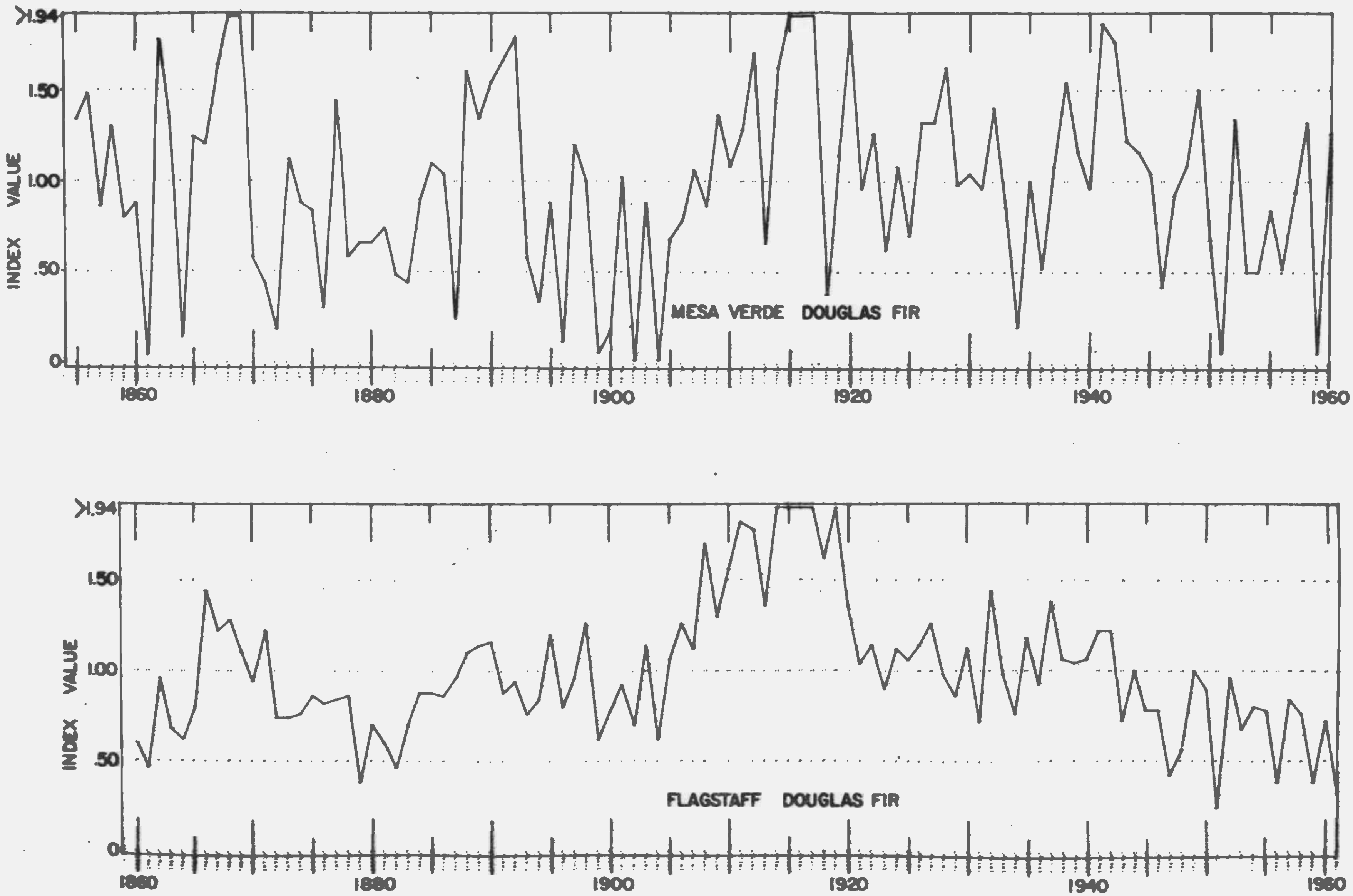


FIGURE 1. Two Douglas fir chronologies representing a serial correlation of 0.23 (Mesa Verde) and 0.66 (Flagstaff).

and variable serial correlation of the series, these means are probably non-significantly different. A notable feature of these data is that the chronologies within and among trees of Douglas fir are more highly correlated than those from pinyon pine. As one might expect the correlation is lowest between the Douglas fir and the highly serially correlated C1 sample. It is also notable that the correlations between Douglas fir and pinyon pine groups are not markedly lower than those between groups of pine.

