A GUIDE TO MEASURING TREE-RING WIDTHS

by

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Revised November, 1976

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ACKNOWLEDGMENT

I wish to express my appreciation to Dr. Harold C. Fritts, Marvin A. Stokes, Laura E. Conkey, and Scott B. Clemans for graciously making suggestions for this guide's improvement. I am particularly indebted to Martha A. Wiseman for her extensive discussions and comments concerning this guide. It should go without saying that any mistakes within this guide are mine alone and should in no way be attributed to any of the people mentioned above.

This work was supported by Grant No. ATM75-17034 from the Climate Dynamics section of the National Science Foundation, H. C. Fritts, Principal Investigator.

I. INTRODUCTION

In reaction to a comment of his on some current event, a person probably has heard the retort,"Ah, you can't make that comparison. You're mixing apples and oranges ..." A situation, he might resolve by showing that indeed the apples are the oranges.

Regardless of how the situation is actually resolved, a person who desires to build a convincing proof for his assertion tries in some way to show the equality, causality, or relationship between the phenomena. He tries to convert the phenomena into a form which will allow direct comparisons. This conversion usually means the quantification of the phenomena. Quantification is usually at the center of all scientific inquires whether they are made on the street or in the laboratory.

Dendrochronologists in their scientific inquires use quantitative data, of which tree-ring widths form a major part. In order to gather the necessary quantitative tree-ring data, someone must be trained to measure the widths of the tree rings. The purpose of this paper is to explain to the person who will actually measure the tree-ring widths how the measuring process should be performed at the Laboratory of Tree-Ring Research.

The following three sections describe the three phases of the measuring process. The first section deals with the preparations that must be performed before the ring-widths can be measured. The second section describes the procedures for measuring the ring-widths. The final section describes the checking procedure used to test the reliability of the measurements.

II. PREPARATIONS BEFORE MEASURING

A. Description of the Core Materials

The cores are delivered to the measuring room by the person who is investigating the site, or by the person who dated the site. The field identification number, the date the cores were collected, and the initials of the collector(s) are marked on one side of the cores. Usually, the inner-most date and the century dates are marked on the cores.

The site worksheet, skeleton plots, and core cards are found in the site folder, which is delivered with the cores. The site worksheet (Appendix A) has five sections which are of if importance to the measurer. The site identification section, at the top of the worksheet, provides the site name and species name, which are used in the identification of the measurements. The specimen number section, at the left, provides the field identification numbers of the cores and a column in which the measurer writes down the core IBM numbers. The dating section provides the core dates which are used to assign dates to the measurements. The measuring section has columns in which the measurer writes down the interval he measures (if not already filled in) and his initials to identify himself as the measurer. If one is the measurement checker, there is a column to write his initials for the cores that he checks. The remarks section contains information from the dater about any problems encountered with, or comments about, the cores. Also in the remarks column, the measurer writes down any problems or comments he has concerning the cores.

Besides the worksheet, the site folder contains the skeleton plots and the core cards which can provide useful core information. The skeleton plots, which were made by the dater, show the exact positions of any missing rings, false rings, and microrings. The core cards, which were completed in the field, do not contain much information for the measurer unless he needs information about the field identification of the cores.

B. Procedure for Assigning IBM Numbers

The first procedure of the measuring process is to assign to each core a six digit computer identification number of which the first three digits identify the site, the next two digits identify the tree, and the last digit identifies the core.

The measurer takes the site worksheet to the data-processing section of the laboratory and obtains the first three digits from the Head of the Data-Processing Section, or his designated representative. In the Site Number Designation File, they record the site name, state and country where the cores were collected, name of the collector(s), and the date when the site number is assigned. They will then give to the measurer the three digit site number. It is best for the measurer to write the three digits at the top of the site worksheet in order to insure that the correct number is assigned.

The measurer sometimes assigns the last three digits. Of these three digits, the first two are used to identify the individual trees starting with 01 for the first tree on up to the total number of trees being measured. For example, if there were twenty-five trees being measured, then the numbers assigned should be 01, 02, 03, ..., 10, 11, 12, ..., 25. The last digit identifies each core of a tree. The numbers used should be 1, 2, 3, etc., depending on how many cores are being measured for any given tree, which usually is only two or three cores per tree.

The last digit is used not only to identify the individual cores, but can also be used to designate certain information about the cores. This can facilitate future analysis of the tree-ring data by making it easier to separate the cores into classes, which are used in the Analysis of Variance. The researcher, who will be using the site for analysis, should determine what the last digit will designate according to the goals of his research design. It is from this person whom the measurer should find out which number system to use for the last digit.

There are three basic last-digit number systems which the measurer will most often encounter. The first number system should be used when the principal investigator wants just to identify one core from another core, or has already assigned letters to the cores for some specific purpose such as north/south exposure, up/down slope, etc. The measurer assigns the numbers 1, 2, or 3 to each of the cores according to the letters used. For example, if a tree has three cores with the identification numbers of 1A, 1B, and 1C, then the last digit for 1A is 1, 1B is 2, and 1C is 3.

Another common system has the last digit signifying the relative age of the earliest ring on the cores -- oldest to youngest. The measurer finds the age of the ~~cores~~ ring by looking on the site worksheet for the date of the inner-most ring. He should assign as the last digit of the with the oldest core ring the number 1, to the next oldest the number 2, and to the youngest the number 3. For example, assume that some tree has three cores (1A, 1B, and 1C) with the date of the inner-most ring of 1A being 1649, 1B being 1725, and 1C being 1609. The oldest core is 1C, so the last digit of its IBM number should be 1; the next oldest is 1A, it should be assigned a 2; the youngest core is 1B, so its last digit should be a 3.

A third number system often encountered by a measurer makes a distinction between the slow and fast growth of a tree. Throughout its circumference, a tree can vary in its rate of growth, which will show up in the cores when they are taken from different areas of the tree. So, for any given year(s), one core may have fewer xylem cells, and thus smaller rings, than will another core from the same tree. A core with smaller rings is considered a slower growing core than a core with bigger rings when their annual rings are compared along the same time interval.

The measurer should use the third system when the principal investigator wants to identify the varying rate of growth throughout the circumference of a tree. The measurer should assign the number 1 as the last digit of the IBM number for the slowest growing core, the number 2 for the next slowest, and the number 3 for the fastest growing core.

However, in trying to decide which cores are the slow and fast growers, a measurer has to be a bit subjective. This is because one core may be the fastest grower in one area, but the slowest grower in another area, when it is compared to other cores. So what the measurer should do is look for the overall growth of the cores, and determine which core, in general, is the fastest or the slowest grower.

A simple procedure for determining the rate of growth is for the measurer to take the cores of a tree and place them next to each other. He aligns them by centuries, and determines which centuries are the slowest and the fastest growing. For example, he aligns the cores at 1700 A.D., and looks along the cores to 1800 A.D. to see which core grew the slowest or the fastest. Then he aligns the cores at 1800 A.D., and determines the growth pattern to 1900 A.D. He does the same for 1900 A.D. to the bark. For the last digit, the measurer assigns the number 1 to the core which is <u>overall</u> the slowest grower, even if it is the fastest grower in some areas. He assigns the number 2 to the next slowest growing core, and assigns the number 3 to the fastest growing core.

If after following the above procedure, the rate of growth looks the same, then the measurer should use the first number system for the last digit of the cores with the same rate of growth. If the measurer has to use the first system, then he should remember one important thing: the purpose of the third number system is to designate slow and fast growth classes; so if there is any feeling, thought, or intuition which makes the measurer feel that one core is growing slower or faster than another core, he should so designate it.

An actual example might make it easier to understand the assignment of the IBM numbers. The Ft. Chimo site (Appendix A) had ten trees with a varying number of cores per tree. The site number, 628, was obtained from the data-processing section. Since the fast/slow growth distinction was desired by the principal investigator, the third number system was used to determine the last digit.

Tree #1 had four cores, but core 1B was not measured because it was not dated. Core 1B did not get an IBM number because only the cores that are measured get an IBM number. The first three digits for the remaining cores of tree #1 were designated 628, since the cores were a part of the Ft. Chimo site. The next two digits for these cores were 01 because the cores were from the first tree. The last digits for the tree #1 cores were determined by the third number system. After placing the cores next to each other, it was found that core 1A was the slowest grower, 1D was the fastest grower, and 1E fell in between. Therefore, the last digit for 1A was 1, 1B was 2, and 1D was 3. The complete six digits for the cores of tree #1 were:

	site	tree	growth
1A	628	01	1
1B	no number - not measured		
1D	628	01	3
1E	628	01	2

Tree #2 and tree #3 were not measured, so they did not get any IBM numbers.

