



Dendrochronology Manual
Tree-Ring Laboratory
Ugyen Wangchuck Institute of Conservation and Environmental
Research And
Forest Resources Management Division

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Foreword

Dendronchronology is gaining momentum in Bhutan and many are acknowledging its vast applications in forest and climate science. Dendroscience played immense role in the National Forests Inventory, which was spearheaded by the Forests Resources and Management Division (FRMD) within Department of Forests and Park Services (DoFPS). This manual developed by the Ugyen Wangchuck Institute for Conservation and Environmental Research, DoFPS, could not have been timed better, and it shall undoubtedly be one of the valuable contributions to scientific community in Bhutan.

I remain appreciative of the concerted efforts put on by FMRD in soliciting funds and helping us realise our dream of producing this manual. I strongly believe that this manual shall not only cater to the needs of academicians but also to those who are venturing into the science of dendrochronology. I think it will be particularly highly useful to those who are interested to learn tree-ring science and provide much needed guidance and references even to the university students.

I congratulate the institute for coming up with this manual and commend the authors for their hard work.

Director
Department of Forest and Park Services

ACRONYMS AND ABBREVIATION

RGoB	:	Royal Government of Bhutan
MoAF	:	Ministry of Agriculture and Forests
DoFPS	:	Department of Forests and Park Services
UWICE	:	Ugyen Wangchuck Institute for Conservation and Environment
CFST	:	Centre for Forest Science and Technology
FRMD	:	Forest Resources and Management Division
NFI	:	National Forest Inventory
DRO	:	Digital Read Out
FYOG	:	First Year of Growth
LYOG	:	Last Year of Growth
LW/AW	:	Late/Autumn Wood
EW/SW	:	Early/Spring Wood
CW	:	Compression wood
RD	:	Reaction wood
GD	:	Growth Difference

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Chapter 1

Introduction

Bhutan's geographical diversity, combined with diverse climate conditions, contributes to country's outstanding range of biological and ecosystem diversity and intact natural heritage. According to National Forest Inventory report, 2016, Bhutan has 71% of the country covered with forests. An article 5 of the Constitution of the Kingdom of Bhutan mandates that 60 percent of the country's land area to remain forested for all times to come. To maintain this mandate, the Department of Forests and Park Services (DoFPS), Ministry of Agriculture and Forests (MoAF) is challenged to balance the country's growing demand for timber, with maintaining the integrity and natural health of its forests. Towards this goal, DoFPS adopted/ adapted many new silvicultural practices and tools and one such tool is dendrochronology. Dendrochronology initially came to Bhutan in 2002 as part of the Conifer Research and Training Partnership (CORET) program in collaboration with the Tree Ring Laboratory of the Lamont Doherty Earth Observatory (TRL-LDEO), Columbia University, United States of America. At that time, tree-ring research was focused in the conifer forests with an emphasis on environmental change. After phasing of the CORET Project in Bhutan, the TRL-LDEO continued their collaboration with DoFPS to develop a program of tree-ring science in Bhutan. With their support, the first fully operational tree-ring laboratory in Bhutan was established at the then Research Development Center, Yusipang, now renamed as Conifer Forest Research Sub-Center housed within the Ugyen Wangchuck Institute for Conservation and Environmental Research (UWICER). In addition to this facility, the College of Natural Resource (CNR), Royal University of Bhutan also houses Tree-Ring Laboratory established in the year 2008.

The use of dendrochronology laboratory gained greater importance with the intention to generate increment and growth data through the national forest inventory (NFI) initiated in 2009. Thus, the collaboration between Forest Resources Management Division (FRMD) and erstwhile RDC, Yusipang was formalized in 2010 to work on analysis of tree cores collected through national forest inventory and on development of allometric equations for biomass. These collaborative activities were supported through Bhutan Trust Fund for Environment Conservation (BT FEC), FAO under UN-REDD–TS, EU, Forest Carbon Partnership Facility (FCPF) supported REDD Readiness project and through BMUB supported GIZ_ICIMOD REDD+ Himalayas project . These support enabled building of institutional capacity of the dendrochronology laboratory through installation of state-of-art equipment and skill development of relevant officials.

