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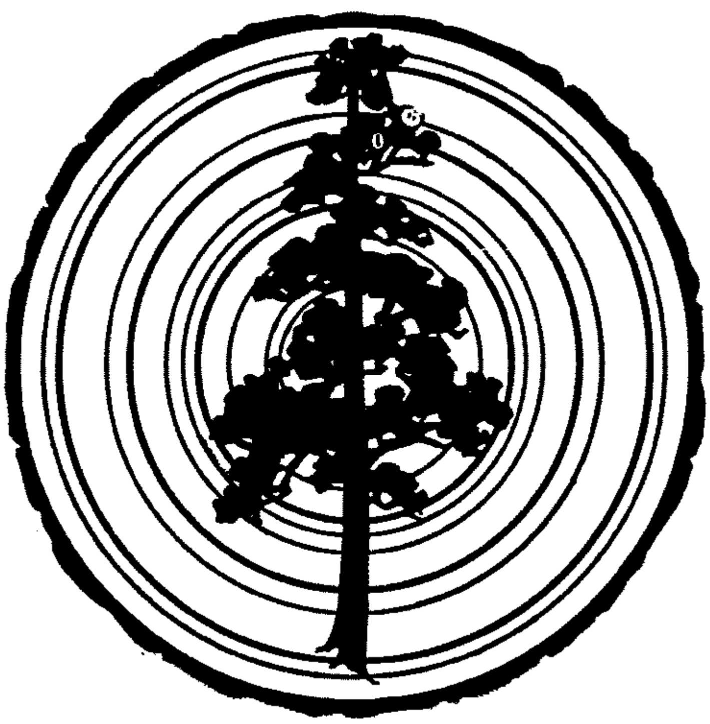

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COMPUTER PROGRAMS FOR TREE-RING RESEARCH

Harold C. Fritts

Abstract

Computer programs are described for: (1) the derivation of tree-ring indices and associated statistical parameters, (2) the dating of unknown tree-ring series against a longer master chronology using correlation techniques, (3) the calculation of cross-correlation to evaluate covariation among a large number of series, and (4) the estimation of variance components for sampled tree-ring series. General applications of these programs are illustrated by reference to an example of archaeological dating, a study of correlation among tree-ring series as a function of distance, and several ecological evaluations of tree-ring variability.

The more recent application of modern statistics to tree-ring problems and the consequent demand for greater replication and objectivity (Bryson and Dutton 1961; Matalas 1962; Fritts 1962a, 1962b) has required the development of new methods for rapid processing and computing of data from measured tree-ring series. During the last two years the author has been engaged in developing several computer programs to meet this growing need. These programs are now integrated into a unified package and are an integral part of the standard procedures used by the Laboratory of Tree-Ring Research. They are written in FORTRAN for use on an IBM 7072 computer, and are compatible with one another, so that the output of certain programs may be used directly as input for others.

Derivation of Tree-Ring Indices

Individual samples of ring series may differ markedly in the average ring width due to differences in growth potential for specific trees or sides of the tree. Ring widths also vary with distance from the central ring. In southwestern America, the datable species exhibit an abrupt rise in growth from the pith to a maximum which occurs about five to ten years from the center, after which the expected ring width diminishes approximating the exponential function $y = ae^{-bx}$, where y is the expected ring width and x is the number of years from the period of maximum growth (Matalas 1962).

However, the absolute variation in ring width also tends to decrease with distance from the center, so that tree-ring widths are a nonstationary time series. To facilitate statistical analyses, these nonstationary series must be transformed to stationary series by deriving indices which are the equivalent of the expected value for the exponential growth curve divided by the corresponding ring width measurement. The variance of this transformed series was shown to be essentially independent of time (Matalas 1962).

The program developed for deriving indices converts ring widths to natural logarithms and calculates by least squares techniques the linear regression coefficient (b, in the above equation) for logarithms of ring width as a function of time which is equal to, or less than, zero. The constant, a, in the above equation, is then calculated so that $\int_{x_{0.5}}^{x_{n+0.5}} ae^{-bx}dx$ equals the sum of the ring widths, thus forcing the average index for every series to approximate 1.00. The mean sensitivity, an additional parameter used in tree-ring evaluation, is calculated as the difference between two adjacent rings divided by their mean. The above data are printed for each ring and the indices are punched on a format of ten indices per card. The index values are also stored on magnetic tape for summarization after all ring series have been transformed. At the end of each series, several summary parameters are printed and punched. These are the first order serial correlation of the indices, their standard deviation, mean, and their sum and the sum of their squares; the mean ring width; the mean sensitivity for the series; and the a and b coefficients for the exponential growth function. The mean sensitivity for the entire series is calculated by squaring and adding the individual values, dividing by n-1, and extracting the square root.

Control cards are used to call back specific series of indices which are added to others to produce a new series representing mean yearly indices. The individual sums, sums of squares, N number, standard deviation, standard error and mean sensitivity are calculated for each year, as well as the above summary parameters for the mean indices. These new indices are also punched in the ten per card format, along with the N number represented by each mean index value. At the end of the program, after all compilations are made, the sums and the sum of the squares for all series are punched on cards, and these are used as input for the analysis of variance program. The index determination program can handle approximately 10,000 ring width values per hour.

CORRELATION PROGRAMS

Two correlation routines are written to process the output from the index program: one measures the cross-correlation at all possible matches between two series of indices, and the other calculates all possible correlations between a group of matched series.

The first correlation routine can be used to date series which cannot be conclusively dated by skeleton plot techniques (McGinnies 1963). For example, archaeological tree-ring samples collected at the Casas Grandes site (Scott 1963) were used to derive a 486-year floating (undated) chronology in northwestern Chihuahua, Mexico. Visual comparisons between this series and the long chronologies from the Rio Grande and Flagstaff areas, which were 400 miles distant, failed to yield conclusive matches. The tree-ring data were converted to indices, and the output representing the chronology for the mean of the Casas Grandes series was correlated with the Flagstaff and Rio Grande master chronologies by means of this program for end dates ranging from 1060 to 1644. In both comparisons, the match at 1336 provided the only significant correlation coefficient (0.001 level) which had a probability markedly less than .0001 of arising by chance alone ($t = 4.44$, $df = \infty$). A plot of these correlations with the Flagstaff series for only the fourteenth century is presented in Figure 1. The program prints the mean of the indices, standard deviation, covariance, correlation coefficient, 0.999 confidence interval, and the null "t" at each match.