Tree #4 was the next tree measured. Since it was the second tree measured, it was given the tree number 02. The fourth tree had two cores: 4A was the slow grower, 4B was the fast grower. The complete six digit numbers for tree #4 were:

4A	628021
4B	628022

All the rest of the trees were assigned their IBM numbers according to the procedure described above. As the IBM numbers were determined, they were written in the IBM column of the worksheet by the measurer.

At this point, the measurer has completed the first phase of the measuring process. He has acquainted himself with the core materials, and he has assigned the IBM numbers to the cores. It is now time for the measurer to begin the second phase of the measuring process.

III. MEASUREMENT OF THE TREE-RING WIDTHS

A. Description of the Measuring Machines

It is of value to the measurer to know how the measuring machines produce and record the tree-ring measurements. It is more comfortable and enjoyable to spend one's time with someone you know than with a stranger, which is especially true for a measurer, since he spends so much time in the company of a measuring machine. Also, knowing how the machines function aids the measurer in detecting any malfunctions in the machines, or in preventing himself from causing any malfunctions.

There are three different measuring machines used at the laboratory. The first of these is the Physics machine, which was designed and constructed by the Physics Department of the University of Arizona. However, the machine is in the process of being redesigned and debugged. So any description of how it works will be done at some future time.

The second type of measuring machine is the Addo-X, which is used primarily by the Archaeology section of the laboratory. It has two main parts: an Addo-X adding machine and a mechanical stage with a precision screw (Fig. 1). As the handle turns, the precision screw moves the stage a distance equal to the width of the tree ring being measured. The screw is attached to the Addo-X adding machine; so when the screw turns, the Addo-X automatically registers internally the revolutions of the screw with each revolution being equal to

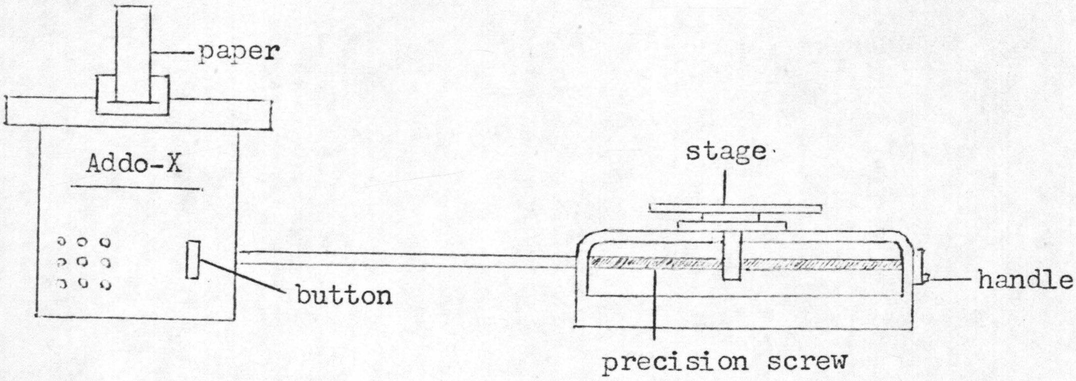


Fig. 1. Addo-X Measuring Machine.

one millimeter. After the ring is measured, the Addo-X button is pushed, and the number of revolutions is recorded on a paper roll. After all the tree rings are measured, the measurer ends up with a paper tape of tree-ring widths, which are measured in hundredths of a millimeter. built by Fred Hermann Co.

The Hewlett-Packard machine is the third measuring machine used at the laboratory. This machine is the one used most often to measure the tree rings. The machine consists of a power supply, transducer, digital voltmeter, and a digital recorder (Fig. 2a).

The Hewlett-Packard works as follows. As the handle turns, a threaded screw moves the stage and the transducer bar a distance equal to the width of a tree ring. The transducer converts the distance into a voltage change (explained below). The digital voltmeter measures the voltage change. The digital recorder prints on a paper tape the voltage readings of the voltmeter, which are equivalent to millimeter readings.

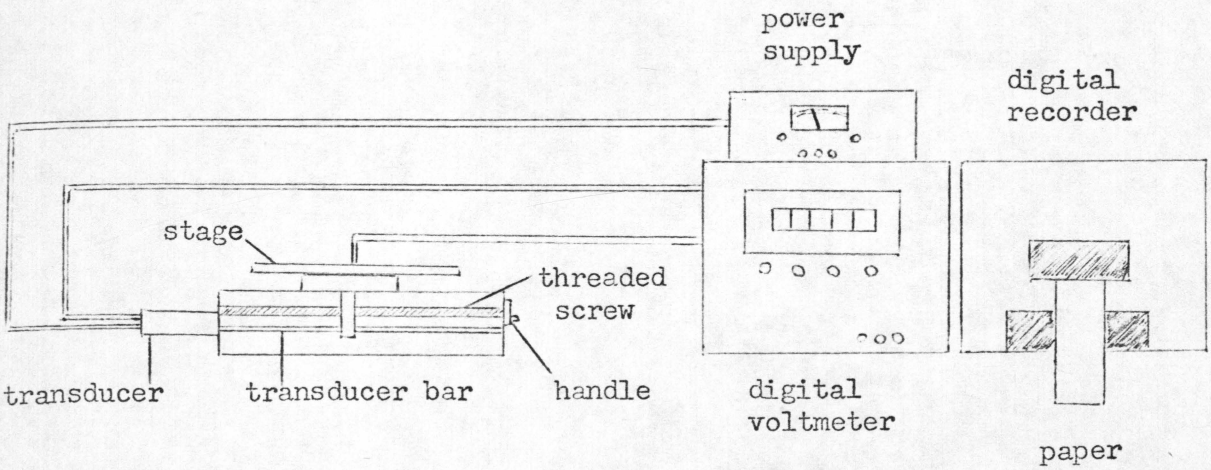


Fig. 2a. Hewlett-Packard Measuring Machine.

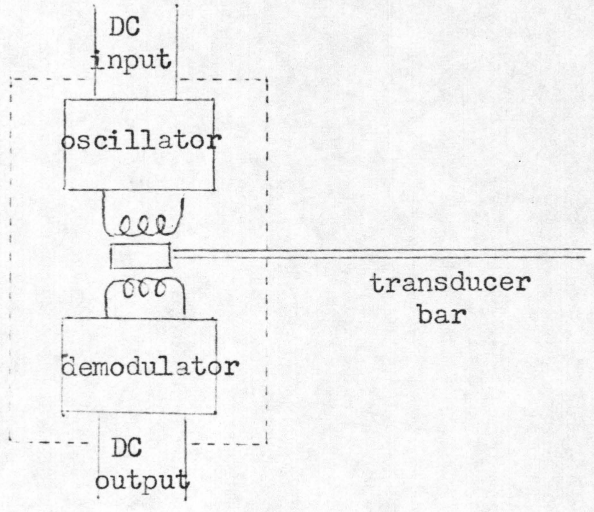


Fig. 2b. Functional Diagram of the Transducer.
(Hewlett-Packard Technical Report 10/68).

The transducer (Fig. 2b) consists of a transformer coil, an oscillator, and a demodulator. The power supply feeds a DC input voltage into the oscillator resulting in a magnetic field. As the transducer bar moves through this field, a voltage change in the output takes place, which is proportional to the distance the bar moves through the magnetic field. The transducer is calibrated in such a way that one millimeter movement of the bar is equal to one volt in the output.

It is the calibration of the transducer -- one millimeter equal to one volt -- which makes the printed voltage readings of the digital recorder equivalent to millimeter measurements of tree-ring widths. The measurements are printed in hundredths of a millimeter. For example, if the recorder prints 153, this means that the tree-ring width is equal to 153 hundredths of a millimeter (or 1.53 millimeters), because of the calibration between volts and millimeters.

This concludes the description of how the different measuring machines work. The new measurer learns how to set up and operate the machines at the time he actually uses the machines. The new measurer should NEVER use the machines unless an EXPERIENCED measurer shows him how to operate them. No written word is sufficient to explain the actual operation of the machines: which dials and buttons to touch, and which ones to keep one's hands off. It takes only a little knowledge and experience to use the machines properly, and a very short time to gain that knowledge and experience. So do it; it can prevent damage to the machines and incorrect measurements.

