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SELECTING AND CHARACTERIZING TREE-RING CHRONOLOGIES FOR DENDROCLIMATIC ANALYSIS

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ABSTRACT

A widely spaced grid of tree-ring chronologies most suitable for dendroclimatic analysis of western North America is selected objectively on the basis of 1) numbers in the sample, length in years, and site locations, 2) statistical characteristics of the chronologies, and 3) correlation of chronologies with those on neighboring sites. The chronology statistics are then analyzed to characterize the quality of the selected set. The procedures used in this study are recommended for future climatic analysis to assure objectivity in the selection of quality tree-ring data and to allow comparisons of the statistics for new chronologies to the established data sets.

INTRODUCTION

A large number of dendroclimatic studies since 1967 have used a set of 49 chronologies from western North America, referred to as the 49-site network, which were originally selected by V. C. LaMarche, Jr. and published in the first of a new chronology series (Stokes and others 1973). Due to three years of continuing ARPA support (AFOSR 72-2406) as well as other grants (NSF Grant GP-4640, NPS Contract CX700050241, NPS Contract 2101-22-1679, and NSF Grant SOC 73-05490-AOZ), a large number of new tree-ring collections have become available from western North America. Therefore, we re-examined approximately 600 data sets listed in the Inventory of Chronologies at the Laboratory of Tree-Ring Research as updated on August 28, 1974, to select candidates for a revised network.

METHODS OF SELECTION

The best of the available chronologies were chosen from climatically sensitive sites covering the same general region as the original 49-site network. The candidates had the following characteristics:

1. The chronologies were derived from measured ring widths of a single species sampled from specific site localities. The samples usually included 10 or more trees with two replications from opposite sides of the stem of each tree making a total of at least 20 radii (cores) for some portion of the derived chronology. The sites were selected in such a way as to obtain the best spatial distribution. In areas where coverage was poor and where no better candidates were available, samples of fewer than 10 trees and 20 cores were accepted.

2. All materials were carefully dated, measured, and computer processed to obtain mean standardized ring-width indices (see Fritts, in press).
3. All candidates began in the year 1700 or earlier and ended after 1963.
4. While the sample sizes, aerial distributions, and chronology lengths were utilized in selecting the candidates, often there was a surplus of minimally qualified chronologies in the well-collected areas.

   In order to maintain uniform coverage of chronologies throughout the entire grid and to maximize chronology quality, the following screening procedures were used. Four statistics of the chronologies were compared, and the respective chronologies were ranked in terms of their suitability for use in climatic reconstruction. The "best" chronologies were assumed to have: a) highest mean sensitivity (a statistic measuring relative year-to-year ring-width variability), b) lowest first-order serial correlation (autocorrelation), c) highest standard deviation, and d) highest percent variance in the mean yearly values of the chronology (see Fritts, in press). Only the first three statistics were available for all cases.

The area covered by the selected set of candidates was divided into a number of geographic regions varying in size and including from 10 to 20 of the highest-ranking chronology sites. The sizes of the regions were arbitrary and usually depended upon geography and the number of high-ranking candidates available. Each of the high-ranking chronologies was treated with a high-pass digital filter (Fritts, in press) which created a new time series with most of the chronology variance at wavelengths from two to eight years but without the lower frequencies. Each was also treated with a low-pass digital filter which created another time series with most of the chronology variance at wavelengths ranging from eight years to infinity but without the higher-frequency variance (Stockton and Fritts 1971).

Three different correlation analyses were performed on the 10 to 20 chronologies of each region using 1) the unfiltered indices of the original chronologies, 2) the high-pass filtered components, and 3) the low-pass filtered components. In each analysis, correlation coefficients were obtained for all combinations of the set of 10 to 20 chronologies, and the means of correlation coefficients associated with a given chronology were used to assess the similarities of that chronology to others in the same region (Stockton and Fritts 1971). When a site was near the margins of two or more of the selected regions, the chronology was analyzed as a part of each region. The mean correlations for the unfiltered and the two filtered sets, the amount of variance measured in the high- and low-frequency components, and the ratio of high-frequency to low-frequency variance were used in the final selection.