The second correlation routine can be used to compare and contrast

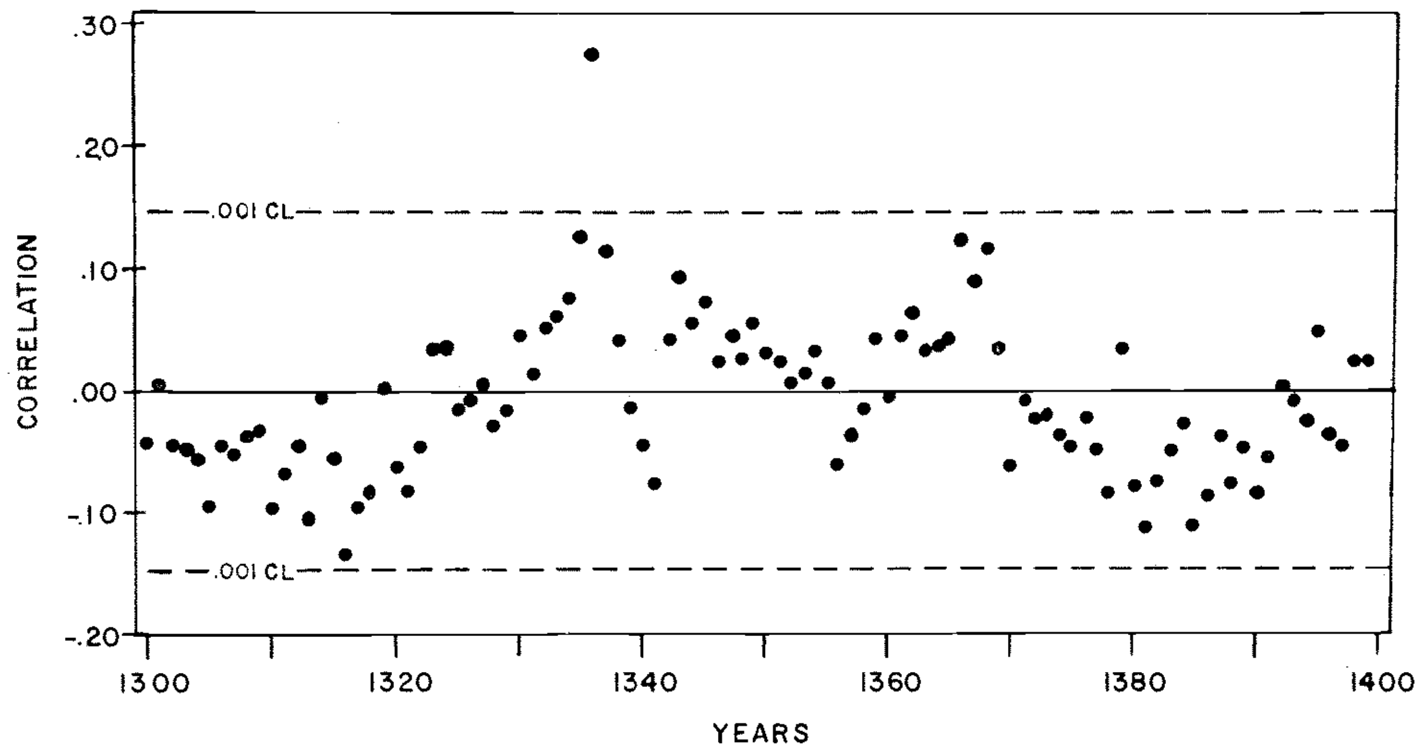

FIG. 1. Correlations of the Casas Grandes indices with the Flagstaff master chronology at every match for end dates during the fourteenth century. The marked high correlation is for 1336.

correlations between series of the same length. The program is written to compute all possible cross-correlations, the group means, standard deviations, and first order serial correlations. It has been employed to evaluate correlations among replicate samples within the same tree, among trees within the same group, and among groups for different sites or species.

Figure 2 is a further example of the use of the second correlation routine. Twenty-one stations in western America were selected where tree-ring indices had been determined (Schulman 1956). The stations ranged from Durango, Mexico, north to the Frazer River Valley of Canada, and from near Susanville, California, east to the Big Bend area of Texas. Tree-ring indices from 1650 through 1920 were used to obtain all possible cross-correlations between pairs of the 21 stations and the correlations were then plotted as a function of the distance between the pairs. These data show that there is highly significant correlation for series less than 300 miles distant, that on the average tree-ring series exhibit significant correlation with distances up to 700 miles, and that some series may exhibit significant correlations where distances are as great as 1100 miles. The superimposed curve in Figure 2 represents an idealized relationship of the correlations of monthly precipitation for December, January, and February at Dodge City, Kansas, with other North American stations plotted as a function of distance (Mitchell 1962). The similarity between the correlation of tree-ring data and the correlation of winter precipitation data with distance is marked.

Both correlation programs read from the output of the index program without format change or card sorting, and as an added feature, both calculate the linear correlations for tree-ring indices then convert them to natural logarithms and repeat the same operations. Minor alterations in the program will allow for any standard transformation.

Analysis of Variance

An analysis of variance program was written to handle a balanced sample of indices for any length but requiring more than one core per tree

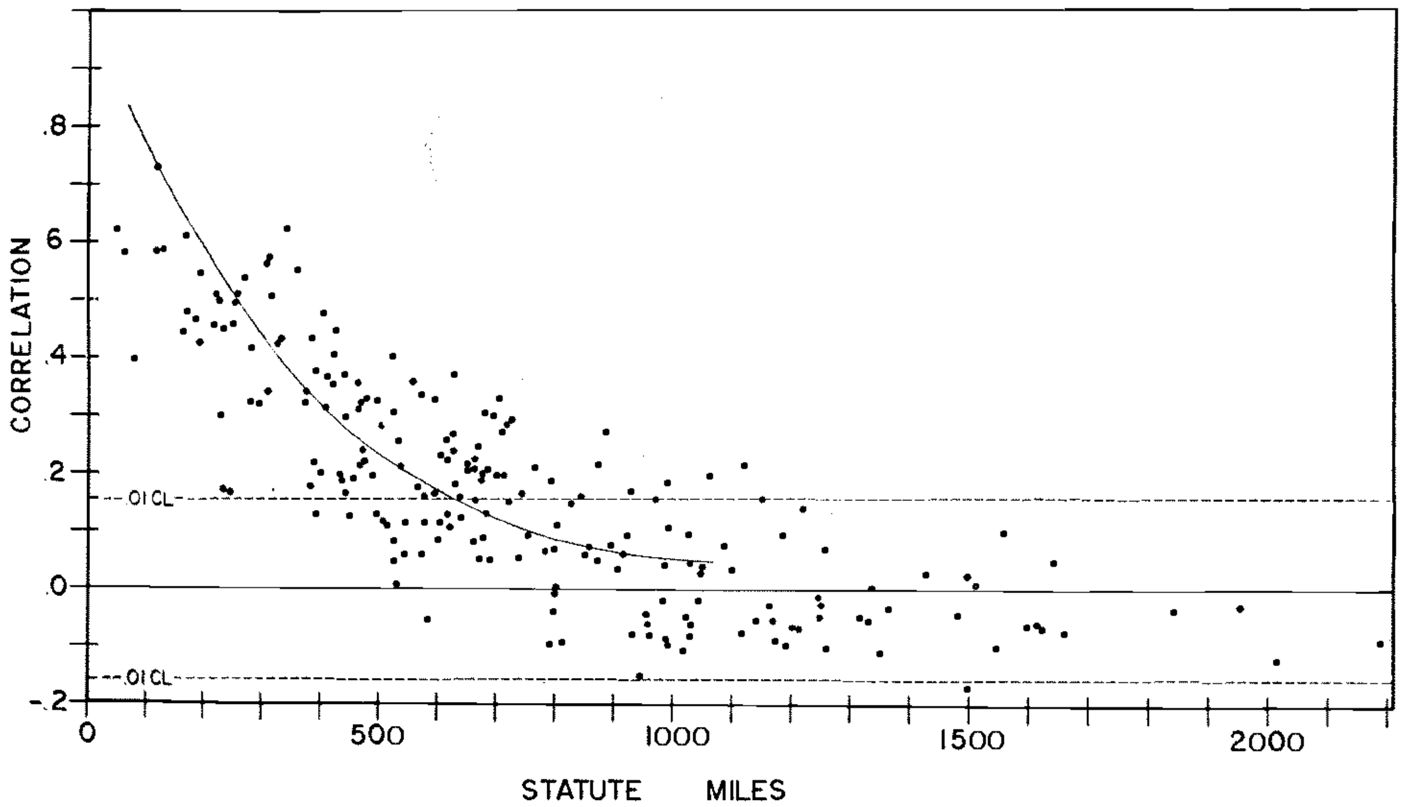

FIG. 2. The correlation between tree-ring series as a function of distance for 21 stations in western North America. The superimposed curve is an idealized relationship for correlation of winter precipitation as a function of distance (Mitchell 1962).

and more than one tree per group. This program uses the last output cards from the index routine as input, and calculates the mean squares and the variance component for the chronology of the total sample, the individual groups, individual trees, individual radii sampled per tree, as well as interactions of the above classifications (Snedecor 1956). This provides an estimate of the sampled variability so that by structuring a sample along environmental, edaphic, or biotic gradients, one can evaluate the relative similarities and differences in the tree-growth response. In addition, such information is of value in estimating the reliability of sampling procedures in tree-ring work.

The program has been used for analyzing a wide variety of samples from five different species in southwestern United States. The highest variance retained in the group chronology is generally found where trees are near their lower forest border, while the highest percent variance attributed to chronology differences among radii and among trees occurs in the forest interior or upper forest border. The species, Douglas-fir, exhibits the greatest similarity in variation among radii of the same tree and among trees of the same group and thus has the highest percent variance attributed to the group chonology, while ponderosa pine is intermediate and pinyon pine and bristlecone pine appear to exhibit the lowest percent variance due to the group chronology.