B. Procedure for Measuring the Ring-Widths

Once the measurer learns how to operate the measuring machines, he is ready to start the measuring of the tree-ring widths. The measurer begins with the preliminary steps of adjusting the equipment and correctly positioning the core under the microscope. Once these steps are completed, the actual measuring of the rings begins.

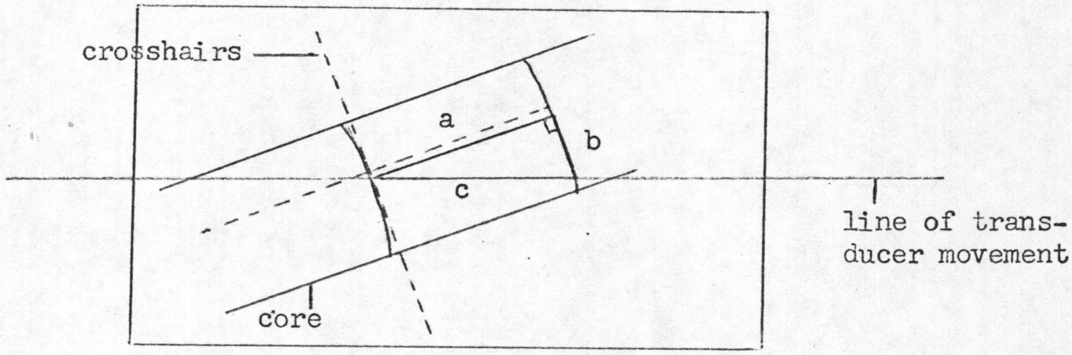


Fig. 3. A ring-width not aligned to the movement of the transducer bar.

A measurer should adjust the equipment -- table, stage, and microscope -- in reference to a straight line. A ring-width measurement is in reality a measurement of the distance that the transducer bar moves along a straight line within the transducer. If the measurement of the ring-width is to be equal to the measurement of the bar distance, then the width of the tree ring must be aligned with the bar movement.

If the ring-width is not aligned with the transducer bar, an incorrect measurement could be made as shown in Fig. 3. The width of the ring that should be measured is represented by side 'a' of the right triangle. If the crosshairs are not aligned with the line of the transducer movement, side 'c' of the right triangle will be the actual length measured resulting in a measurement larger than the width of the ring. The larger the ring, the larger the error will be. With small rings the error is not going to be great, but it still remains that the error could be significant. To eliminate the possibility of this kind of error, the measurer should make sure that the equipment is aligned to the straight line movement of the transducer bar before he begins to measure.

The first step in adjusting the equipment is to align the edge of the stage with the edge of the table so that they are parallel. Part of the stage is the transducer bar, which, as decribed above, is the straight line reference point. Because the stage is not anchored to the table, it is easily moved. If this happens, the transducer bar will no longer be aligned with the stationary table and the microscope. Thus, aligning the edge of the stage with the edge of the table allows the measurer to quickly check that the transducer bar is in the correct position.

The second step in adjusting the equipment on a straight line is to align the cross hairs of the microscope to the stage. The measurer looks through the oculars of the microscope to get the cross hairs into view. Then he raises his eyes from the oculars until he gets into view, at the same time, the cross hairs and the edge of the stage. Then he turns the ocular that contains the cross hairs until the horizontal cross hair is parallel to the edge of the table. The cross hairs now are adjusted to the straight line of the transducer bar (Fig. 4).

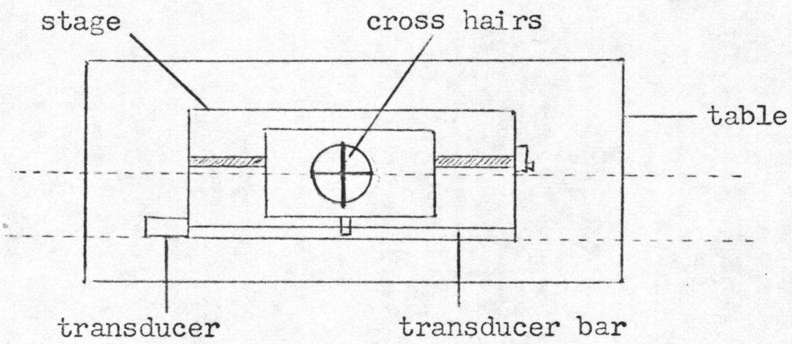


Fig. 4. The Correct Plus Position of the Cross Hairs.

The cross hairs can be placed in two different positions. Either position can be used, so the measurer should use the position that is most comfortable. The correct plus position is shown in Fig. 4. The other position is the X-position, which is shown in Fig. 5. Even if the X-position is used, it is still aligned parallel to the transducer bar.

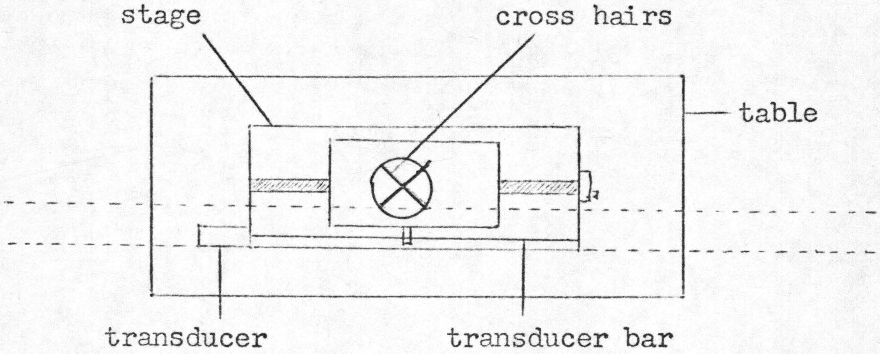


Fig. 5. The Correct X-Position of the Cross Hairs.

Now that the equipment is aligned, the next procedure is to correctly place the core under the microscope. The first step of this procedure is to determine the appropriate line of measurement for the tree-ring width. The second step is to align the appropriate width to the straight line movement of the transducer bar.

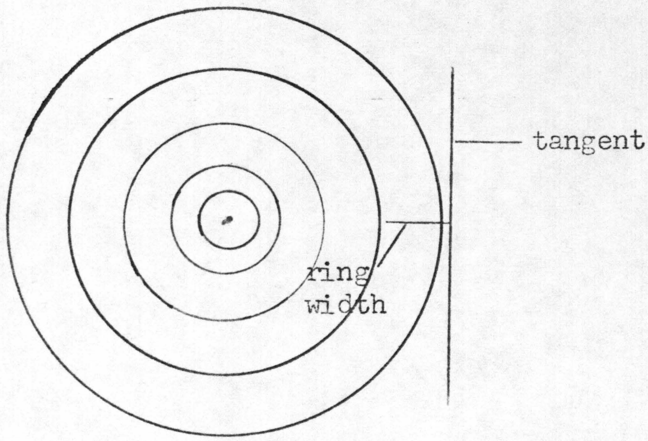


Fig. 6. A Tree Cross-Section with Perfectly Concentric Rings.

If a tree grew perfectly concentric rings (Fig. 6), a ring-width would be the length of the line bound by the previous ring and perpendicular to a tangent of the ring. That is, the ring-width would be some portion of the radius of a circle. It is this portion of a radius which should be measured as the tree-ring width. Thus on a core with perfect rings (Fig. 7), the tree-ring width would be a line perpendicular to a tangent of a ring.

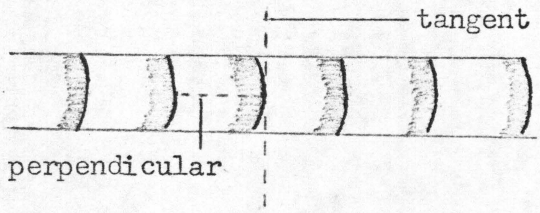


Fig. 7. A Core with Perfect Tree Rings.

However, trees do not grow perfectly concentric rings. There is a large amount of variation of width in many tree rings (Fig. 8).

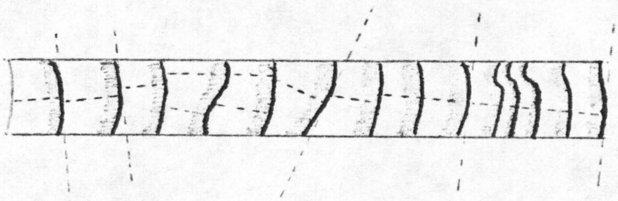


Fig. 8. A Core Showing the Width Variability within Tree Rings. It also shows, through the use of the tangent and perpendicular, the line along which a measurer could measure the widths.