This dendrochronology manual is one of the important output targeted through this collaboration and publication supported by the BMUB funded GIZ_ICIMOD REDD+ Himalayas project.

This manual is being developed with the objective to serve as a reference for tree ring sample collection methods and laboratory protocols. It has been designed to guide the users in various aspects of dendrochronology: collecting core samples, preparing the samples, measuring and building a tree-ring chronology.

1.1 What is dendrochronology?

- Dendro : The Greek word for “tree”,
Chronology : “The science that deals with time and assignments of dates to particular events”.
- Dendrochronology: It is the study of precisely dated tree rings.
Dendrochronology as a tool in environmental science, may be applied wherever trees are found with distinct annual rings. Dendrochronology is possible because most of the tree species produce distinct annual rings.

1.2 Sub-fields of Dendrochronology

Dendroarchaeology:	Dating of archaeological monuments
Dendroclimatology:	Developing a record of past climates
Dendrogeomorphology:	Dating geomorphological events and their movement
Dendrohydrology:	Study of periodical river flow and flooding events
Dendroglaciology:	Study of past glacial retreats and expansion
Dendrovolcanology:	Dating volcanic eruptions
Dendrochemistry:	Monitoring soil chemistry or tree health
Dendroecology:	Study of ecological processes such as tree line movement, insect outbreaks, and distribution of invasive tree species
Dendropyrochronology:	Studying and dating past forest fires events and their impacts
Dendroentomology:	Reconstructing past insect population levels and impacts
Dendromastecology:	Reconstructing cycles of fruit years.

1.3 Types of Tree-Ring Samples

The most common samples used in dendrochronology are increment cores. The increment corer takes 5-11mm radial cores of wood from a tree, thus, it is perceived to be non-destructive sampling method. Multiple cores or radial sections, from a single tree are extremely valuable in determining mean annual ring-width as it validates the information obtained from a single core. Other sources of tree-ring information are obtained through whole stem disc or partial stem sections, or any piece of wood that has distinct ring boundaries, which makes cross dating possible. This could include dead trees, buried stems, archeological timbers, and pieces of art made from wood.

Chapter 2

Equipment

2.1 Increment borer

- I. **Increment borer:** An increment borer is the most important instrument in a Dendrochronologists' toolbox. It is essential for extracting a core of wood from tree, logs, poles or any other type of timber. Most of the increment borers have Teflon coated bits. This coating helps reduce friction, protects against rust and keeps the bit cleaner and extends the life of the bit. Nearly all increment borers are made in Sweden and Finland. An increment borer is a precision instrument and should be handled accordingly.

- II. **Anatomy of increment borer:** An increment borer consists three components:
 - i. The core barrel, or bit, is a finely machined hollow steel tube threaded at one end; the tip of which is finely chiseled to cut wood as it goes through a tree. The hollow opening of the barrel starts as small opening at the cutting tip and then increases diameter towards the handle. This structure of the corer barrel provides enough space for the borer's extracting spoon to slide under a core of wood inside the barrel and remove core sample.

 - ii. Core extracting spoon is used to extract cores from within the borer barrel.

 - iii. The handle is used to transport the extractor and borer, as well as to turn the borer in and out of the tree.

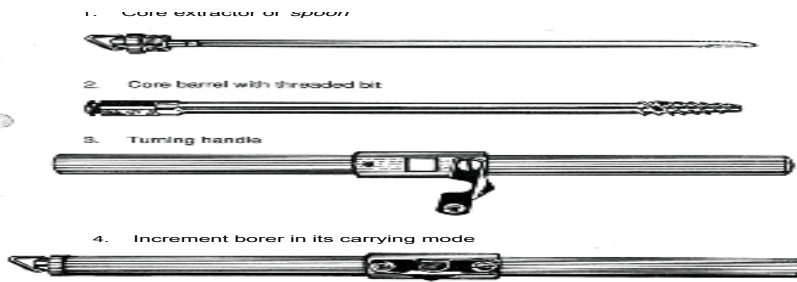


Fig.1 Anatomy of increment borer (Jozsa, 1988).