Table 1 includes four analyses used in an ecological study of three groups of ponderosa pine growing on the same site but distinguished by needle numbers per fasicle (Dodge 1963). The phenotype with three-needle fasicles ranged from the study site to higher elevations, and the five-needle phenotype generally extended to lower elevations. The group with fasicles varying in needle numbers exhibited a range intermediate to the above two classes. The variance sample includes 80-year chronologies from six trees per group and two cores per tree which had been processed by the computer routine for index derivation. The analysis of the total sample showed that differences in the year-to-year chronology of the three groups (Y x G, see Table 1) were small; but the analyses of individual needle classes indicate that the five-needle group, which was at its upper alti-

TABLE 1. Analyses of variance for three-needle, mixed-needle and five-needle ponderosa pine from the Santa Catalina Mountains, Arizona.

TOTAL ANALYSIS					ANALYSES OF INDIVIDUAL GROUPS		
Source of Variation	*Mean Square*	*df*	*Estimated Mean Square*	*Percent EMS*	*Percent EMS*		
					Group		
					Three-Needle	*Mixed Needle*	*Five-Needle*
Groups	.012	2	......				
Cores	.004	1	......				
Trees	.019	15	......				
C x G	.013	2	......				
C x T	.005	15	......				
Years	3.395	79	.092	55	65	64	41
Y x G	.170	158	.006	3	....	....	....
Y x T	.101	1185	.032	19	14	17	30
Y x C	.029	79	.000	0	1	1	0
Y x C x G	.042	158	.001	1	....	....	....
Y x C x T	.036	1185	.036	22	20	19	29

tudinal limits, had only 41 percent of the total variance retained in the group chronology (Years, see Table 1), while the three-needle group, which was growing near its limits, retained 65 percent of the total variance in the group chronology.

Since high variance for the group chronology is associated with trees near their lower forest border while proportionally lower variance for the group chronology is associated with trees in the forest interior or upper forest border, these results are thought to indicate different growth potentials for the two extreme phenotypes. Thus in the sampled site the three-needle trees are nearer their lower altitudinal limits than the five-needle trees, yearly climatic variation is more frequently limiting to their growth, and the year-to-year ring patterns among the radii and among trees of the group are more similar. These two needle classes appear to be hybridizing and producing the mixed-needle class (Dodge 1963), and the analysis of variance indicates that the ring patterns for this class are more similar to the three-needle parent.

SIGNIFICANCE

Once tree-ring samples are crossdated, measured, and ring widths punched on cards, one can make a number of analyses on any series with a minimum of card handling and computer time. For example, a recent sample of eighty 100-year long cores from twenty trees was completely analyzed, including correlation and variance analysis of a variety of groups and subgroups with five trees per group and four cores per tree, and the computer time used was less than two hours. An even more significant feature is that once specimens are dated and measured, the treatment is objective, making results completely reproducible. In addition to the rapid and objective derivation of indices, estimates are automatically provided on a variety of other statistical parameters.

Although there are still cases where traditional methods of eye-fitted curves and manual derivation of indices may be more economical, in cases where large numbers of data are to be handled, and where there is interest in statistical measures on the parameters of tree-ring variation, a computer package of this nature is a major necessity.

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TREE-RING DATES FROM THE NAVAJO LAND CLAIM
I. THE NORTHERN SECTOR*

M. A. STOKES and T. L. SMILEY

ABSTRACT

This, the first of five articles, gives the dates from specimens collected by the Navajo Land Claim Field Research teams. All specimens came from the Northern Sector of the Navajo Land Claim area. Out of a total of 237 specimens worked, 145 of them were dated and are listed here. Several specimens from each area were measured and plotted with modern cores from the area. The indices for each area are given, as well as the average indices for the Northern Sector.

The material reported on in this, and subsequent articles, was collected by the Navajo Land Claim Field Research, Window Rock, Arizona. Processing of the specimens was done by the Laboratory of Tree-Ring Research. The Navajo Tribe is in the process of presenting evidence before the United States Indian Claim Commission in an attempt to show that during the period of initial American government contact with the Navajo Indians (mid 1800's), the Tribe occupied areas that are now outside the present day reservation boundaries. One aspect of their research involved collecting wood that was used in the construction of now-abandoned hogans. Dates derived are being employed in the interpretation of use and occupancy of the disputed areas by Navajo Indians.

The Laboratory of Tree-Ring Research was asked to do this dating, and agreed to do so, reserving the right as an impartial group to publish the dates obtained and to date specimens submitted by other interested parties. The interpretation of the dates obtained for individual specimens, however, was to be the responsibility of the experts engaged on the project by the Tribe.

A very large collection of specimens from Navajo structures in Arizona, New Mexico, Colorado, and Utah were sent in to the Laboratory over the years. A total of 3,647 specimens were collected from "old" hogans, sweat hogans, corrals, animal traps, windbreaks, and fortified crags. Since most of these samples came from hogans, the term "hogan specimen" will be applied to all of these specimens regardless of origin. All of these hogan specimens were collected by personnel of the Navajo Land Claim Field Research. The collection was begun under the direction of Dr. Malcolm Farmer. Later, R. F. VanValkenburgh assumed the direction of the field research and continued in that capacity until his death in 1958. From then until the present, supervision has been under the direction of J. Lee Correll.

In addition to the large hogan collection, approximately 1,000 cores from living trees were collected. Of these, 506 were cataloged and used for establishing regional chronologies. Most of these cores were collected in two summers by the Laboratory, the rest by members of the Land Claim Field Research teams.

Early in the development of the project, an index system was established for the area of study. The Tree-Ring Laboratory utilized the same system in order to be able to coordinate the modern cores with the hogan sites. The area of collection was first divided into four sectors, designated

*Many people were involved in the preparation of specimens, dating, plotting, and filing. Our thanks goes to the Navajo Tribe for giving financial support, and grateful acknowledgment is made to the following individuals for their aid: John Bradner, Robert F. Charles, Jr., Eileen Ferguson, George Glick, Robert Hall, Allen G. Haury, Stuart Scott, Richard Shutler, Jr., David Smith, Charles St. Clair, and Hollis Waldon. Our special thanks to John Bradner for enduring so long.

as Northern, Southern, Eastern, and Western. These sectors were further divided into areas and subareas, usually on the basis of river drainage. The discussion of the Northern Sector to follow will clarify the system of indexing.

Emphasis in field collection of hogan specimens was placed upon locating and collecting information on sites outside the present day boundary of the Navajo reservation. Modern cores were collected as close as was practical to a number of individual hogan sites. These cores were an aid in establishing small subarea chronologies which could be used for dating the hogan specimens. In this way the effects of local peculiarities of climatically influenced tree growth were easily recognized. For final presentation, however, these subarea chronologies were combined to provide tree-ring indices for the entire area and sector.

The plan of publication for the dates resulting from this project is to publish each list of dates by the sector designation. The first to be presented here is the Northern Sector. The fifth and final article will be a synthesis of all sectors.

THE NORTHERN SECTOR

The Northern Sector includes areas in Colorado, New Mexico, and Utah. These areas are the Upper San Juan, the San Juan, the Middle San Juan, and the Lower San Juan. The subarea designations, as used in the list of dates, are given in the code index (Table 1).

The San Juan River delineates the southern boundary for most of this sector (Fig. 1). The Upper San Juan is that area east of the Los Pinos River, the San Juan is that area between the La Plata River and Los Pinos River, the Middle San Juan extends from the Los Pinos River to a line running southwest-northeast just to the east of the McElmo River drainage, and the Lower San Juan encompasses the area west from the above line to the Colorado River. The northern boundary extends along an east-west line from the Colorado River to the Blue Mountains, then to the Dolores River in Colorado. From there, the boundary runs southeast to the point where the San Juan River crosses the border between New Mexico and Colorado.

A total of 297 specimens has been sent to the Laboratory from the Northern Sector. Of this total, 237 samples have been processed and examined for dates, and Table 2 lists the 145 dates derived. This represents a dating percentage of 49 percent. All but two of the specimens were *Pinus edulis* Englm. (pinyon pine). The two exceptions were tentatively identified as *Abies lasiocarpa* (alpine fir) and these two were not dated.