Because of the ring variation, the measurer needs a method which allows him to determine the appropriate ring-width to measure. The measurer should use a tangent and its perpendicular just as if the rings were perfectly concentric. The measurer visualizes a tangent line which looks like the best fit to the outer edge of the ring being measured. Then he visualizes a line perpendicular to the tangent line. It is this perpendicular line which is considered the appropriate ring-width to measure (Fig. 8).

Because the ring varies in width, the measurer might find it difficult to determine the tangent and perpendicular lines for a ring. It is possible for the measurer to find more than one tangent line for a ring, or find more than one perpendicular line for a tangent. When the measurer has this difficulty, he must find an area in the ring that looks like the average width for thr ring. It is a matter of personal judgment, which becomes easier to make as the measurer increases in experience.

Having learned how to determine the appropriate ring-width to measure, the measurer must learn how to correctly position the core under the microscope. As was mentioned earlier, the cross hairs, stage, and table were aligned along parallel lines. This was done to adjust the equipment to the movement of the transducer bar. To properly align the core, it is only a matter of lining up the ring-width to the transducer bar.

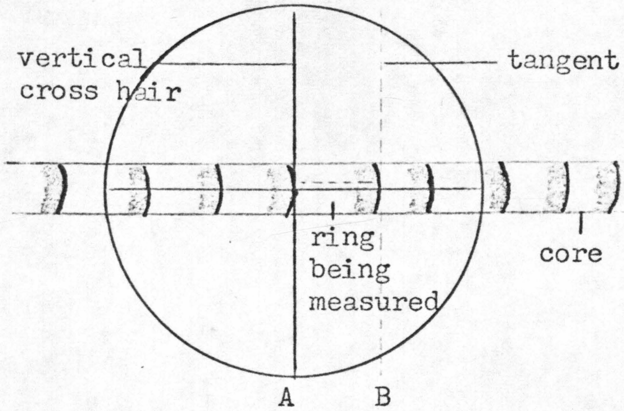


Fig. 9a. The Alignment of the Core Under the Microscope. This is the position of the core and vertical cross hair at the start of measurement.

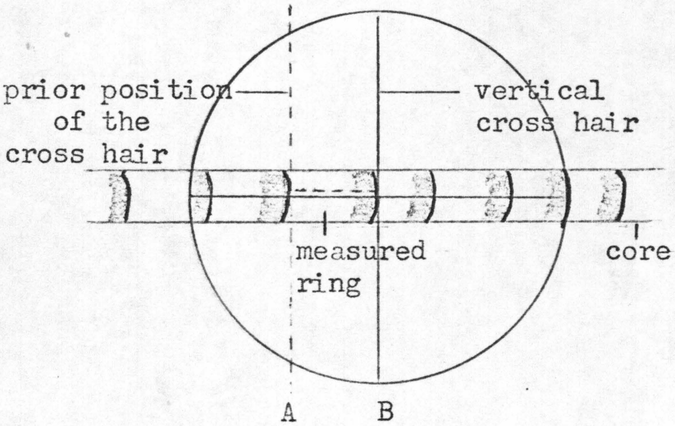


Fig. 9b. Position of Cross Hairs after Measurement. The vertical cross hair is now in the position of the tangent in Fig. 9a.

The procedure for positioning the core under the microscope is as follows. The measurer places the core under the microscope and visualizes the tangent and perpendicular of the ring being measured. He turns the core under the microscope until the tangent is parallel to the vertical cross hair, and the vertical cross hair is touching the edge of the prior ring. At this time (Fig. 9a), the vertical cross hair is in position A, and the tangent, which is parallel to the vertical cross hair, is in position B. The horizontal cross hair is parallel to the perpendicular of the tangent.

Having positioned the core under the microscope, the measurer can now measure the ring-width. The measurer moves the handle on the stage until the vertical cross hair is in position B (Fig. 9b). The vertical cross hair is now on top of the tangent line at the edge of the latewood of the ring being measured. It may appear to the measurer that the cross hairs moved, but in reality it was the core and the stage that moved. After the vertical cross hair is in position B, the measurer presses the stage button. The ring is now measured and recorded. The measurer repeats the procedure until all of the rings are measured.

Now that the measurer knows how to measure the width of a tree ring, there are other things which he must know in order to successfully complete the measuring of the ring-widths. He must know where to begin and end the core measuring, know how to interpret the core markings, and know how to keep from losing his place while measuring a core.

The measurer starts measuring a core with the first complete ring, and he ends his measuring with the last complete ring. For example, as seen on the site worksheet (Appendix A), core 1L-1D has a beginning year of 1762 and an end year of 1974. Since 1762 is only partially present, the measurer starts measuring the first complete year of 1763. The last year dated, 1974, is only partially complete because the tree was cored during the 1974 growing season. Therefore, 1973 should be the last ring measured, because it is the last complete ring.

However, the measurer can notice from the worksheet that the last year measured was 1974. In this case, the dater, or the researcher, determined that enough of 1974 was present to account for a complete ring. Therefore, 1974 was measured. Under normal conditions, the measurer measures only the last complete ring unless he is told to do otherwise. He will be told in the remarks section, or he will find the interval column of the worksheet already filled in.

The measurer must also know how to interpret the core markings (A summary of the core markings is given in Appendix B). When the measurer receives the cores, they are already dated and marked through the use of pinpricks, which are easily seen under the microscope. The dater marks the cores for the years, missing rings, microrings, and false rings.

The years are marked as in Fig. 10. A single pinprick stands for a decade. Two vertical pinpricks stand for half a century, and three vertical pinpricks stand for a century.

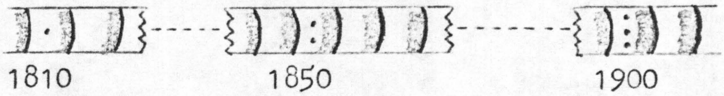


Fig. 10. The Core Markings for Years.

A missing ring is designated by two diagonal pinpricks with one on each side of the latewood edge of the ring which lies immediately before the missing ring(Fig. 11). The missing ring is measured as a zero by pressing the stage button without moving the stage.

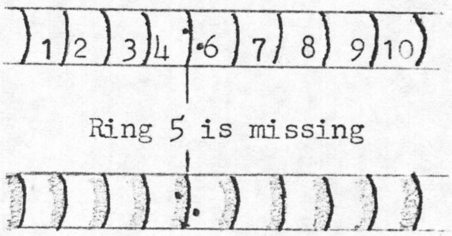


Fig. 11. The Core Marking for a Missing Ring.

A microring is designated by two horizontal pinpricks with one on each side of the microring (Fig. 12a). It is marked in this way in order to tell the measurer that a ring is present. It is measured just like any other ring. However, the microring may be so small that the measurer may not be able to see the ring. It will look like the two pinpricks are on each side of a single latewood edge (Fig. 12b).

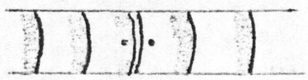


Fig. 12a. The Core Marking for a Microring.

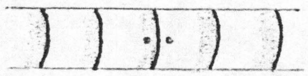


Fig. 12b. What the core marking for a microring looks like when the microring cannot be seen.

The dater determined that a microring is present. In this case, the measurer should barely move the stage handle in order to register a very small number, preferably the number one.

Occasionally, a microring and a missing ring are present at the same spot. In this case, three pinpricks are used to designate a combination of both a microring and a missing ring (Figs. 13a and 13b).

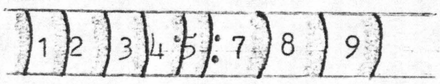


Fig. 13a. The Core Marking for a Combination of a Microring and a missing ring. Ring #5 is the microring and Ring #6 is the missing ring.

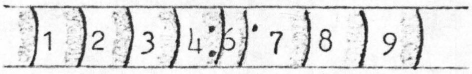


Fig. 13b. The Core Marking for a Combination of a Missing Ring and a Microring. Ring #5 is the missing ring and Ring #6 is the microring.

Whether the missing ring comes before or after the microring depends on the positioning of the three pinpricks. If there is one pinprick before the microring, and two vertical pinpricks after the microring, then the microring is measured before the missing ring. For example, in Fig. 13a, the fifth and sixth rings must be accounted for. Since the single pinprick comes before the two vertical pinpricks, ring 5 is the microring, and ring 6 should be considered the missing ring. If there are two vertical pinpricks before the microring, and one pinprick after the microring, then the missing ring is measured before the microring. For example, in Fig. 13b, Since the two vertical pinpricks comes before the single pinprick, ring 5 should be considered the missing ring, and ring 6 is the microring. In general, the missing ring is measured first, if the two vertical pinpricks come first; the missing ring is measured second, if the two vertical pinpricks come second.