2.2 Dimensions of Increment borer

The length of increment borer varies from 150mm to 1000mm (6 to 40inches). The most popular lengths are 300, 350 and 400mm (12, 14 and 16 inches). The most common core diameters are 4.5, 5.0, and 12mm. For most dendrochronological work, the 5mm diameter borers are preferred. The 12mm diameter borers are most commonly used for wood anatomical, and x-ray density studies.

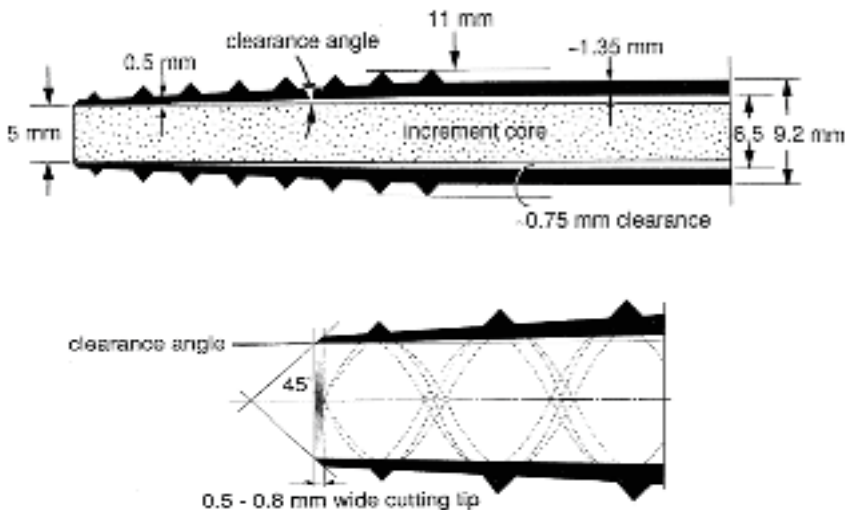


Fig. 2 Dimensions of the increment borer (Jozsa, 1988).

Chapter 3

Tree coring Protocol

Only with practice can one become good at coring trees. Otherwise, one will experience lots of trouble like jammed cutting tips, missed pith, broken cores and even injuring oneself. Trees that are growing on leveled ground can be cored from almost any direction but those growing on a slope should be cored parallel to the slope's contour. The location where to core a tree will ultimately depend on the goals of the study, or the investigators use of the resulting tree ring information. Here are the basic steps to take before coring.

- I. Before coring a tree, apply beeswax to the core barrel. This will make penetration and removal of the borer bit easier by making the borer smooth and helping to reduce the degree of friction to which the borer will twist under strain.
- II. Never bore into the rotten center or a decayed portion of a tree. A rot pocket is often identified when there is sudden change in boring resistance; all of a sudden the borer turns freely with less effort. Rotten wood will render the difficulty in bringing out the core barrel from the wood as the threaded bit will not have solid wood to hold and push against to reverse coring direction of borer.
- III. The goal is to bore directly towards the pith, however sometimes the pith is not in the geometric center of the tree. This is often the case with leaning trees, trees growing on a slope and tree species (gymnosperm and angiosperm tree species).

3.1 Avoid branch whorls and obvious wounds

It is very difficult to core through branch knots due to their hardness and the resulting cores contain confusing twisted and pinched ring patterns due to the interference of the branches. Usually there are some marks on the outside of a tree that are evidence of branch stubs and wounds made behind the bark. The same is true for the area nearest obvious wounds where the tree has tried to close the wound with reaction wood.