The rationale for the method is based on the principle that the more climate is limiting to the trees of a given region, the better the correlation among chronologies at all frequencies. However, the more nonclimatic factors unique to a particular site are highly limiting, the more the low-frequency variance and the less the correlation of the low-frequency component with those of neighboring sites (Fritts, in press). Thus, disturbance from site factors such as fire, disease, and cutting is indicated by a low correlation of the low-frequency variance of the particular chronology with the variance in chronologies from neighboring sites. In addition, the ratio of high-pass to low-pass variance is less.

Correlations among chronologies can also be low if the trees on neighboring sites have responded to different climatic factors (LaMarche 1974a) or if the climatic signal varied because of the distance or difference in microclimates of the two sites. In such cases, both of the correlation coefficients for the high-frequency and the low-frequency variances will be proportionately reduced. Exceptions to the above are the temperature-sensitive chronologies at high elevations that are generally characterized by much larger amounts of low-frequency variance than high-frequency variance (LaMarche 1974a), and the low frequency variance is highly correlated from one site to the next because it is the result of variations in climate (see LaMarche 1974b).

Therefore, the final selected chronologies include the largest and longest available samples providing the best available spatial coverage over western North America. They also are chronologies with the highest mean sensitivities, standard deviations, and percent variances in the mean chronology, and the lowest serial correlations. In addition, they are those with the highest correlations with neighboring chronologies for both the low-frequency and the high-frequency components and include the highest ratios of high-frequency to low-frequency variance.

CHARACTERIZING THE REVISED CHRONOLOGY SET

The final selections include a total of 102 chronologies. The site name, collector, identification number, species, location, elevation, and the most important statistical characteristics are published in Table I of Drew (1976) along with complete data on all 41 of the previously unpublished chronologies. Numbers 1 through 40, shown as triangles in Figure 1, represent all the chronologies which began in the years prior to and including A.D. 1500; numbers 41 through 65, shown as open circles in Figure 1, are those beginning in the years A.D. 1501 through 1600, inclusive; numbers 66 through 89, shown as solid circles, are those chronologies beginning in the years A.D. 1601 through 1700, inclusive. An additional 13 chronologies, numbers 90 through 102, are included to provide a dense grid for chronologies in and around the state of Arizona. In addition to these, the Arizona network includes 47 of the first 89 chronologies, making a total of 60 chronologies.*

This arrangement allows easy use of the data for climatic analysis. Any of the four sets may be selected depending upon what is needed. The longest set of 40 chronologies does not cover western North America as well as the shorter and larger sets (Figure 1). The entire 65-chronology set has a somewhat more uniform distribution, but some chronologies begin as late as A.D. 1600. The 89-grid set is denser but is continuous to only A.D. 1700. The remaining 60-chronology set selected for Arizona is the most dense, but it provides the least spatial coverage.

The depth of the chronologies (number of trees used) has been improved over those of the 49 set published by Stokes and others (1973). For the earlier set only 59% of the chronologies that were included were from samples of 10 or more trees, while for the 40-, 65-, and 89-chronology sets the percentages of sites with more than 10 trees are 72%, 69%, and 69% respectively. We are gratified with this improvement but hope to raise the percentages to at least 90%. The reason for these low percentages is that a number of the original undersized chronologies from the 49-site set had to be reused. This situation will not be fully remedied until field parties can return to the areas collected earlier, either to obtain new and large chronologies or to update, enlarge, and lengthen the original

*The numbers of these chronologies are: 17-28, 33-40, 53-64, 71, 73, 75-86, 89-102 (Drew 1976: Table I).