Because of the slow growth in the area of microrings and missing rings, more than one microring or missing ring may occur. It may be difficult to interpret the pinpricks. For example, :):, could be a correct combination of pinpricks. However, it is very hard to determine which ring should be designated the microrings and the missing rings. In cases like this, a measurer has to look in the remarks section of the worksheet to see if the dater explained which rings are which, or he can use the skeleton plots, which should show the positions of the microrings and the missing rings.

False rings are those rings which have a slash through them (Fig. 14). The measurer measures through the false ring as if the false ring were not there.

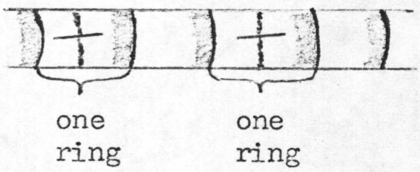


Fig. 14. The Core Marking for a False Ring.

Although there is no special core marking for a break, something must be said about how to handle breaks when they are encountered during measuring. Breaks should not be measured as a part of any ring (Fig. 15). If a break occurs within a ring, the measurer measures the first part of the ring up to the edge of the break. He then moves the core, without registering the measurement, until the cross hairs are aligned with the other side of the break. He then continues measuring the ring. Only after the measurer reaches the outer edge of the latewood, will he record the measurement.

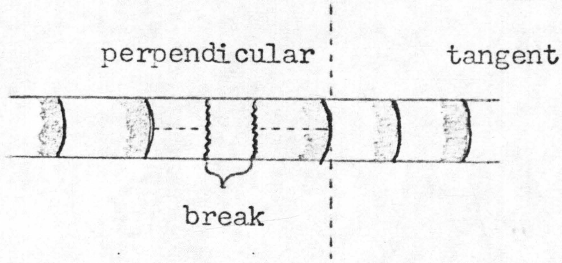


Fig. 15. Breaks are not Measured as a Part of a Ring.

If the measurer has any problems with the core markings, or any doubts as to which ring goes where, then he should go to the dater of the cores. The dater worked out the dating pattern, so he should be able to solve the measuring problems. It is up to the dater to make sure that the cores are properly marked. It is up to the measurer to make sure that all the rings for each decade are measured.

The measurer should also know how to keep from losing his place while measuring. Since the machines, except for the Physics machine, do not print out the decade dates when the measurements are recorded, the measurer should devise some system to keep track of where he is. The measurer can use any system that he chooses. I find it easiest to skip a space between each decade, and I mark on the paper tape the date for each half century and century. Then if I make a mistake or I lose my place, I can easily look at the tape to determine exactly where I am.

The measurer has a few more things to do before the procedure for measuring the ring-widths is completed. After a core has been completely measured, the measurer should write on the paper tape the field and

IBM identification numbers in order to identify one core's measurements from another core's measurements. The measurer should also write the IBM number, date measured, and his initials on each core. Finally, he should enter on the worksheet his initials and the interval he measured for each core.

Before we leave this section on ring-width measuring, it is best to point out that cores are not the only type of tree specimen which the measurer will have to measure. Sometimes the measurer will have to measure whole cross sections of a tree. The measuring procedure for cross sections is the same as described above. The only difference is that the cross sections are marked with a number of radial lines, which are measured as if each line were a core. The measurer should try to measure as close to the radial line as is possible, in order to help the checker find the correct area to check.

A description of the procedure for measuring ring-widths is now complete. The procedure for adjusting the equipment and measuring the rin-widths, the things a measurer must do to successfully complete the measuring procedure, and the procedure for measuring cross sections were described. It is now time to go into the procedure for mounting the ring-width measurements.

C. The Procedure for Mounting the Ring-Width Measurements

The ring-width measurements are printed on paper tapes by the machine. The paper tapes are perforated where the tape is folded. Since the tape easily tears at the perforations, the ring-width measurements are pasted onto 8½" by 11" sheets of yellow paper, in order to facilitate the storage of the measurements and to prevent the lose of the measurements.

The first step of the mounting procedure is for the measurer to make sure that all of the rings are present and marked by decades. The measurer should count each decade in order to make sure that ten rings are present. He then should write to the right side of the measurements the dates for the first and last year measured and the date for the beginning year of each decade. Next, he should underline each decade.

The next step is for the measurer to cut off all the extraneous paper leaving only the ring measurements and the dates to the right side of the measurements.

The measurer then pastes the ring-widths onto 8½" by 11" yellow sheets of paper starting in the lower left-hand corner of the sheets (Appendix C). If there are too many ring-widths for a single sheet of paper, the measurer uses additional sheets, which he tapes together.

The next step is to identify the ring-width measurements for each core by writing in the upper right-hand corner of the first sheet the following (Appendix C): name of the site, field identification number, IBM identification number, scientific name of the tree, dated interval, initials of the dater, measured interval, and the initials of the measurer.

If there is more than one sheet of measurements for a core, the measurer writes on each additional sheet: site name, field identification number, and IBM identification number. This is done in order to insure that the measurements are identified in case the sheets become separated.

The last step of the mounting procedure is for the measurer to check to see that all of the cores have been measured and that all of the measurements have been mounted. The measurer also checks to see that all of the measurements have been properly identified.

Once the measurer has completed the mounting procedure, the second phase of the measuring process is complete. The measurer has familiarized himself with the measuring machines. He has measured all of the tree-ring widths. Finally, he has mounted all of the ring-width measurements. It is now time for the measurer to move onto the last phase of the measuring process, which is described in the next section of this paper.

IV. PROCEDURE FOR CHECKING THE RELIABILITY OF THE MEASUREMENTS

A. The Statistical Test

It is of importance that the ring-width measurements be as accurate as possible, since they form part of the basic data used in the analysis of tree rings. Care is taken at each step of the measuring process to eliminate as much error as possible. Due to the precision of the machines, the machine error is negligible. The largest and most significant error in tree-ring measuring is due to human error. So it is of importance that some check be made on the reliability of the measurer's measurements.

One procedure that could be performed is to have two people measure a site and then average the measurements. However, to accomplish this, a great deal of time must be invested on the part of both measurers. To save time, and still arrive at an even more reliable check, a statistical method has been devised to objectively check the accuracy of the measurements.

Before we get into a description of the statistical check, it is important to note that a measurer never checks his own measurements. The purpose of the checking procedure is defeated if a measurer checks himself, since it is both the measurer and the ring-widths which are being checked. Another measurer will check the reliability of the ring-widths. In addition, the same machine used by the measurer is also used by the checker because there may be a difference in measurements from one machine to another.

The first step in the checking procedure is to take a sample of the cores from the site which is being checked. One-third, or more, of the cores from a site are selected for checking. The easiest way to select the cores is to take the site worksheet and check off one-third, or more, of the cores in a random manner as the measurer moves down the sheet.

Once the checker has determined which cores will be sampled, then the next step is to select a sample of the rings from the chosen cores. The entire core is not checked; only one-third, or more, of the total number of rings of a core is checked. The easiest way to choose the rings is to take the measurements for each of the chosen cores and pick out twenty-year intervals throughout the cores which represent one-third of the rings. Two consecutive decades are chosen as the twenty-year intervals. To illustrate, the intervals could be 1930-49, 1820-39, 1910-19, etc.

The next step is to measure the selected twenty-year intervals, which will then be compared with the ring-widths of the original measurer.

The statistical test is done as follows (Appendix E). The checker writes the ring measurements into the columns of the large-squared graph paper (Appendix D). The original measurements are listed in the first column, and the checker's measurements are listed in the next column. The checker subtracts the two measurements. He squares the individual differences. Then he adds up the squared differences for each 20-year interval. If the cores are conifers from a typical arid site and if each of the sums of the squares for each 20-year interval of the core is equal to or less than the acceptable limit (0.10), then that core is considered to be measured accurately (Appendix E). The checker performs this operation for each of the selected cores. If all of the cores are acceptable, that is, if each of the sums of squares is equal to or less than the limit, then the entire site is accepted as being measured accurately.