Analysis of variance is employed to evaluate the sources of sampled variation. The complete variance table for the 3 major analyses is represented in Table 2 while the percent estimated mean squares for all analyses are rearranged and presented in descending order in Table 3. The ratio of mean squares is used for testing, while the estimated mean square (ems) represents the variance component due to each source of variation.

It can be noted from the tables that, except for the analysis of the seven low years, there is not even random variation in the means for groups, trees, and cores, because in computing the indices, all means for each series were forced to unity. The variance due to chronology (Y) and the interactions with groups, trees, and cores are the primary concern in this study.

Perhaps the most significant information in these analyses is that the variance in the average year-to-year chronology (Y) contains as much as 59 percent of the total variability even when Douglas fir is treated as part of the sample. However, when the two highly correlated pinyon pine groups from the canyon are analyzed, the percent estimated mean square due to chronology is 54.6% which may or may not be significantly different from 59%. These two groups however have the greatest difference in variance which reduces that portion of estimated mean square attributed to their common chronology and inflates the portion due to individual cores. In such cases of differing variance the correlation coefficient which is a relative parameter may provide the better estimate of association.

Table 2. Analysis of Variance of Total Sample with Cores Classified as to Compass Direction and Slope

| Source of Variation | PINYON PINE | | | | | | | | PINYON PINE AND DOUGLAS FIR | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 Groups Compass Direction | | | | 2 Groups Canyon Slopes[1] | | | | 4 Groups Compass Direction | | | |
| | df | ms | ems | % ems | df | ms | ems | % ems | df | ms | ems | % ems |
| G = Groups | 2 | .048 | - | - | 1 | .039 | - | - | 3 | .037 | - | - |
| T = Trees in g | 12 | .035 | - | - | 8 | .053 | - | - | 16 | .028 | - | - |
| C = Cores | 3 | .010 | - | - | 3 | .014 | - | - | 3 | .013 | - | - |
| C x G | 6 | .005 | - | - | 3 | .018 | - | - | 9 | .006 | - | - |
| C x T in g | 36 | .012 | - | - | 24 | .008 | - | - | 48 | .009 | - | - |
| Y = Chronology | 105 | 14.792 | .2412 | 58.9 | 105 | 11.689 | .1900 | 54.6 | 105 | 18.932 | .2331 | 58.7 |
| Y x G | 210 | .729 | .0204 | 5.0 | 105 | .515 | .0113 | 3.3 | 315 | 1.008 | .0363 | 9.1 |
| Y x T in g | 1260 | .321 | .0582 | 14.2 | 840 | .288 | .0477 | 13.7 | 1680 | .282 | .0518 | 13.0 |
| Y x C | 315 | .109 | .0014 | 0.3 | 315 | .083 | .0010 | 0.3 | 315 | .092 | .0009 | 0.2 |
| Y x C x G | 630 | .090 | .0004 | 0.1 | 315 | .101 | .0009 | 0.2 | 945 | .076 | .0003 | 0.1 |
| Y x C x T in g | 3780 | .088 | .0880 | 21.5 | 2520 | .097 | .0972 | 27.9 | 5040 | .075 | .0746 | 18.8 |

[1]Group M2 excluded since slope was negligible.

Table 3. The percent estimated mean squares from analyses of tree-ring indices obtained from Mesa Verde National Park (1855-1960)

| Source of Variation | Pinyon Pine Analyses: Three Groups (direction) | Pinyon Pine Analyses: Canyon Groups (slope) | Pinyon Pine Analyses: Years 4 & 9[1] | Pinyon Pine Analyses: Years 2 & 7[2] | Pinyon Pine Analyses: Seven Low Years[3] | Pinyon Pine and Douglas Fir: Four Groups (direction) |
|---|---|---|---|---|---|---|
| Average Chronology | 58.9 | 54.6 | 67.8 | 47.9 | 21.8 | 58.7 |
| Chronologies Among Individual Cores | 21.5 | 27.9 | 16.9 | 26.4 | 23.2 | 18.8 |
| Chronologies Among Individual Trees | 14.2 | 13.7 | 12.2 | 17.7 | 30.5 | 13.0 |
| Chronologies Among Individual Groups | 5.0 | 3.3 | 2.4 | 7.3 | 8.0 | 9.1 |
| Chronology Among Sampled Directions or Slopes[4] | 0.4 | 0.5 | 0.7 | 0.8 | 0.0 | 0.3 |
| Average of trees | 0.0 | 0.0 | 0.0 | 0.0 | 12.9 | 0.0 |
| Average of groups | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 0.0 |
| Average of Cores | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cores x Trees | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 |
| Cores x Groups | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 |

[1]Mean index = 0.87
[2]Mean index = 1.15
[3]Mean index = 0.15
[4]Represents both Y x C and Y x C x G from Table 2.