3.2 Coring position

Once you have selected the tree for coring, and determined a suitable location on the stem to take the sample, find a secured ground position and place the borer barrel 90-degree to the tree trunk (Fig.3). All you need to do now is to steadily spin the borer into the tree, maintaining the 90-degree with tree trunk and directing borer towards the pith position.

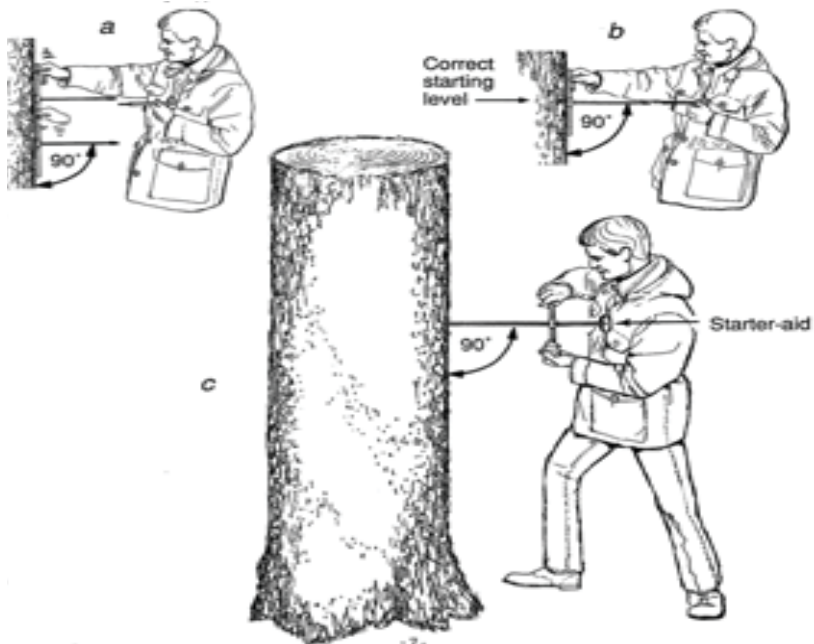


Fig. 3 Tree coring position (Jozsa, 1988).



Fig. 4 Position of dendrochronologist while coring a tree

3.3 When to push and how hard

At the start, the most common approach is to hold the borer near the center of the handle with one hand and while pushing with the palm of your hand, slowly turn the cutting tip clock wise into the tree. The other hand may be used to steady the bit to prevent it from wobbling and to maintain a 90-degree angle with the stem. Once the bit has penetrated about 2 cm into wood of the tree, and the cutting threads are completely in the wood, pushing the borer is no longer required except clock wise rotation.

Take note on the following:

- I. The height at which one cores is dependent on the objectives of the study, and the use of the tree-ring information recovered. If the study is interested in finding the total age of a tree, or if the objective is to obtain the longest record of tree ring growth, then coring height position is to be closed to the root collar of the tree.

- II. If the objective is to convert the radial increments obtain from a tree into some volume by use of a volumetric conversion table then sampling at breast height (1.37 meter) is preferable (Fig. 5). This is especially true if measures of incremental growth are to be converted to volumes, and the volumetric conversion tables used are based on breast height measurements.