In practically all cases, complete cross-sections were used for dating. In cutting these cross-sections from the bulk piece, the cut was made so as to include bark if present on the specimen. If there was no bark, the cut was made where there were the most rings present on the outside. Every effort was made to find the outermost ring. In some cases, this meant examining the entire circumference. On other specimens, only spot checks were made at selected points around the outside of the specimen.

As each group, subarea, and area was worked, certain of the dated specimens were set aside for measuring. These specimens were selected on the basis of (1) freedom from distortion of ring pattern, (2) total number of years in the ring sequence, and (3) degree of crossdatability with other specimens. From this group of measured specimens, anywhere from five to eight were plotted for each area. In Figure 2, the plotted indices are given for each area. In addition to the hogan specimens used to derive the mean indices, three or four modern cores for each area are included. Thus, each of the area curves represents from 8 to 11 specimens. The average for the four areas is plotted and the Mesa Verde chronology is shown for comparative purposes. Tables 3 through 6 contain the indices for the areas. Table 7 gives the average indices of the four areas.

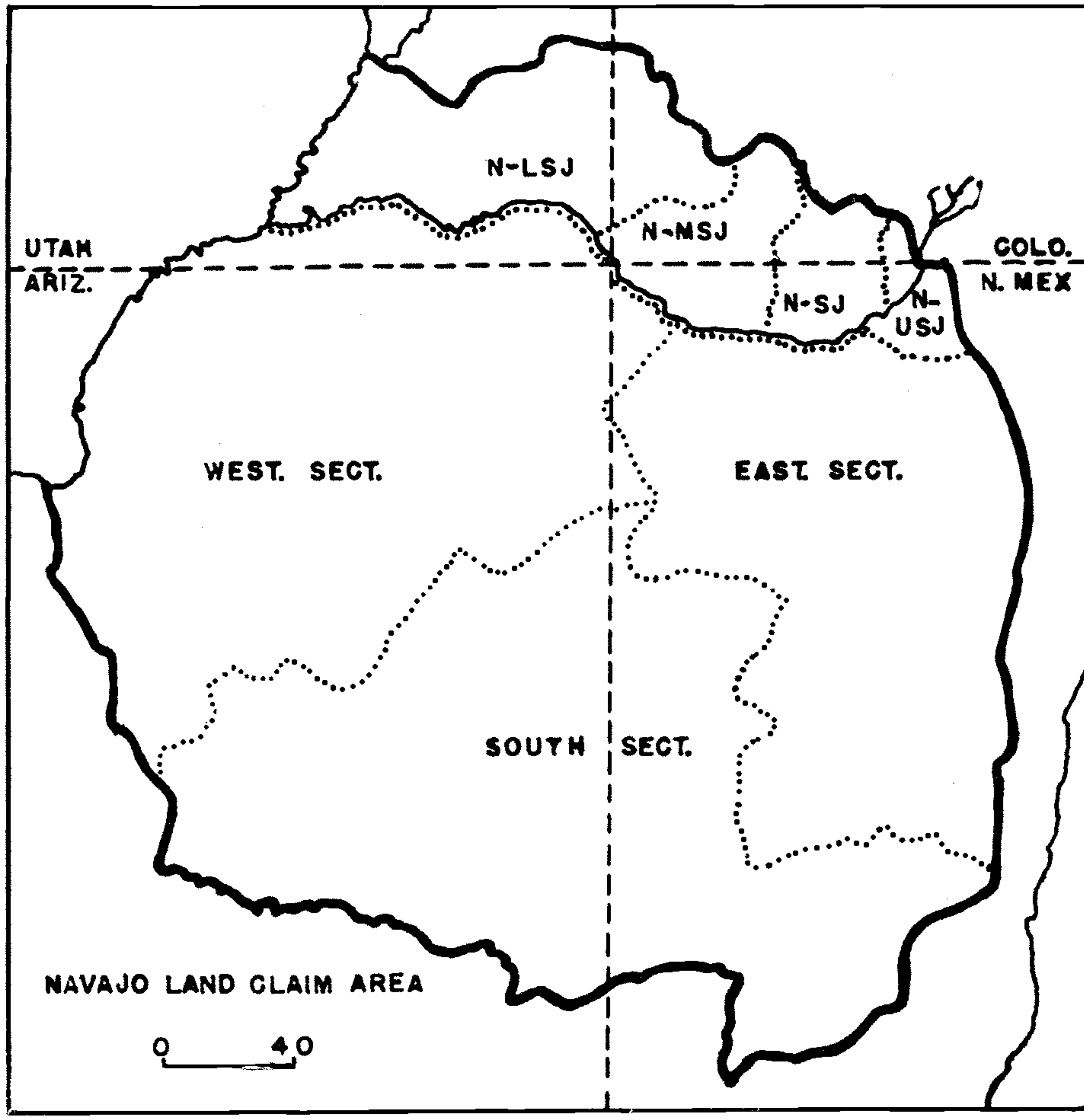

FIG. 1. Map of the Navajo Land Claim. Areas in the Northern Sector are indicated by letter designations and are defined by dotted lines. The three other sectors are also shown. The heavy line shows the approximate limits of hogan collections.

The date list (Table 2) is arranged by areas, with Upper San Juan the first area given and Lower San Juan the last. The dates are given just as they were submitted to the Land Claim Research group. Table 2 also includes the explanation of the symbols used with the dates.

The presence of bark on a specimen is the only definite proof that the date of the outermost ring represents the last year of growth. Such specimens that did have bark are indicated by the letter "B" following the outside date. A number of dates are listed with the symbol "G". This means that beetle galleries were noted on that specimen. These galleries represent the channels created by bark beetles which were present in the tree while alive. The beetles create these galleries while burrowing through the soft tissue of the cambial area. Since no galleries have ever been found to be healed over by subsequent cambial activity, it is believed that surfaces which exhibit these galleries are very close to the true outside. If much erosion had occurred after the death of the tree, the galleries would have been obliterated. Therefore, those dates with "G" are felt to be very close to the true terminal date.

TABLE 1. Index Code for Northern Sector.

USJ: Upper San Juan
- GLJ: Gobernador-La Jara Canyon

SJ: San Juan
- UA: Upper Animas River
- LA: Lower Animas River

MSJ: Middle San Juan
- BD: Barker Dome
- MR: Mancos River

LSJ: Lower San Juan
- BE: Bear's Ears
- MC: Montezuma Creek
- WC: White Canyon
- MEC: McElmo Creek
- CC: Caracas Canyon; Cottonwood-Comb Washes
- GG: Grand Gulch