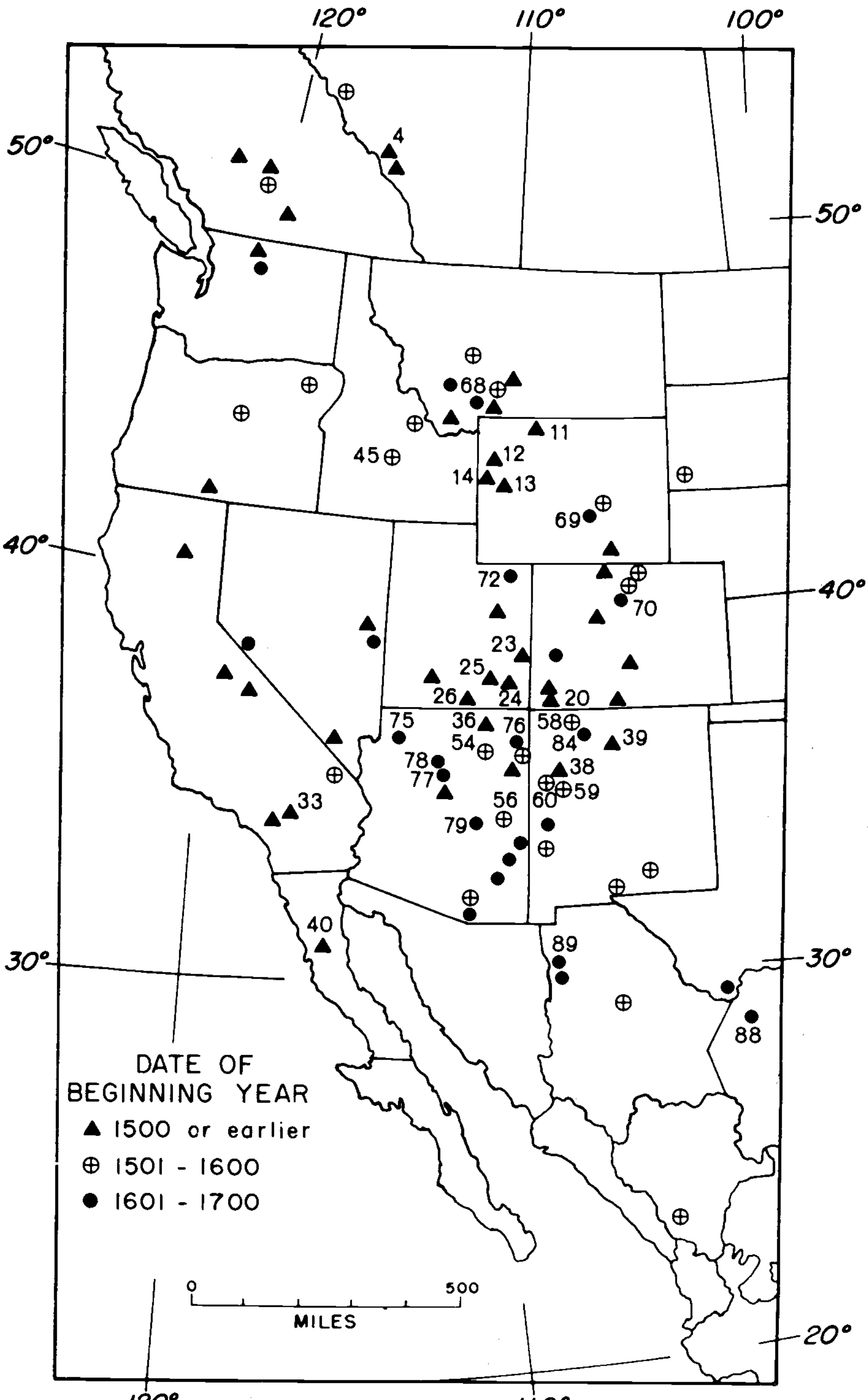

Figure 1. A map of sites selected to obtain the 89 chronology network. Numbers indicate the new chronologies published for the first time.

limited-sized collections. The effort to increase the chronology depth also will be facilitated if, in the future, collectors will increase the amount and quality of material they sample before leaving a site.

In order to evaluate and document the statistics of these new data sets, the statistics of the chronologies were examined by stratifying them into different subsets, then obtaining for each stratified subset the mean, median, maximum, and standard deviation for 1) mean sensitivities, 2) first-order serial correlations, 3) standard deviations, and 4) chronology lengths. The standard deviations and means were used to calculate the 50% theoretical limits of the population (± 0.67 standard deviation) and the 95% theoretical limits (± 2 standard deviations) for the four statistics (Stevens 1976).