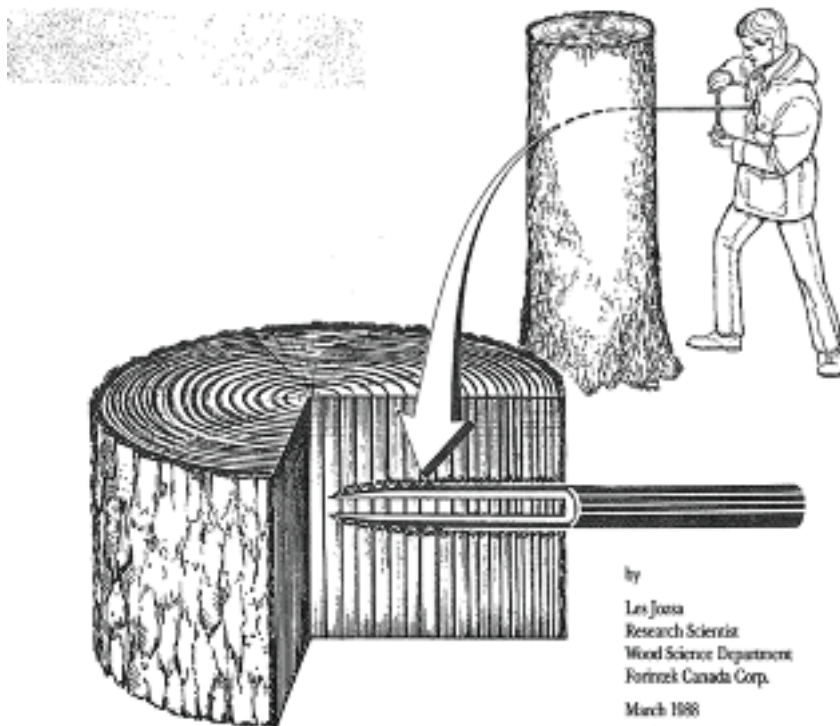


Fig. 5 Coring position and barrel orientation (Jozsa, 1988).

- III. There are instances when one might core at other heights along the stem depending on the research questions, but most commonly we suggest coring at height that is comfortable and safe for the working conditions in the field.

3.4 How to find the position of the pith

Even experienced workers sometimes have difficulty in hitting the pith position. Use branches above to guide you towards the pith position of the tree; most all branches originate from the pith, the exception being adventitious branches common to some hardwoods, particularly those growing in coppice stands. Consequently, one can use the orientation of the branches to help guide the direction of the borer. If you end up with arched rings instead of the pith you can estimate the number of missing rings/left out rings using the formula given below. This will help you to calculate the distance to the pith and number of rings between the last ring and the pith position (Fig. 6).

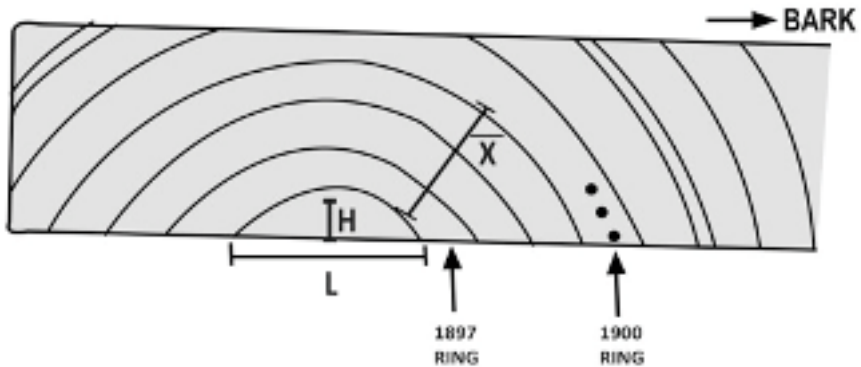


Fig. 6 Parameters to measure to calculate missing rings to the pith (Duncan, 1989)

For example: The last completed ring is 1897

- i) Measure (to the nearest mm) the height (H) and length (L) of the incomplete 1896 ring using a caliper.
- ii) Measure the width of the innermost complete rings and then average it ($X = \text{measured width}/3$).
- iii) Calculate the distance (r) to the pith r
- iv) Estimate the number of rings to the pith $= r / X$

3.5 Where to keep core extractor spoon while coring

It is best to place extractor spoon into a furrow in the bark of the tree at slightly above your eye level. Gently slip the extractor spoon tip into a crack in the bark letting the serrated tip of the extractor to hold the extractor in place. This prevents misplacing the extractor and more importantly accidentally stepping on or bending the extractor.