The limit set at 0.10 or less for each of the 20-year intervals is used for arid-site conifers, but not for Quercus (oak). Due to the large vessels which grow within an oak tree ring, the latewood edge is distorted. A second measurer could not replicate the ring-width measurement unless he happened to hit the exact spot of the original measurement. In order to take into account problems with this species, the sums of squares limit had to be increased. For oak, the sum of squares is acceptable if it is equal to 0.175 or less (Appendix F). If other species and sites are encountered with measuring problems unlike the above, a new population of sums of squares may have to be generated by expert measurers and a new acceptability limit obtained.

B. The Interpretation of the Results of the Statistical Test

Theoretically, if any of the 20-year intervals fail the test, then all of the site ring-width measurements should be rejected. This is due to the nature of a statistical test. Since the sample chosen is supposed to represent the entire population, the acceptance or rejection of the sample determines whether the entire population will be accepted or rejected.

However, some of the twenty-year intervals could fail the test, and yet the ring-width measurements might still be accept~~ed~~able. The twenty-year intervals could fail the test for one of two reasons. First, the errors due to ring variation might cause the failure. Second, the errors due to the measurer might cause the failure. If the checker can attribute the failure to ring variation, then the measurements could be acceptable.

To discover which of the two errors is at fault, the following procedure is used. The checker looks at the twenty-year intervals which are over the acceptable limit. Within the twenty-year intervals, there probably will be only a few of the measurements which caused the intervals to exceed the limit. The checker remeasures each of these problem ring-widths three or more times distributing the measurements over the entire ring in order to get some idea of the range of variation within the problem rings.

If both the measurer's ring-widths and the checker's ring-widths fall close to, or within the range, then the discrepancy is due to ring variation and not due to measuring error. To illustrate, in Table I, ring #1 has a wide range of variation -- 95-125 -- with both the measurer and thr checker falling within the range. The checker should conclude that it was the core variation which caused the trouble. The measurer and the checker had only measuredin two different places within the ring.

Table I. Measurements of two rings with differing ring variation.

	Ring #1	Ring #2
Measurer	123	120
Checker	98	103
Remeasured values of the Rings	95, 120, 125	99, 103, 105
Range of the Remeasured Values	95-125	99-105

If the error is due to ring variation, like in ring #1, then the checker accepts the measurer's ring-widths as being correct. An average of all the measurements for a particular ring could be used for the ring-width value, but an average is not used in order to save time. There is no way of knowing, from just a core sample, what a ring's variation is like throughout the circumference of a tree. An average ring-width value taken from a core could be unrepresentative of the average ring-width value of the ring around the entire circumference, since it is quite common for some rings to have a very wide variation in width throughout the circumference of a tree. It is quite conceivable that the measurer's measurement could be the best representative width for the entire ring. Therefore, in order to save the time which would be used to average the values, the checker accepts the measurer's ring-width as being correct, if the discrepancy between the checker's and measurer's ring-widths is due to ring variation.

The checker then changes, on the checking worksheet, his measurement to one of the remeasured width values which is closest to the measurer's measurement. An average value of the remeasured width values could be used, but it is not done in order to save time. At this stage of the checking procedure, the checker is only trying to determine why the measurements failed the test. Since the checker knows that the failure was due to ring variation and he has already accepted the measurer's ring-width as being correct, the checker needs only a value (one of his own remeasured values), which will be close enough to the measurer's width value, to pass the sum of squares test.

Once all of the problem rings have been checked by the procedure above, and the measurement discrepancy between the checker and the measurer has been attributed to ring variation, then the checker performs the statistical test over again. If the twenty-year intervals of a core now fall within the limit, then the checker temporarily accepts the core measurements. If all of the cores are now acceptable, then he temporarily accepts the entire site measurements as being correct.

If, after taking three measurements of a ring, the checker finds that the measurer's measurement is out of the range of the remeasured values, i.e., they exceed the sum of squares test, then he concludes that the discrepancy between the checker's ring-width and the measurer's ring width is due to the measurer's error. To illustrate, in Table I, ring #2 has a small range of variation (99-105) with only the checker falling within the range. Since the measurer is outside of the range, the checker concludes that the measurer made an unacceptable measurement error. It is this type of error that the checker is trying to find. It is this type of error for which the entire set of measurements will be rejected.

So far in this section on the interpretation of the statistical test, the checker has been making the decisions on the acceptance or rejection of the measurements. It is quite acceptable for the checker to do this on a limited basis if the checker remembers that the final judgment belongs to the principal investigator who will be using the tree-ring data for analysis. It is the investigator's responsibility to insure that he is using correct data, and it is his reputation as a researcher that is at stake if wrong conclusions are made based on bad data.

Therefore, it is important for the checker to know exactly what the limits are to his decision-making. There are two instances where the checker will be the final judge and will not have to consult the site researcher. First, if the entire checking sample passes the statistical test on the first try, then the checker can accept the site measurements as being correct. Second, if the measurer determines that the discrepancy between himself and the measurer is due <u>clearly</u> to ring variation (not measurer's error) then the checker should correct the measurement if appropriate or, in severe cases, have the site remeasured. In the latter case, the severe discrepancies should be reported to the principal investigator. If the checker has determined that any one of the ring-width discrepancies was due to the measurer's error, then he must take the measurements to the researcher to have him make the acceptance or rejection decision.

The checker should write on the checking worksheet whenever he changes the first measurement to one of the remeasured values which was close to the measurer's ring width. The checker should also write down on the checking worksheet the remeasured values. If there is any doubt about his decision, he should consult the researcher as to whether or not his decision was correct. He should never make the decision when a measurer's error is detected.

Once the ring-width measurements have been accepted, the checker pastes his checking measurements on yellow sheets of paper in order to facilitate storage and prevent the loss of the checking measurements. To conserve paper, the checker should squeeze as many of the measurements on one sheet as he can. He then identifies each core's checking measurements by placing the site name, core number, the words 'measurement check', and his initials at the top of each of the core's measurements (Appendix G).

Once the checking measurements are mounted, the checker places the checking worksheet and the mounted checking measurements into the site folder. He then returns the site folder and the cores to the person who measured the site. The checking procedure is now complete.

V. CONCLUSION

The description of the measuring process is now complete. Any person who desires to measure ring-widths should now have the necessary background information to enable him to produce accurate ring-width measurements.

The measurer should now know that the measuring process starts when he familiarizes himself with the core materials, seeks out the necessary measuring information contained in the core materials, and assigns the computer identification numbers necessary for all subsequent analysis of the tree-ring data.

The measurer should have learned that the actual measuring of the ring-widths begins during the second phase of the measuring process. He should also have learned something about how the machines operate, the procedures used in the actual production of the ring-width measurements, and how to preserve the measurements from loss.

The measurer should also know that he may be called upon to be a checker during the third phase of the measuring process. When he is called upon to be a checker, the measurer should know how to statistically test the ring-widths, and how to interpret the results of the test.

In short, the measurer should know how to produce accurate quantitative data, which is needed by all dendrochronologists for their scientific inquiries. With this quantitative data supplied by the measurer, a dendrochronologist is prepared to defend his position whenever he is accused of mixing his apples with his oranges.

A. Example of a Site worksheet

LABORATORY OF TREE-RING RESEARCH

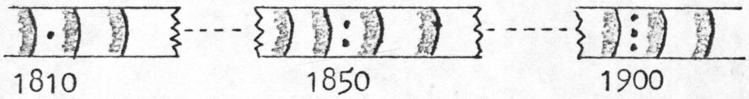
Site Ft. Chimo Site (1L), Diana Lake West, Ungava, Canada — Collection date August 7, 1974

Species Larix laricina — Collector H. C. Fritts, Jaan Terasmas, — Wini

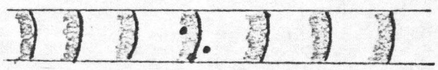
Specimen Number: Field	Lab.	IBM	Core no.	Core length	Dating: Inner-most	Bark year	Dated by	Ckd. by	Measured: Interval	By	~~NAL~~ MEAS CHECK	Remarks
1L - 1A		628011			1738p	1974B	MAW	TPH	1739 - 1974	JMB	JBH	
1B												
1D		628013			1762	1974	MAW	TPH	1763 - 1974	JMB		
1E		628012			1744	1974	"		1745 - 1974	JMB		
1L - 2					1892+	1974	"	TPH	—			mounted incorrectly
1L - 3	missing core											
1L - 4A		628021			1722	1974	MAW		1723 - 1974	JMB	JBH	
4B		628022			1722	1974	"		1723 - 1974	JMB		
1L - 5A		628031			1769p	1974	"		1770 - 1974	JMB		disregard extra material outside
1L - 6A		628042			1717p	1974	"	TPH	1718 - 1974	JMB	JBH	
6B		628043			"	"	"		" "	JMB		
6C		628041			"	"	"		" "	JMB		
1L - 7		628051			1815	1974	"	TPH	1818 - 1974	JMB	JBH	
1L - 8A		628061			1793	1974	"	TPH	1794 - 1974	JMB		
8B		628062			"	"	"		" "	JMB		
1L - 9A		628071			1799p	1974	"	TPH	1800 - 1974	JMB	JBH	
9B		628072			"	"	"	TPH	" "	JMB		
1L - 10A		628081			1806	1974	"	TPH	1807 - 1974	JMB		