Table 1 includes selected data for the chronologies stratified into numbers 1 through 40, numbers 41 through 65, numbers 66 through 89, and numbers 90 through 102. The mean lengths of the chronologies shown at the bottom of the table range from 655 years for the 1 through 40 set to a mean of 323 years for the 66 through 89 set. The averages of mean sensitivities, serial correlations, and standard deviations are similar for the first two sets. The chronologies 66 through 89 exhibit, on the average, higher mean sensitivities, 0.390, higher standard deviations, 0.397, but lower serial correlations, 0.379. Chronologies 90 through 102 have somewhat lower mean sensitivities than the 66 through 89 set and higher serial correlations and standard deviations than the other three sets. The standard deviations are not greatly different among the four sets, so that the 50% and 95% upper and lower limits are governed largely by the means of each statistic.

Table 1. Summarization of characteristics for the entire data set stratified into groups representing differences in the three length classes and the additions to the Arizona grid. (Chronologies are identified by their number)

Characteristic		*Length Classes* 1-40	41-65	66-89	*Arizona Grid* 90-102
Mean Sensitivity	Mean	0.355	0.352	0.390	0.372
	Standard Deviation	0.107	0.116	0.096	0.076
	Upper 50% Limit	0.427	0.430	0.455	0.424
	Lower 50% Limit	0.283	0.273	0.326	0.321
	Upper 95% Limit	0.568	0.583	0.582	0.525
	Lower 95% Limit	0.142	0.120	0.198	0.220
Serial Correlation	Mean	0.415	0.433	0.379	0.446
	Standard Deviation	0.112	0.096	0.098	0.097
	Upper 50% Limit	0.490	0.498	0.445	0.512
	Lower 50% Limit	0.340	0.368	0.312	0.381
	Upper 95% Limit	0.638	0.626	0.575	0.640
	Lower 95% Limit	0.192	0.240	0.182	0.252
Standard Deviation	Mean	0.370	0.371	0.397	0.400
	Standard Deviation	0.086	0.092	0.081	0.082
	Upper 50% Limit	0.428	0.433	0.451	0.456
	Lower 50% Limit	0.311	0.309	0.342	0.344
	Upper 95% Limit	0.543	0.556	0.558	0.565
	Lower 95% Limit	0.197	0.187	0.235	0.235
Chronology Length (yrs.)	Mean	655	409	323	337

These data indicate that there are no great differences in the statistical characteristics of the four sets. While the first 40 chronologies form the longest and most continuous set, the coverage is poor so that the tree rings may not include the climatic variations occurring in the spatial voids of the set. The coverage is improved somewhat by adding the chronologies 41 through 65 so that spatial variations in growth throughout the West may be better represented. The chronologies 66 through 89 do not substantially increase the coverage, and they decrease the length of continuous coverage of the entire set. However, the statistics of this latter group indicate better dendroclimatic quality and, therefore, may provide the best, as well as the largest, set for any analyses not requiring complete tree-ring information for the 16th and 17th centuries. A question has been raised that too many of the chronologies 66 through 89 may be located near the center of the network so that the most central chronoligies may dominate, decreasing the importance and usefulness of those at the boundaries of the grid. Research is underway to test this possibility and to measure the total information in each of the four sets.

Since no major differences in statistics exist, the 89 chronologies were pooled and stratified first by species (Table 2, Figure 2), by latitude (Figure 3), and by elevation (Figure 4). In the latter two classifications all species were pooled and stratified and then stratified again by species. Only the results for all species and for Douglas-fir (*Pseudotsuga menziesii* – PSME) are shown in Figures 3 and 4.

Table 2. Summarization of characteristics of the three major species included in the 89 selected chronologies.

Characteristic		Species PIED	PSME	PIPO
Mean Sensitivity	Mean	0.412	0.376	0.348
	Standard Deviation	0.097	0.096	0.131
	Upper 50% Limit	0.477	0.441	0.437
	Lower 50% Limit	0.347	0.311	0.260
	Upper 95% Limit	0.605	0.568	0.611
	Lower 95% Limit	0.219	0.184	0.086
Serial Correlation	Mean	0.361	0.400	0.452
	Standard Deviation	0.079	0.097	0.116
	Upper 50% Limit	0.414	0.465	0.531
	Lower 50% Limit	0.307	0.335	0.374
	Upper 95% Limit	0.520	0.593	0.685
	Lower 95% Limit	0.202	0.207	0.220
Standard Deviation	Mean	0.395	0.393	0.366
	Standard Deviation	0.079	0.082	0.105
	Upper 50% Limit	0.448	0.448	0.436
	Lower 50% Limit	0.342	0.337	0.295
	Upper 95% Limit	0.553	0.557	0.575
	Lower 95% Limit	0.238	0.228	0.156
Number of Chronologies		11	44	21