3.6 Removing the core

Insert extractor spoon like this “∩” into the borer from the handle end, so that it slides between the core and the metal sides of the borer. Once the spoon has been inserted the full length, the borer is given a half turn counter-clockwise to break the core from the tree and also to turn the spoon like this “□”. The core is then withdrawn from the tree by pulling the extractor out of the corer.

3.7 Handling the Core

Cores are fragile so handle them very carefully. Before pulling the spoon and the core out from the borer, be ready with a plastic straw or paper straw to capture the core. After inserting and securing the core, close the opening ends of the straw and label the straw with the necessary ID code. ID code should have information like: site name, species, core serial number, and collection date.

3.8 Testing for decayed wood inside tree

It is not uncommon to come across rotten wood within trees, especially in old trees. The presence of hollow and rotten wood in trees can sometimes be determined by striking a blow to the tree and listening for a resonating sound. The presence of hollow inside the tree sounds like a drum. Another way of detection while boring is by the sudden change in boring resistance and sound. In decayed wood, the increment borer turns easily with very less effort. Conversely, a sudden increase in resistance means that the borer has hit a branch stub/knot; do not force it further, take the borer out and try another location on the tree.

3.9 What to do with struck borer

Obtain core samples as quickly as possible. It is best to remove the bit almost all the way out of the tree even before examining the sample. This will reduce the possibility of the bit becoming stuck or locked in the tree. If a borer is struck, first try pulling while continuously twisting counter-clockwise (Fig. 7). If pulling and twisting do not work, then loop a rope around the borer's handle and the adjacent tree directly behind the borer. Twisting the looped rope in a clockwise direction causes the rope to shorten thus pulling the borer backward. The goal is to put enough reverse-pull on the borer to engage the threads in some solid wood so the threads can push the borer backwards. This is dangerous because a tight loop will produce lot of reverse pull on the borer. Keep in mind that the only thing holding the borer handle on the core barrel is the small keeper (clip/locker) on the handle which, if not in good condition or fastened tightly, may slip off causing the handle to fly backwards in the direction of the rope's anchor.



Fig. 7 Removing a struck borer (Jozsa, 1988).

3.10 Coring a small diameter tree

If you are taking bark-to-bark cores (one core through a tree), special precaution must be taken to ensure that the threaded cutting tip does not come out fully on other side of the tree. If this does happen, it gets extremely difficult to withdraw the borer from the tree as the borer's threads have no wood to push back against. When extracting your core from the borer be aware that the extractor spoon may push all or some of the core out of the borer. Before inserting the extractor spoon, push the core back into the borer away from the cutting tip (bit), with a small piece of wood to prevent breaking or loosing your sample. Then, holding the core in place with your stick inside the borer, insert the extractor spoon and remove the core.

3.11 Coring a large diameter tree

The greater the diameter of the tree, the longer the length of the borer is required to reach the pith. When using long borers, bear in mind that increment borers are not designed to withstanding bending stress (up-down-left-right). One trick to coring large trees is to start by taking the first core with a short borer (16 inches). If the short core comes out complete put it in a straw and take a second core, in the same hole, with a longer borer. This step may be repeated with progressively longer borers until one is satisfied with the result. Be certain to label your cores correctly so you can properly reassemble the complete core in the lab.

Footnote: Be aware of any changes in resistance when boring large trees. Also, be sure not to bend a long borer when coring. Increment borers are built to withstand a lot of twisting force but not to stand bending stress.

3.12 Putting the borer back into the handle

Be cautious while putting the borer back into the handle. If you are careless, it can cause serious damage to the cutting tip and you may not be able to use the tool again. Hold the handle near the opening with one hand and with your other hand gently insert the spiraled bit into the handle without touching the metal edge of the handle (Fig. 8). One must ALWAYS prevent the cutting tip of the borer from touching anything other than wood.



Fig.8 Method of placing core barrel back into the handle (Jozsa, 1988).