While 59% variance is in the average chronology of all samples, only 18.8 to 21.5% of the variance is due to differences among the four radii of each tree (YxCxT in g). The percent variance due to differences between trees ranked next (13.0 to 14.2%), and in the case of pine only 3.3 to 5.0% was due to differences in groups. However when Douglas fir was added, the group percent estimated mean square increased to 9.1. No significant differences in chronologies can be attributed to the compass direction or slope orientation of the sampled radii.

An analysis was made of the seven low years in the pinyon pine groups (Table 3). The variance of this sample is only 0.04 and since all seven years represent low values in the common chronology, its estimated mean square is small. The greatest variation during these years appears to lie in differences in means and chronologies for the different trees but not for the different groups.

Further analyses were made by systematically dividing the total pinyon pine sample into subsamples using the years ending in 4 and 9 as one group and years ending in 2 and 7 in another. The major difference that can be noted is that there is a greater proportion of estimated mean square in the common chronology of the former than the latter. Further examination showed that the former subsample has a mean index of 0.87 while the latter has a mean of 1.15 which suggests a direct relationship between the mean and variance of the yearly indices. Correlations were then made between the yearly mean indices and the yearly variance and standard deviation of each pine sample. In all cases the correlations between the means and standard deviations were higher than between the means and variances. Data for the correlations and regressions of average index and standard deviation are presented in Table 4, while a plot of the regression for the total sample is reproduced in Figure 2. A significant and consistent relationship is evident. As the mean of the indices becomes greater,

Table 4. Correlations and regressions for standard deviation as a function of the mean index per year in the pinyon pine samples.

| Sample | Correlation | Regression Coefficient | Constant | Mean Y (Standard Deviation) | Mean X (Average Index) | Number of Observations Per Year |
|---|---|---|---|---|---|---|
| M2 | 0.667 | 0.212 | 0.135 | 0.347 | 0.999 | 20 |
| C1 | 0.846 | 0.235 | 0.124 | 0.356 | 0.990 | 20 |
| C3 | 0.667 | 0.155 | 0.167 | 0.321 | 0.998 | 20 |
| Total | 0.863 | 0.218 | 0.159 | 0.376 | 0.995 | 60 |