The 11 pinyon (*Pinus edulis* – PIED) in the 89-chronology set exhibited higher average mean sensitivities and lower average serial correlations than the 44 Douglas-fir and the 21 ponderosa pine (*Pinus ponderosa* – PIPO). In may be inferred from these results that, on the average, the pinyon chronologies exhibited the "best" dendroclimatic

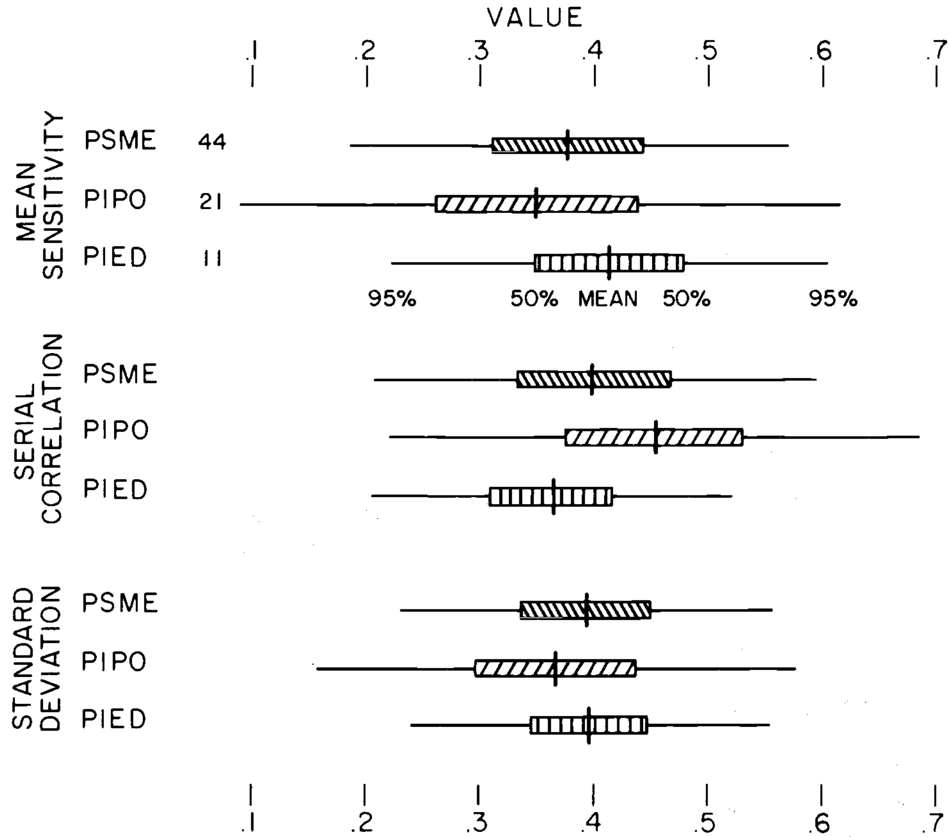

Figure 2. The means, the 50% ranges, and the 95% ranges of three statistics for the 89 chronologies stratified according to species. The numbers for each of the species are shown in the upper left.

statistics indicating that they contained the most information on climatic variations. The ponderosa pine chronologies, on the average, exhibited the poorest statistics and, therefore, appear to have the least information on climatic variations. However, there is considerable overlap and variation among them, so that a large number of chronologies from each of the species are of high quality.

Using the data from Table 2, a "good" climatic chronology for pinyon would be expected to have a mean sensitivity of 0.412, but half of the time the statistic will be higher than 0.477 or lower than 0.347. It would be rare ($p < 0.05$) for a "good" climatic chronology for pinyon to have a mean sensitivity higher than 0.605 or lower than 0.219. Similarly, statements on the expected values for other statistics and species may be deduced from the other data in the table.