3.13 How to dislodge jammed tips

Never use the extractor spoon or any metal items to clear a jammed tip. Often a small twig can dislodge jammed tips. It is advisable to carry wooden chopsticks so you won't have to search for something suitable that fits inside the jammed tips (Fig. 9).

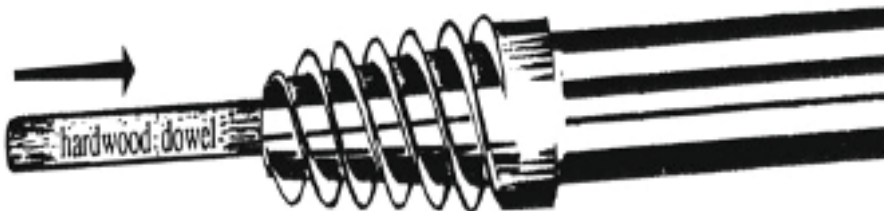


Fig. 9 Dislodging jammed threaded tip (Jozsa, 1988).

Chapter 4

Maintenance of Increment borer

4.1 Increment borer cleaning and maintenance in the field

If maintained properly, an increment borer will last for many years. If not, they can be useless after the first time out in the forest. Here are a few suggestions that will be helpful in maintaining the tool's efficiency and extending the life of increment borer.

Always clean and lubricate your borer at the end of each day after it is used. Never store the borer wet and dirty because rust will destroy the thin cutting edge. Wrap a small piece of tissue paper on the serrated spoon tip (Fig. 9) and spray a light oil, like WD-40, down the barrel. Use the extractor spoon and a small piece of tissue dipped in any petro-chemical, like diesel or kerosene, to clean up the inner section of the core barrel.



Fig. 10 Preparation to clean the borer (Jozsa, 1988).

4.2 Sharpening the cutting tip

One will need a flat and a round sharpening stone of fine grit and thin oil to float away the metal particles from the stone. Apply few drops of oil to the flat stone and place the beveled cutting tip on the stone at about 45° orientation (Fig. 10). Move the tip back and forth along the stone gently, while rotating the bit continuously between the fingers. Do not apply any pressure; just let the weight of the core barrel resting on the stone do all the work. Support the other end of the core barrel on something stationary and hold the flat stone steady. Inspect the tip with a hand lens and continue until it gets sharpened. The next step is to remove the burr from the inside edge of the cutting tip. Using the pointed end of the round stone, which has oil on it, the work on removing burr will be done. Adjust the alignment until the stone is in direct contact with the cutting edge and the inside wall of the tapered threaded bit. Rotate the borer shaft a few times until the inside burr is removed. Inspect with a hand lens.

Footnote: One should only sharpen a borer when there is a need to do so. If your cores are coming out of the tree with a long spiraled scratch that is a good sign there is some damage to the tip. Before sharpening, inspect the tip with a microscope or hand lens to be sure the borer needs sharpening.

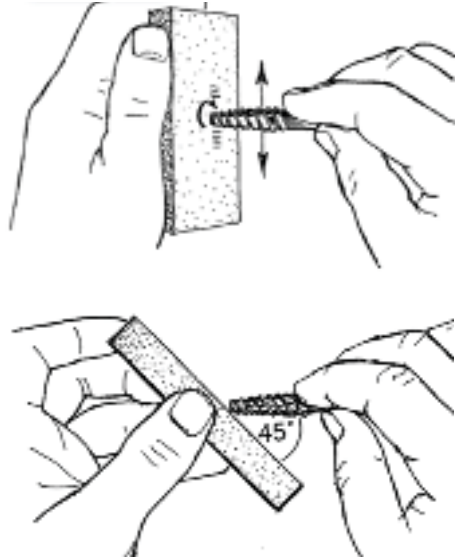


Fig. 11 Sharpening cutting tips (Jozsa, 1988)

Sample preparation for Cross Dating

Sample preparation is done in the laboratory in order to carefully preserve the sample and mount the cores properly.