TABLE 2

NORTHERN SECTOR

NLC	*Group*	*Specimen*	*Tree-Ring Laboratory Date, A.D.*
		UPPER SAN JUAN AREA	
1793	N—USJ—GLJ—B	Hogan 1	1630 p—1743 +
1795	N—USJ—GLJ—C	Hogan 1	1597±nc—1741 +
1796	N—USJ—GLJ—C	Hogan 2	1631± —1747 inc
1797	N—USJ—GLJ—C	Hogan 2	1600± p—1701 inc
1798	N—USJ—GLJ—C	Hogan 2	1621± p—1731 +
1799	N—USJ—GLJ—C	Hogan 2	1630 fc—1741 +
845	N—USJ—GLJ—D	Roof beam	1612± p—1732 inc
846	N—USJ—GLJ—D	Roof beam	1622± p—1732 inc
997	N—USJ—GLJ—E	Unit house, Forti. crag	1587± p—1715 +
999	N—USJ—GLJ—E	Same specimen as NLC 997	1587± p—1718 inc
1000	N—USJ—GLJ—E	Unit house, Forti. crag	1582±nc—1717 inc
1002	N—USJ—GLJ—E	Unit house, Forti. crag	1585± p—1715 inc
998	N—USJ—GLJ—E	Unit house, Forti. crag	1620± p—1731 inc
1003	N—USJ—GLJ—U	Hogan 4	1621 p—1715 G
1009	N—USJ—GLJ—U	Hogan 4	1454± p—1668 +
1010	N—USJ—GLJ—U	Hogan 4	1588± p—1707 c
1006	N—USJ—GLJ—U	Fortified crag	1647± p—1731 + G
1008	N—USJ—GLJ—U	Fortified crag	1511 p—1712 inc G
1011	N—USJ—GLJ—U	Fortified crag	1570± p—1745 c G
1012	N—USJ—GLJ—U	Fortified crag	1617 p—1721 G
1007	N—USJ—GLJ—U	Fortified crag	1664 p—1724 c G
1004	N—USJ—GLJ—U	House structure	1622 p—1720 G
1005	N—USJ—GLJ—U	Unit house	1624 p—1728 G
993	N—USJ—GLJ—V	Fortified crag	1586 p—1713 inc
994	N—USJ—GLJ—V	Fortified crag	1512 p—1679 +
988	N—USJ—GLJ—CC	Hogan 1	1658± p—1791 + G
989	N—USJ—GLJ—EE	Hogan 1	1613 p—1734 inc
990	N—USJ—GLJ—GG	Sheep corral 4	1529± p—1684 +
850	N—USJ—GLJ—LL	Hogan 2	1603 p—1744 + inc
851	N—USJ—GLJ—LL	Hogan 2	1613 nc—1728 +
979	N—USJ—GLJ—QQ	Fortified crag	1581± p—1703 G
980	N—USJ—GLJ—QQ	Fortified crag	1532± p—1715 inc
981	N—USJ—GLJ—QQ	Fortified crag	1615 p—1725 c
985	N—USJ—GLJ—TT	Tower of unit 1	1677 p—1745 C
986	N—USJ—GLJ—TT	Fortified crag 1	1634 p—1743 inc G
1055	N—USJ—GLJ—TT	House unit 1	1697 p—1743 inc
847	N—USJ—GLJ—UU	Roof beam, cut 1	1615± p—1713 c
848	N—USJ—GLJ—UU	Roof beam, cut 2	1590±nc—1712 inc
849	N—USJ—GLJ—UU	Roof beam, cut 3	1596± p—1713 inc

TABLE 2. (Continued)

NLC	*Group*	*Specimen*	*Tree-Ring Laboratory Date, A.D.*
		SAN JUAN AREA	
833	N—SJ—UA—G	Corral 4	1786± p—1909 c G
834	N—SJ—UA—G	Corral 4	1726± p—1881 +
838	N—SJ—UA—G	Sweathouse	1637± p—1814 + G
1700	N—SJ—LA—D	Hogan 1	1568±nc—1771 +
823	N—SJ—LA—E	Hogan 2	1616±nc—1745 +
821	N—SJ—LA—F	Sheep corral 2	1681 nc—1885 + G
		MIDDLE SAN JUAN AREA	
275	N—MSJ—BD—B	Hogan 2	1769± p—1897 inc
276	N—MSJ—BD—B	Sweathouse 5	1811 p—1890 + G
277	N—MSJ—BD—B	Sweathouse 5	1803± p—1888 inc G
825	N—MSJ—BD—J	Windbreak 1, cut 2	1849± p—1916 c G
826	N—MSJ—BD—J	Windbreak 1, cut 3	1816± p—1916 c C G
827	N—MSJ—BD—J	Windbreak 1, cut 1	1843± p—1916 c C G
828	N—MSJ—BD—K	Windbreak 2, cut 2	1773± p—1916 G
829	N—MSJ—BD—K	Windbreak 1, cut 1	1834 p—1916 C G
830	N—MSJ—BD—K	Windbreak 1, cut 2	1788 p—1916 G
266	N—MSJ—MR—B	Hogan 1	1712± p—1884 + G
267	N—MSJ—MR—B	Hogan 1	1705± p—1889 +
268	N—MSJ—MR—B	Hogan 1	1753 nc—1887 c G
270	N—MSJ—MR—B	Hogan 1	1720± p—1888 G
271	N—MSJ—MR—B	Hogan 1	1592 p—1737 +
820	N—MSJ—MR—B	Hogan 1	1802± p—1872 G
273	N—MSJ—MR—B	Sweathouse 2	1735± p—1861 +
274	N—MSJ—MR—B	Sweathouse 2	1809 p—1881 G
1801	N—MSJ—MR—C	Hogan 1	1738± p—1892 B
1804	N—MSJ—MR—C	Hogan 1	1687 p—1889 + G
1805	N—MSJ—MR—D	Hogan 1	1723 p—1873 G B
1806	N—MSJ—MR—D	Hogan 1	1632± p—1849 + G
1810	N—MSJ—MR—D	Hogan 1	1609± p—1875 + G
1807	N—MSJ—MR—E	Hogan 1	1671± p—1816 inc
1808	N—MSJ—MR—E	Hogan 1	1693± p—1877 + G
1809	N—MSJ—MR—E	Hogan 1	1765± p—1879 + G
1813	N—MSJ—MR—G	Hogan 1	1605± p—1858 + inc
260	N—MSJ—MR—H	Hogan 1	1755± p—1869 inc
261	N—MSJ—MR—H	Hogan 1	1783 p—1869 inc
262	N—MSJ—MR—H	Hogan 1	1788± p—1871 +
263	N—MSJ—MR—H	Hogan 1	1761 p—1867 inc
264	N—MSJ—MR—H	Hogan 1	1791 p—1871 +
265	N—MSJ—MR—H	Hogan 1	1789 —1872 + G
816	N—MSJ—MR—K	Hogan 1	1691± p—1879 + G
819	N—MSJ—MR—K	Hogan 1	1655± p—1887 + G
818	N—MSJ—MR—K	Sheep corral	1638± p—1873 + G
807	N—MSJ—MR—M	Sheep corral 2	1746± p—1891 + G
808	N—MSJ—MR—M	Sheep corral 2	1757± p—1878 + G
810	N—MSJ—MR—M	Sheep corral 2	1722± p—1890 inc B
812	N—MSJ—MR—M	Windbreak 1	1777 p—1899 + G
813	N—MSJ—MR—M	Windbreak 1	1767 p—1898 c G
814	N—MSJ—MR—M	Windbreak 1	1790 p—1899 + G
1952	N—MSJ—MR—N	Hogan 1	1629± p—1907 + G
		LOWER SAN JUAN AREA	
177	N—LSJ—BE—A	Hogan 1	1622± p—1824 + inc
179	N—LSJ—BE—B	Hogan 1	1468 p—1715 +
456	N—LSJ—BE—D	Hogan 1	1671 p—1906 + inc C
457	N—LSJ—BE—D	Hogan 1	1646 p—1906 c C

TABLE 2. (Continued)