The data stratified by latitude (Figure 3) indicate how the statistics vary from north to south over the grid. The largest mean sensitivities and standard deviations are to be expected between latitudes 30°N and 40°N, largest serial correlations between latitudes 40°N and 50°N, and smallest serial correlations at latitudes greater than 50°N. However,

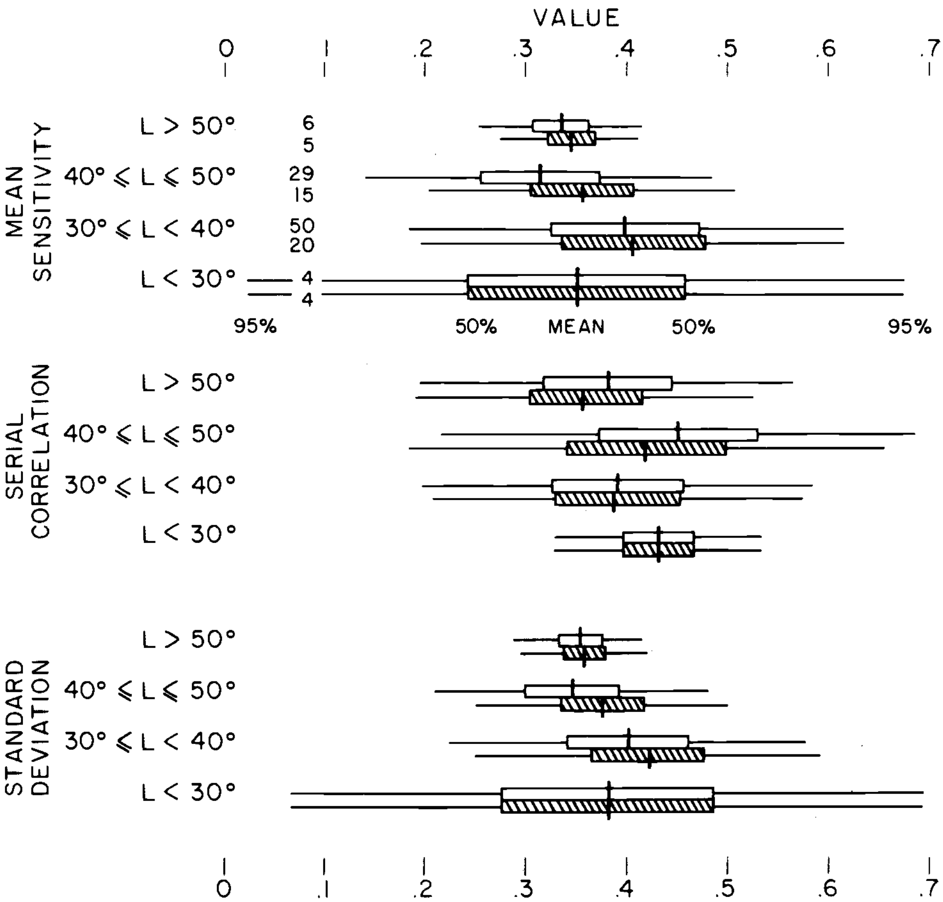

Figure 3. The means, the 50% ranges, and the 95% ranges of three statistics for the 89 chronologies stratified according to latitude for all species (open bars) and for Douglas-fir (hatched bars). The numbers in each of the classes are shown in the upper left.

mean sensitivities and standard deviations range most widely at low latitudes, and serial correlations range most widely at latitudes between 40°N and 50°N.

The data in Figure 4 indicate the effects of increasing elevation. Both mean sensitivities and standard deviations are generally largest at elevations ranging from 6,000 feet (1829 m) to 7,500 feet (2286 m), while serial correlations are generally largest at the highest elevations. In general, the changes in statistics associated with latitude and elevation for Douglas-fir appear similar to the other species, although the differences are more systematic (less variable from one stratification to the next) when only Douglas-fir is included rather than when all species are considered as a single set.