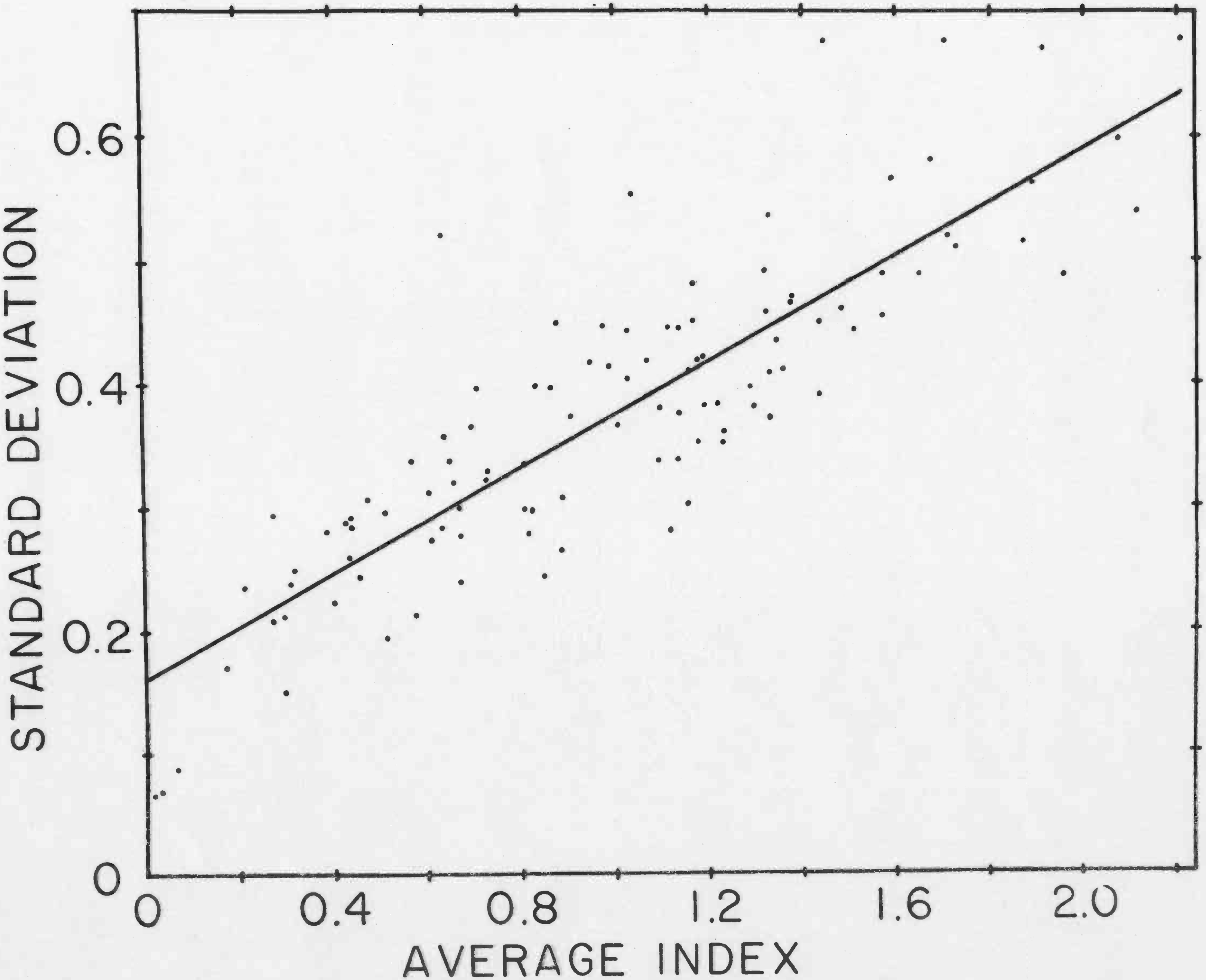


FIGURE 2. The relation between the mean of the yearly indices and their standard deviation for the 15 pinyon pine trees (60 cores) from Mesa Verde National Park.

both the standard deviation and the standard error of the mean becomes greater. These data demonstrate that during years when the tree-ring index is small there is less variability among cores, trees, and groups than when the index is large.

## Conclusions

The study shows that all of the sampled cores from this local area at Mesa Verde National Park exhibit a similar and prominent year-to-year variation in tree-ring index which is highly significant and represents 59% of the total variability. Differences among radii of each tree are considerably less and account for approximately 20% of the total variability, while differences among trees are of even lower magnitude, accounting for only 14%. Year-to-year variation among the chronologies for the 3 pinyon pine sites is relatively small, amounting to only 5% of the total variability. The average chronology, representing both pinyon pine and Douglas fir, exhibits a year-to-year variation equivalent to that of the pinyon pine sample, but there are significant differences in the chronologies from these 2 species.

The low amount of variation attributable to site differences indicates an overall macroclimatic control which is conditioned by the tendency for plant density to vary with the site potentiality. Even though the average growth may vary from site to site, the year-to-year variations in growth remain proportionally the same.

Douglas fir is apparently a more suitable species for dendroclimatic studies than pinyon pine because not only does it attain a greater age, but it has a greater uniformity among radii of the same tree, a greater similarity among chronologies of different trees, and a high serial variability with a low serial correlation.

The direct relationship between the mean of the yearly indices and their standard deviation gives support to the traditional procedure of emphasizing the small rings in cross-dating. It is also indicative of a greater uniformity in growth response during years of more limiting environments.

There is apparently no basis for sampling a particular direction or side of a tree as far as the relative chronology is concerned. Replicate samples from the same tree will undoubtedly provide more precision and a measure of the error, but where the objective of a sample is to characterize the chronology for a given region, it would seem more appropriate to include all sources of variation by collecting and averaging one core from many trees, sampled from a variety of sites.

However, some selection appears necessary to provide variable and homogeneous series with low or at least equal serial correlation. Further work is needed to evaluate and explain the factors governing these parameters. The answers will probably be found in a lagging relationship between growth and the processes governing photosynthetic potential, food accumulation and storage, and the structural modifications in the leaves, stems and roots.