NLC	*Group*	*Specimen*	*Tree-Ring Laboratory Date, A.D.*
458	N—LSJ—BE—D	Hogan 1	1644 p—1833 + inc G
459	N—LSJ—BE—D	Hogan 1	1628± p—1840 inc B
462	N—LSJ—BE—D	Hogan 1	1656± p—1804 inc
448	N—LSJ—BE—D	Hogan 3	1645 p—1816 inc
451	N—LSJ—BE—D	Hogan 3	1694 p—1826 inc
466	N—LSJ—BE—D	Sweathouse 4	1506 p—1794 + B
467	N—LSJ—BE—D	Sweathouse 4	1768 p—1940 inc B
472	N—LSJ—BE—D	Sweathouse 4	1618 p—1832 + G
473	N—LSJ—BE—D	Sweathouse 4	1647 p—1868 inc G
476	N—LSJ—BE—D	Sweathouse 4	1620 p—1836 + C
468	N—LSJ—BE—D	Windbreak 5	1612± p—1824 + inc G
461	N—LSJ—BE—D	Game rack 6	1646 p—1923 + inc G
168	N—LSJ—MC—HH	Lean-to 1	1495± p—1846 +
169	N—LSJ—MC—II	Hogan 1	1518 nc—1760 +
172	N—LSJ—MC—II	Hogan 1	1522 p—1780 +
188	N—LSJ—MC—II	Hogan 1	1545± p—1720 +
175	N—LSJ—MC—II	Sweathouse 2	1652 p—1809 + inc
176	N—LSJ—MC—II	Sweathouse 2	1592 p—1838 inc
1688	N—LSJ—MC—II	Sweathouse 2	1625± p—1813 inc C
173	N—LSJ—MC—II	Windbreak 3	1599± p—1835 inc
187	N—LSJ—MC—II	Windbreak 4	1532± p—1701 +
171	N—LSJ—MC—II	Shelter 1	1627± p—1837 inc
185	N—LSJ—MC—JJ	Windbreak 1	1639 p—1819 inc
2152	N—LSJ—MC—AAA	Hogan 1	1743± p—1937 inc G
2156	N—LSJ—MC—CCC	Sweathouse 1	1589 p—1874 inc G
2158	N—LSJ—MC—CCC	Sweathouse 1	1677 p—1885 inc G
167	N—LSJ—WC—B	Corral 2, post	1506± p—1752 +
181	N—LSJ—WC—D	Hogan 1	1642 p—1812 inc
484	N—LSJ—WC—D	Hogan 1	1697 p—1869 inc G
485	N—LSJ—WC—D	Hogan 1	1570 p—1800 +
486	N—LSJ—WC—D	Hogan 1	1701 p—1855 inc C
487	N—LSJ—WC—D	Hogan 1	1638 p—1873 + inc G
488	N—LSJ—WC—D	Hogan 1	1551 p—1789 inc C
489	N—LSJ—WC—D	Hogan 1	1615+ p—1830 +
490	N—LSJ—WC—E	Hogan 2	1520± p—1775 inc
491	N—LSJ—WC—E	Hogan 2	1404± p—1783 + inc
492	N—LSJ—WC—E	Hogan 2	1422+ p—1620 +
493	N—LSJ—WC—E	Hogan 2	1399 p—1702 +
495	N—LSJ—WC—E	Hogan 2	1397 p—1747 +
1954	N—LSJ—MEC—A	Sweathouse 1	1828 p—1931 inc G
2174	N—LSJ—MEC—T	Hogan 1	1674 p—1900 +
2175	N—LSJ—MEC—T	Sweathouse 2	1867 p—1950 B
425	N—LSJ—CC—C	Hogan 1	1495+nc—1801 inc
427	N—LSJ—CC—C	Hogan 1	1580+ —1812 + inc G
432	N—LSJ—CC—C	Hogan 4	1595± p—1790 +
435	N—LSJ—CC—D	Hogan 1	1592±nc—1816 + inc
436	N—LSJ—CC—D	Hogan 1	1601± p—1749 +
437	N—LSJ—CC—D	Hogan 1	1614± p—1802 + inc
439	N—LSJ—CC—D	Hogan 1	1672± p—1849 + inc
440	N—LSJ—CC—D	Hogan 1	1637± p—1843 inc G
443	N—LSJ—CC—D	Sheep corral 3	1612± p—1802 +
445	N—LSJ—CC—D	Sheep corral 3	1560± p—1789 + G
2171	N—LSJ—CC—J	Hogan 1	1488±nc—1730 +
2350	N—LSJ—GG—A	Game corral	1622± p—1825 + inc

Explanation of symbols used with dates. p—pith ring; nc—indicates that the pith was gone from the specimen, and that the inside dated ring is "near center"; fc—used when the pith is gone from the specimen and the inside dated ring is determined to be quite far out from the pith; ±—center portion is difficult to date and this symbol indicates a ring count only; +—outermost rings are very small and a ring count only could be made to the outside; inc—indicates that the outside ring of a specimen is incomplete in growth; c—outermost ring is complete in growth; C—outermost ring is continuous around the circumference of the specimen implying that the date is close to the cutting date; G—beetle galleries present; B—bark present on the specimen.

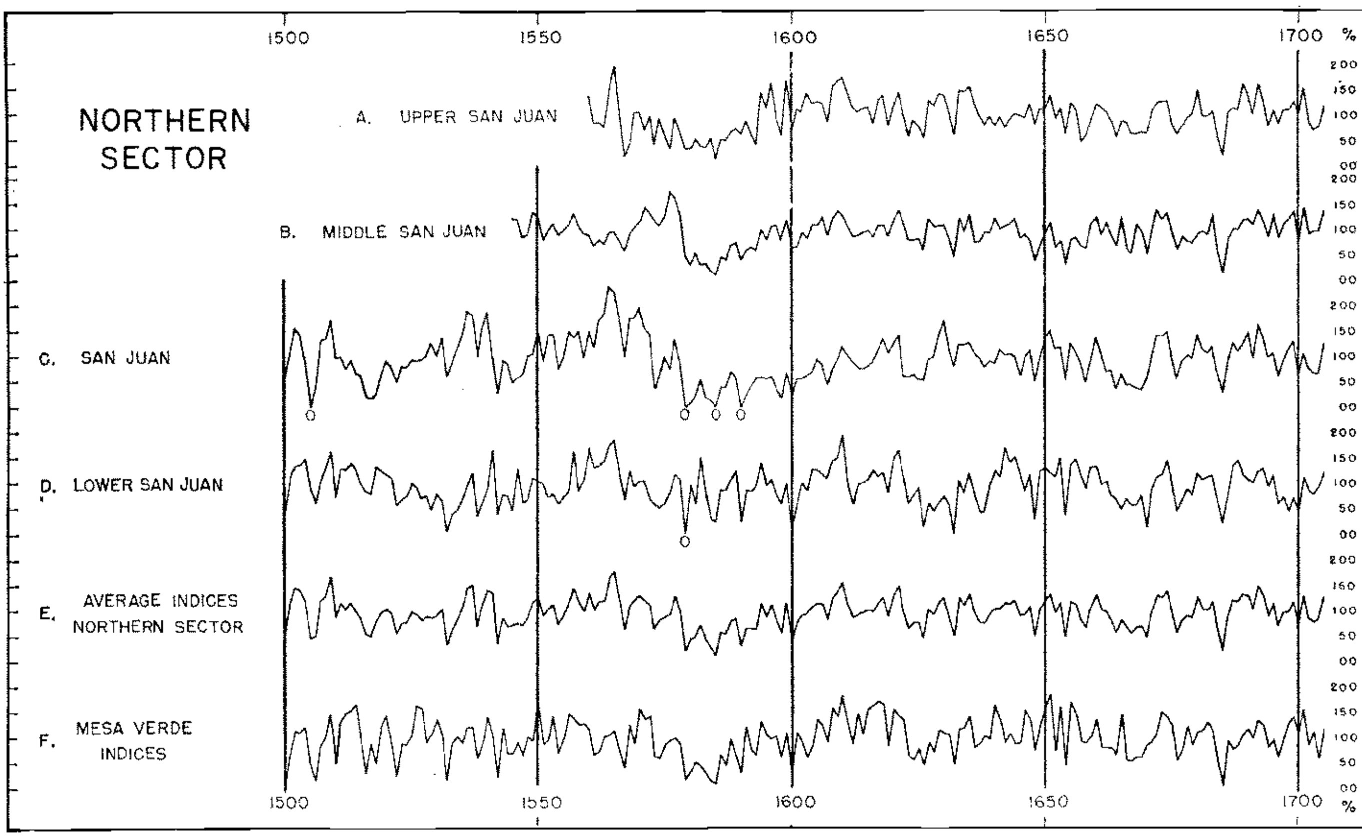

FIG. 2. Standardized indices for the Northern Sector. The Mesa Verde indices are given for comparison. Locally absent rings are indicated by zeros.

TABLE 3. Indices for the Upper San Juan area. These were derived from six hogan specimens and three modern specimens.