It is interesting to note from the data in these figures and tables for chronologies from arid sites, how infrequently values of mean sensitivity are less than 0.2 and how infrequently values of serial correlation are above 0.6; yet, such values appear to be common for chronologies from temperate or more polar sites. It would be very useful for

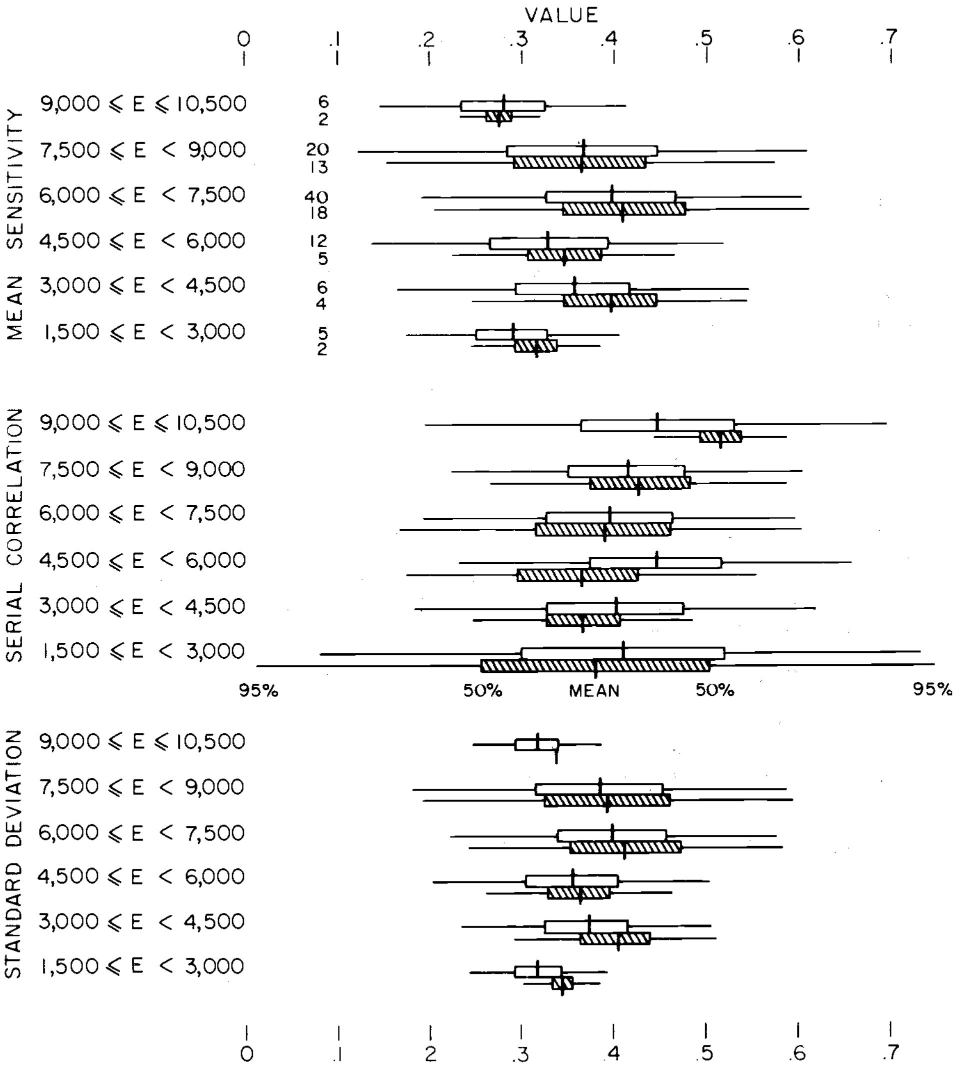

Figure 4. The means, the 50% ranges, and the 95% ranges of three statistics for the 89 chronologies stratified according to elevation for all species (open bars) and for Douglas-fir (hatched bars). The numbers in each of the classes are shown in the upper left.

comparative purposes to have these same statistics for all areas studied throughout the world.

As data from well-dated tree-ring chronologies become available from other areas in North America or from areas around the globe, the aforementioned characteristics should be examined in a similar manner to select materials for constructing new data sets or for expanding and improving the old grids. It would also be desirable for comparisons with other data to assess the final selection through stratification and measurement of the variability in the most important chronology statistics. These statistics can then serve as guidelines for evaluating new collections and for assessing the extent of any improvements or existence of undesirable characteristics that may be encountered when using them.

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