B. Summary of Core Markings

1. Years:

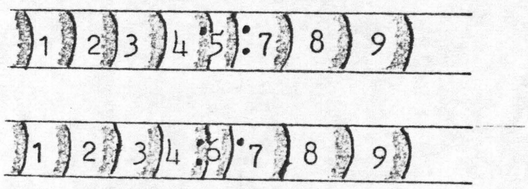


2. Missing Ring:

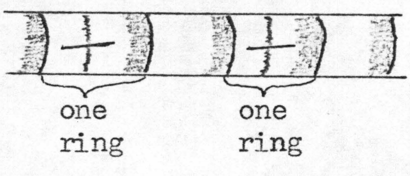


3. Microring:

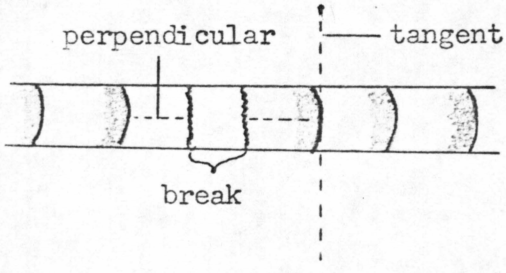
4. Combination of Missing and Microrings:



5. False Ring:



6. Break:



C. Example of Mounted Ring-Width Measurements

Nain A, Labrador 421.

16 A

862161

Picea glauca

dated: 1897-1974 JMB

meas: 1898-1973 JMB
7/75

[illegible]
01[illegible]8
0147
[illegible] 1930

0149
0243
0258
0264
02[illegible]8
0216
0228
0206
0183
0190 1920

0173
0124
0148
0134
0090
0060
0054
0157
0200
0138 1910

0147
0138
0124
0123
0080
01[illegible]
0077
0101
0112
0087 1900

008[illegible]
009[illegible] 1898

0154
0131
0163
0116
0123
0137
0122
0120
0149
0154 1960

0156
0143
0145
0118
0141
0106
0074
0122
0134
0128 1950

0097
0091
0087
0099
0091
0057
0064
0071
0079
0084 1940

0089
0111
0079
0093
0159
0120

0161 1973
0143
0114
0174 1970

D. Example of a Checking Worksheet

Nain A, Salvador

16A

862161

		MEAS JMB	MEAS SS	DIFF	SQ DIFF			MEAS JMB	MEAS SS	DIFF	SQ DIFF
19	20-	190	193	3	9	19	50-	128	131	3	9
19	39	183	179	4	16	19	69	134	135	1	1
		206	208	2	4			122	118	4	16
		228	224	4	16			74	72	2	4
		216	213	3	9			106	105	1	1
		238	231	7	49			141	141	0	0
		264	270	6	36			118	123	5	25
		258	257	1	1			145	148	3	9
		243	241	2	4			145	144	1	1
		149	148	1	1			156	157	1	1
		203	202	1	1			154	156	2	4
		147	145	2	4			149	149	0	0
		128	129	1	1			120	121	1	1
		145	147	2	4			122	123	1	1
		120	125	5	25			137	140	3	9
		159	169	10	100			123	124	1	1
		93	97	4	16			116	116	0	0
		79	85	6	36			163	166	3	9
		111	113	2	4			131	132	1	1
		89	93	4	16			154	160	6	36
					352						129

Laboratory of Tree-Ring Research
TEST FOR ACCURACY OF RING-WIDTH MEASUREMENTS.

1. Measure 20 successive rings twice in hundredths of a millimeter using the same measuring machine.

2. Subtract each ring width from the corresponding ring width in the other measured series.

3. Square the differences between each of the 2 measurements (expressed in hundredths of a millimeter, i.e., decimal point to the right, xxx.) and sum the squared differences over a 20-year period.

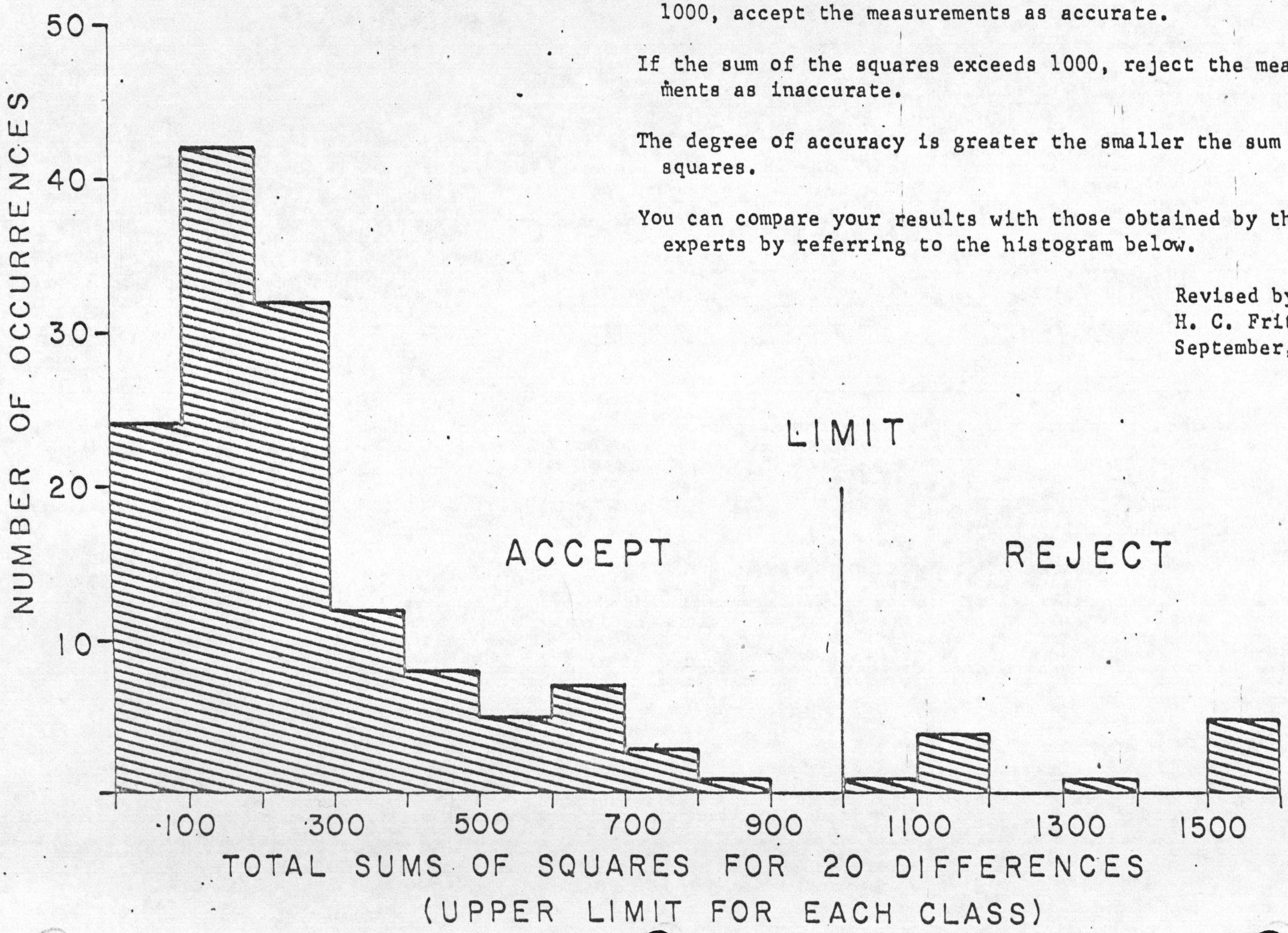
If the sum of the squares of the 20 differences is less than 1000, accept the measurements as accurate.