A.D.	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1560	136	84	86	77	152	193	107	18	45	104
1570	104	70	98	43	93	60	34	93	64	33
1580	34	52	39	37	54	13	52	50	67	73
1590	63	87	61	40	145	113	163	93	59	169
1600	70	113	106	142	122	126	123	85	157	168
1610	173	143	114	106	111	114	82	129	138	79
1620	115	144	98	57	88	76	54	128	117	140
1630	137	100	70	146	144	154	118	96	80	95
1640	78	94	73	91	101	97	93	120	80	111
1650	110	138	90	113	62	124	106	44	59	91
1660	124	112	103	86	53	86	83	62	61	64
1670	63	105	123	125	126	79	60	76	92	101
1680	148	95	96	106	53	18	104	112	109	160
1690	134	100	158	126	76	108	80	108	108	125
1700	101	150	83	68	75	116	126	51	78	93
1710	121	106	97	102	68	97	73	89	109	88
1720	140	111	76	109	84	135	151	117	104	53
1730	98	109	138	112	133	40	79	77	104	85
1740	90	94	94	124	67	122	114	104	28	106
1750	77	76	64	73	163	84	82	89	88	104
1760	109	120	141	91	136	75	137	83	128	98
1770	130	133	126	77	107	119	81	71	92	85
1780	58	71	60	93	138	87	104	118	67	98
1790	97	115	129	146	126	123	124	107	108	144
1800	113	93	116	84	103	88	68	118	113	103
1810	107	104	89	101	122	139	140	120	86	74
1820	69	103	61	49	61	103	88	97	118	94
1830	95	107	111	82	81	87	95	96	93	113
1840	144	138	102	82	91	91	99	57	95	127
1850	115	72	106	118	101	111	119	98	94	69
1860	91	14	101	78	56	102	125	130	137	111
1870	69	64	72	98	107	78	63	103	71	52
1880	74	74	71	39	85	97	72	71	100	88

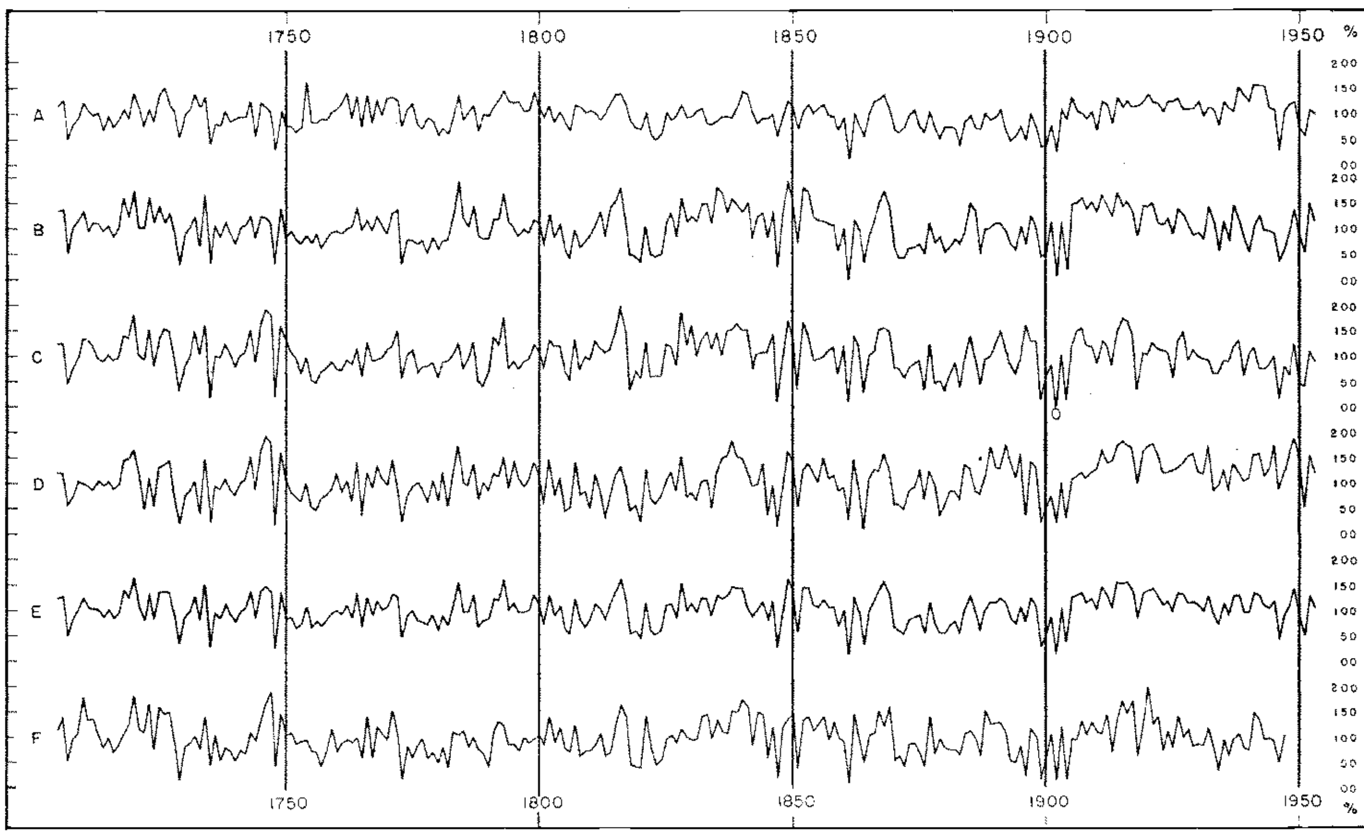

FIG. 2. (Continued)

TABLE 3. (Continued)

A.D.	0	1	2	3	4	5	6	7	8	9
1890	93	108	68	47	58	76	49	99	73	35
1900	39	78	27	108	88	132	105	101	90	103
1910	68	124	118	81	132	111	125	114	115	123
1920	138	122	119	102	122	123	134	109	109	109
1930	125	94	112	107	77	122	110	104	150	134
1940	121	156	156	153	111	106	28	102	119	123
1950	71	55	107	98	109	......	......	......	......	......

TABLE 4. Indices for the Middle San Juan area. These were derived from seven hogan specimens and three modern specimens.

A.D.	0	1	2	3	4	5	6	7	8	9
1540	......	......	......	......	......	122	118	85	91	135
1550	124	79	99	111	88	99	109	131	107	92
1560	88	68	79	70	93	95	77	58	92	104
1570	115	144	132	118	108	125	173	163	128	48
1580	30	53	36	37	18	12	45	39	70	74
1590	38	59	65	59	100	79	106	109	79	118
1600	64	67	93	81	108	108	123	88	119	136
1610	127	105	85	88	95	99	85	108	109	85
1620	115	138	111	80	79	82	60	119	106	108
1630	109	82	48	121	95	128	74	78	95	93
1640	121	103	107	111	120	83	90	78	38	72
1650	95	114	64	77	32	79	83	67	64	110
1660	125	88	113	89	67	123	63	52	109	96
1670	52	94	137	119	132	90	59	85	76	73
1680	89	96	89	128	57	11	82	102	100	118
1690	119	108	138	114	84	129	82	109	118	135
1700	74	142	88	97	95	134	137	53	102	117
1710	136	95	111	109	95	108	82	103	160	122

TABLE 4. (Continued)

A.D.	0	1	2	3	4	5	6	7	8	9
1720	171	103	101	161	112	144	111	129	94	29
1730	90	103	123	66	164	33	105	81	113	90
1740	69	103	107	125	82	123	122	111	31	139
1750	81	96	78	71	87	72	91	61	77	92
1760	96	91	99	104	142	97	117	96	123	107
1770	91	129	137	33	77	75	69	75	54	82
1780	59	75	78	126	187	121	103	143	84	79
1790	81	119	117	167	113	103	86	99	92	118
1800	109	66	126	82	108	63	43	97	64	75
1810	86	108	134	87	142	155	180	117	48	47
1820	35	103	49	44	49	111	131	84	158	113
1830	123	114	149	150	111	182	168	132	159	146
1840	133	151	81	124	131	82	134	26	127	194
1850	149	73	182	171	124	116	114	109	107	56
1860	99	01	117	99	35	88	119	152	173	144
1870	64	42	43	62	64	70	52	109	72	84
1880	55	66	80	70	91	150	135	51	99	102
1890	111	109	97	69	59	104	69	125	104	44
1900	52	114	07	113	21	149	150	161	138	151
1910	134	166	144	123	169	146	154	137	86	145
1920	143	149	111	109	121	89	140	128	108	88
1930	92	79	141	112	58	115	76	146	115	79
1940	54	106	126	98	96	92	35	58	94	138
1950	87	53	150	115	......	......	......	......	......	......

TABLE 5. Indices for the San Juan area. These were derived from five hogan specimens and four modern specimens.