If the sum of the squares exceeds 1000, reject the measurements as inaccurate.

The degree of accuracy is greater the smaller the sum of the squares.

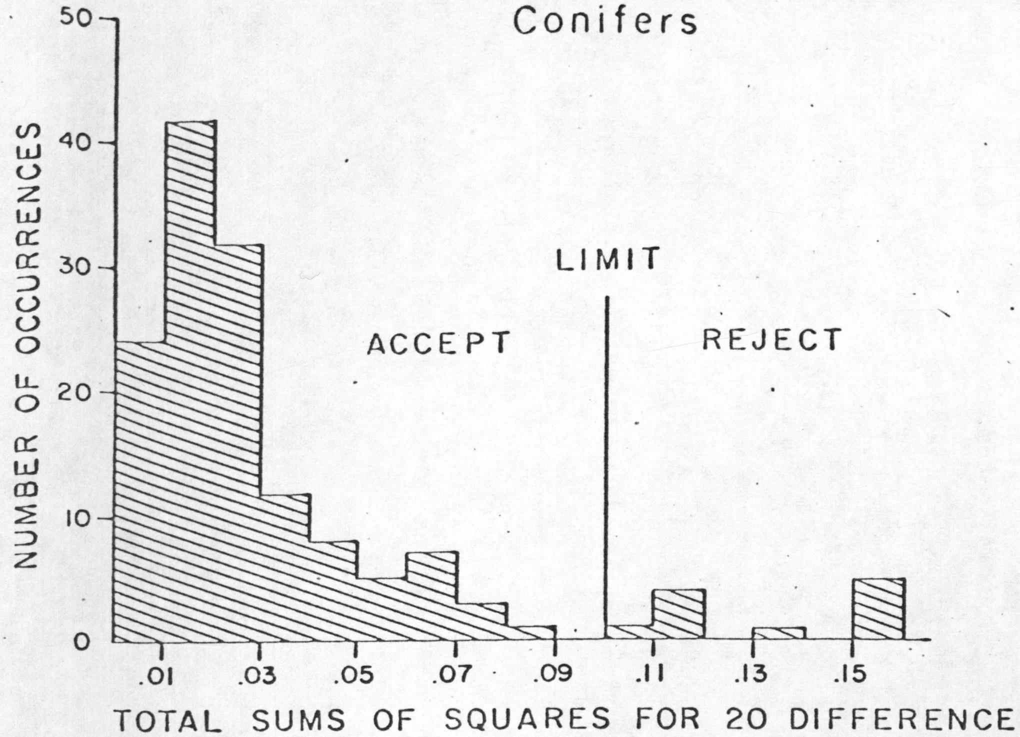
You can compare your results with those obtained by the experts by referring to the histogram below.

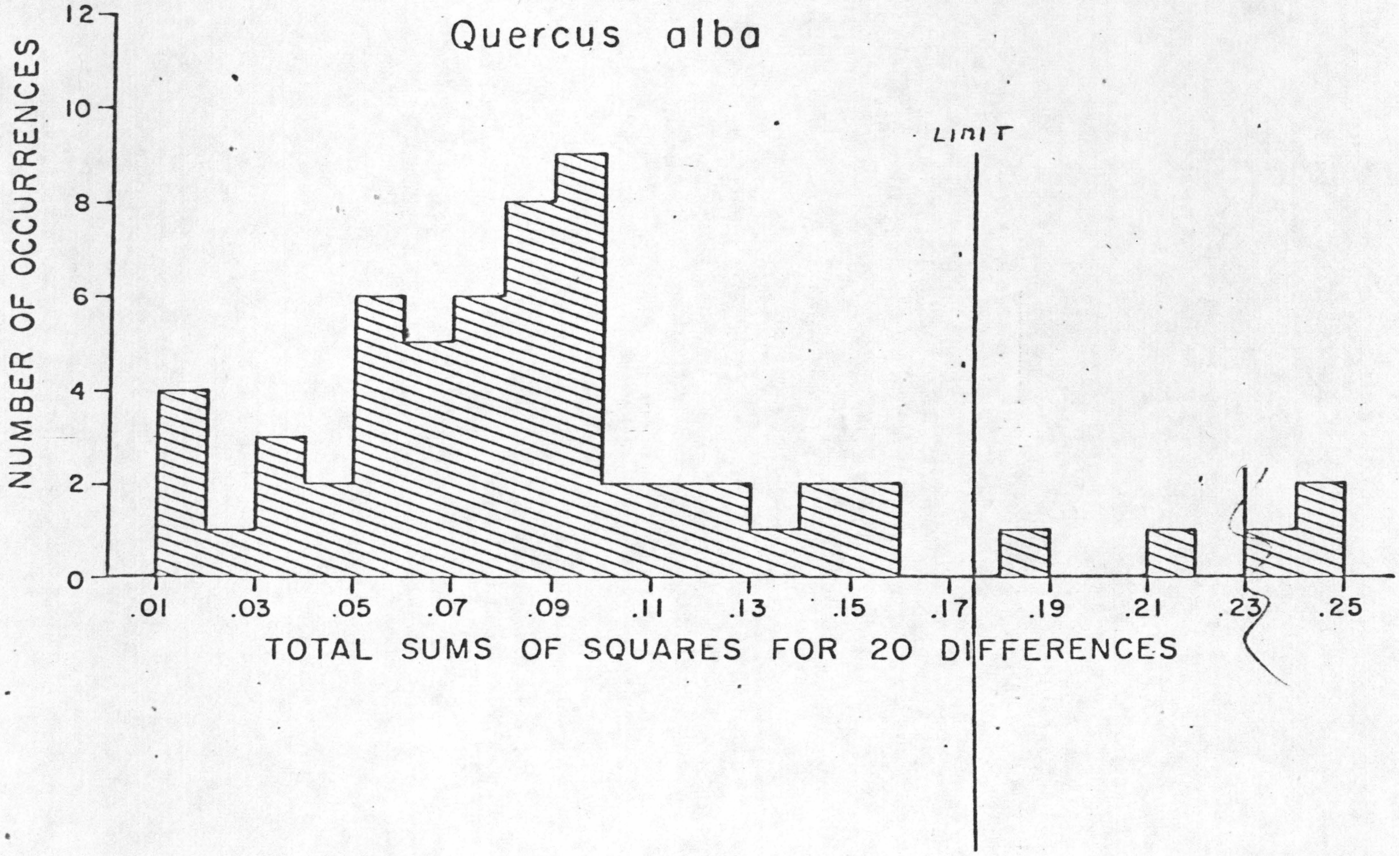
Revised by
H. C. Fritts
September, 1973



E. Plot of the Distribution of Sum of Squares with Appropriate Acceptability Limit for Arid-Site Conifers

F. Plots of the Distribution of Sum of Squares with Appropriate Acceptability Limits for Arid-Site Conifers and for Oak





(from Fritts, H.C., Tree Rings and Climate, Chap. 6, in press)

Fig. 6-1

G. Example of Mounted Checking Measurements

NAIN A 13A

meas check

0089
0047
0082
0042
0058
0084 1880
0047
0069
0085
0056
0077
0073
0078
0054
0040
0084 1870

0093
0101
0064
0068
0097
0156
0126
0176
0145
0188 1830
0123
0137
0145
0181
0135
0135
0164
0170
0162
0137 1820

S.S.

0108
0087
0103
0085
0103
0151
0084
0102
0112
0099 1950

0047
0039
0048
0049
0044
0042
0048
0042
0066
0034 1910
0041
0045
0051
0070
0030
0067
0044
0040
0061
0039 1900

0049
0049
0048
0061

0079
0083
0105
0092
0095
0089
0086
0119
0143
0113 1960

NAIN A 16A

meas check

0124
0140
0123
0121
0149
0156 1960
0157
0144
0143
0123
0141
0105
0072
0118
0135
0131 1950

0095
0113
0085
0097
0169
0125
0147
0129
0145
0202 1930
0148
0241
0257
0270
0231
0213
0224
0208
0179
0193 1920

S.S.

0160
0132
0166
0116

NAIN A 17A

meas check

0093
0080
0062
0075
0108
0096 1950
0088
0086
0075
0116
0096
0097
0092
0095
0107
0082 1940

0151
0115
0138
0133
0098
0115
0153
0139
0161
0093 1910
0114
0107
0111
0111
0081
0147
0111
0147
0160
0132 1900

S.S.

0091
0084
0093
0074