A.D.	0	1	2	3	4	5	6	7	8	9
1500	55	102	157	143	95	00	39	132	136	173
1510	98	100	75	93	68	64	23	18	27	66
1520	89	80	52	82	80	93	91	93	100	125
1530	102	136	61	86	116	145	189	182	102	159
1540	186	105	30	93	86	49	60	67	100	105
1550	149	91	144	144	74	100	149	137	150	98
1560	150	117	169	183	238	228	171	102	176	176
1570	195	155	145	36	69	100	76	133	88	00
1580	10	24	54	20	15	00	39	41	71	59
1590	00	24	44	58	61	56	62	36	18	68
1600	23	56	57	62	69	96	84	46	76	94
1610	120	102	87	78	76	82	91	111	135	108
1620	128	144	62	61	65	56	54	95	100	145
1630	172	116	81	124	122	127	112	97	78	91
1640	85	114	103	105	101	61	102	114	51	102
1650	138	154	116	118	54	127	111	86	49	89
1660	137	108	70	72	35	66	44	44	38	35
1670	56	97	142	140	149	100	55	90	103	95
1680	143	113	107	120	65	28	92	128	110	125
1690	148	94	164	133	98	108	60	91	116	131
1700	65	106	76	67	67	125	126	46	75	98
1710	136	132	119	97	89	103	92	98	142	136
1720	183	102	92	154	82	133	155	150	98	33
1730	80	100	149	103	161	20	101	98	123	103
1740	78	101	109	153	88	164	193	182	21	160
1750	106	82	74	66	98	53	48	69	77	89
1760	74	73	92	84	116	60	126	89	94	97
1770	114	120	148	57	103	113	68	78	79	87
1780	60	88	90	104	125	76	95	126	52	40
1790	68	138	120	175	76	90	75	89	96	123
1800	108	76	131	120	120	71	52	132	75	100
1810	94	129	115	107	114	146	198	150	36	71
1820	57	127	60	61	62	123	120	83	186	120
1830	161	101	134	148	114	146	103	151	153	163

TABLE 5. (Continued)

A.D.	0	1	2	3	4	5	6	7	8	9
1840	151	152	75	103	109	108	143	13	102	170
1850	128	35	165	143	92	94	99	112	116	67
1860	120	11	140	120	30	102	112	152	156	150
1870	77	76	58	78	85	91	35	120	47	52
1880	32	63	86	40	96	138	97	46	95	101
1890	126	153	120	83	65	93	160	130	130	14
1900	59	84	00	104	15	118	150	156	121	120
1910	87	131	120	83	150	173	169	142	36	107
1920	104	127	116	113	107	59	131	149	92	113
1930	100	97	93	66	67	91	90	120	132	63
1940	106	117	77	76	84	100	18	81	63	124
1950	46	40	108	89	......	......	......	......	......	......

TABLE 6. Indices for the Lower San Juan area. These were derived from seven hogan specimens and three modern specimens.

A.D.	0	1	2	3	4	5	6	7	8	9
1500	42	119	136	138	149	94	62	108	133	163
1510	75	130	128	139	130	101	84	80	133	127
1520	118	112	57	70	76	101	95	71	77	48
1530	80	68	06	39	49	73	98	119	36	66
1540	91	165	40	79	52	47	128	64	71	110
1550	106	100	73	79	59	74	88	162	85	108
1560	168	132	135	146	176	186	120	68	124	94
1570	104	104	70	60	52	60	84	118	108	00
1580	98	60	150	78	30	24	88	87	110	126
1590	25	88	84	95	140	95	110	82	66	101
1600	10	58	101	85	128	127	120	110	145	150
1610	194	97	58	98	101	108	126	114	122	82
1620	149	166	113	62	76	91	12	63	46	63
1630	76	59	02	106	81	119	77	42	46	97
1640	126	112	171	141	154	120	84	120	29	125
1650	132	121	113	149	38	137	149	117	91	132
1660	134	98	102	77	69	49	69	58	58	76
1670	14	85	112	117	144	108	45	67	88	77
1680	119	107	113	115	67	23	72	133	145	116
1690	108	101	123	129	93	116	59	73	44	70
1700	44	112	85	78	90	122	121	58	74	105
1710	102	96	87	105	95	105	88	99	147	150
1720	165	115	52	110	56	131	136	146	70	23
1730	76	87	105	42	147	24	94	88	110	87
1740	75	100	113	145	100	146	164	145	29	137
1750	76	88	41	86	85	57	96	61	79	90
1760	120	82	106	64	141	37	120	91	133	109
1770	96	145	87	25	74	92	101	88	65	104
1780	64	120	56	118	171	102	95	135	70	101
1790	84	118	113	150	91	144	107	92	112	141
1800	116	58	146	75	112	45	52	141	77	85
1810	50	117	83	32	74	115	132	96	44	57
1820	27	124	69	60	74	107	122	85	150	71
1830	81	68	103	106	52	121	149	155	182	153
1840	148	122	94	99	138	38	96	15	88	162
1850	140	54	128	140	124	104	148	109	116	85
1860	92	28	146	89	12	108	127	124	157	128
1870	60	58	48	85	92	126	71	123	96	36
1880	59	84	84	68	137	129	84	81	113	171
1890	131	131	174	137	110	158	39	142	132	24
1900	50	74	24	100	32	108	114	121	110	120
1910	128	166	142	144	174	183	174	170	101	162
1920	173	177	156	122	121	125	138	140	152	158
1930	124	118	173	84	95	126	86	138	121	106
1940	111	156	158	115	131	174	90	123	162	188
1950	148	54	154	120	......	......	......	......	......	......

TABLE 7. Northern Sector indices. Average of standardized ring widths from the four areas; Upper San Juan, Middle San Juan, San Juan, and Lower San Juan.

A.D.	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1500	49	111	146	141	122	47	51	120	135	168
1510	87	115	102	116	99	83	54	49	80	97
1520	104	96	55	76	78	97	93	82	89	87
1530	91	102	34	63	83	109	144	151	69	113
1540	139	135	35	86	69	73	102	72	87	117
1550	126	90	105	111	74	91	115	143	114	99
1560	135	100	117	119	165	176	119	62	109	120
1570	130	118	111	64	81	86	92	127	97	20
1580	43	47	70	43	29	12	56	54	80	83
1590	32	64	64	63	112	86	110	80	56	114
1600	42	74	89	93	107	114	113	82	124	137
1610	153	112	86	93	96	101	96	116	126	88
1620	127	148	96	65	77	76	45	101	92	114
1630	124	89	50	124	111	132	95	78	75	94
1640	103	105	114	112	119	90	92	108	50	103
1650	119	132	96	114	47	117	112	79	66	105
1660	130	102	97	81	56	81	65	54	67	68
1670	46	95	129	125	138	94	55	80	90	87
1680	125	103	101	117	61	20	88	119	116	129
1690	127	101	146	126	88	115	70	95	97	115
1700	71	128	83	78	82	124	128	52	82	103
1710	124	107	104	103	87	103	84	97	140	124
1720	165	108	80	134	84	136	138	136	92	35
1730	86	100	128	81	151	29	95	86	113	91
1740	78	100	106	137	84	139	148	136	27	136
1750	85	86	64	74	108	67	79	70	80	94
1760	100	92	110	86	134	67	125	90	120	103
1770	108	132	126	48	90	100	80	78	73	90
1780	61	89	71	110	155	97	99	131	68	80
1790	83	123	120	160	102	115	98	97	102	132
1800	112	73	130	90	111	67	54	122	82	68
1810	84	115	105	82	113	139	163	121	54	61
1820	47	114	60	54	62	111	115	87	153	100
1830	115	98	124	122	90	134	129	134	147	144
1840	144	107	88	102	117	80	118	28	103	163
1850	133	59	145	143	110	106	120	107	108	69
1860	101	14	126	97	33	100	121	140	156	133
1870	68	60	55	81	87	91	55	114	72	56
1880	55	72	80	54	102	129	97	62	102	115
1890	115	125	115	84	73	108	79	124	110	29
1900	50	88	15	106	39	127	130	135	115	124
1910	104	147	131	107	156	153	156	141	85	134
1920	140	144	126	112	118	99	134	132	115	117
1930	110	97	130	92	74	114	91	127	130	96
1940	98	134	129	111	106	118	43	91	110	143
1950	88	51	130	106	......	......	......	......	......	......

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