5.1 Mounting the Core

Cores are small and fragile so it is necessary to mount them before any surfacing works. If the cores are still moist, they should be dried for a few days before mounting, so that they will not shrink and pull apart in the mount as they dry. When cores have dried, glue is applied in the groove of the wooden core mount to hold the cores securely in place. You cannot mount the core haphazardly because if the core's fiber direction is improperly positioned then the annual rings will not be distinct (Fig. 11). Once a core is properly placed in it's core mount, secure the core to the mount tightly with string or tape to prevent the core from bending until the glue dries. There is another technique to mount cores, especially for species which have faint fibers. In this case, hold the core at both ends and rotate slowly. You will see light reflection on the sides of the core, mount the reflective surfaces facing sideways.



Fig. 12 Fiber orientation in relation to properly positioned cores (left), and improperly positioned cores (right) in core mounts

5.2 Labeling the core mount

At the time of core removal from its straw, copy the ID from straw and write it on the core mount. The identifying label should also be recorded in the inventory log sheet (e.g, ID: RP12540105A). Here, the RP represent Research plot; 1254 is the plot number, 01 identifies the species; and last two digits refers to tree number “05” and ‘A’ refers to the first core.

5.3 Surfacing the Core

After the glue is set and the string or tape is removed, the cross-sectional surface of the core is sanded by a series of progressively finer sandpapers. Depending on the density of the wood, the initial paper may be as coarse as 80 to 120 grit. Once 2/3rds of the protruding core surface has been sanded away by this first paper, a suitable progression of finer papers is used to polish the surface (e.g., 280, 320, 420, 600). Continue sanding with the same grit until you see no further improvement in the wood. Only when there is no further improvements in the appearance of the wood, a finer grit of sand paper may be used.

Care must be taken not to sand away too much of the core with the first two papers, and to produce a polished surface that is flat, or parallel to the core mount. After sanding, a buffer is used to clean up the dust from specimens. Keep in mind that the sanding procedure is a violent step, one must be certain that the core is adequately glued into its core mount, otherwise it may be broken during this step.

Chapter 6

Cross Dating

Using a stereomicroscope, count the rings in each samples starting from the bark toward the pith. If the sample was taken from a living tree, at or near the end of the growing season, then the date of the outer most ring near the bark will be the year the sample was taken. Working from this date, count backwards one year for every visible ring. Mark the wood sample with a sharp pencil at every tenth ring. There should be one mark for each decade (e.g. 1970, 1980, 1990). There should be two marks for every half century (e.g. 1950, 1850). There should be three marks for every century (e.g. 2000, 1900...). After counting, assign a calendar year for every half century and full century with a start with the most recent and then continue towards the pith.



Fig. 13 Cross dating two samples of *Tsuga demosa* in Bhutan
(Source: Yesehy Khandu, 2016)

The matching of ring-width pattern among wood samples is known as cross dating. It would be simple if all trees in a given area contained the same pattern of wide and narrow rings but in most cases they do not. Similar tree ring patterns exist in varying degrees between trees growing under similar climatic conditions (Fig. 12). This is because atmospheric circulation, rainfall patterns, and mountain ranges divide the earth's surface into numerous "macroclimatic" sites. Within these climatic macrosites, the annual meteorological conditions vary uniformly on a relative scale and

one may consider each area to have homogenous climate. Due to this, the ring patterns throughout a macroclimate zone will be relatively similar even though individual tree's absolute growth rates, within the same climatic zone may differ.



Fig. 14 Cross dating and the identification of common ring-width patterns between core samples (Stokes and Smiley, 1968).

6.1 Marking dates for rings

As mentioned in chapter 6 it is essential to mark every tenth ring of a sample. This will serve as reference/pointer mark. If you do not, then it may irritate you when you lose count especially in old trees. Some people mark the rings with a pin (Fig. 14)

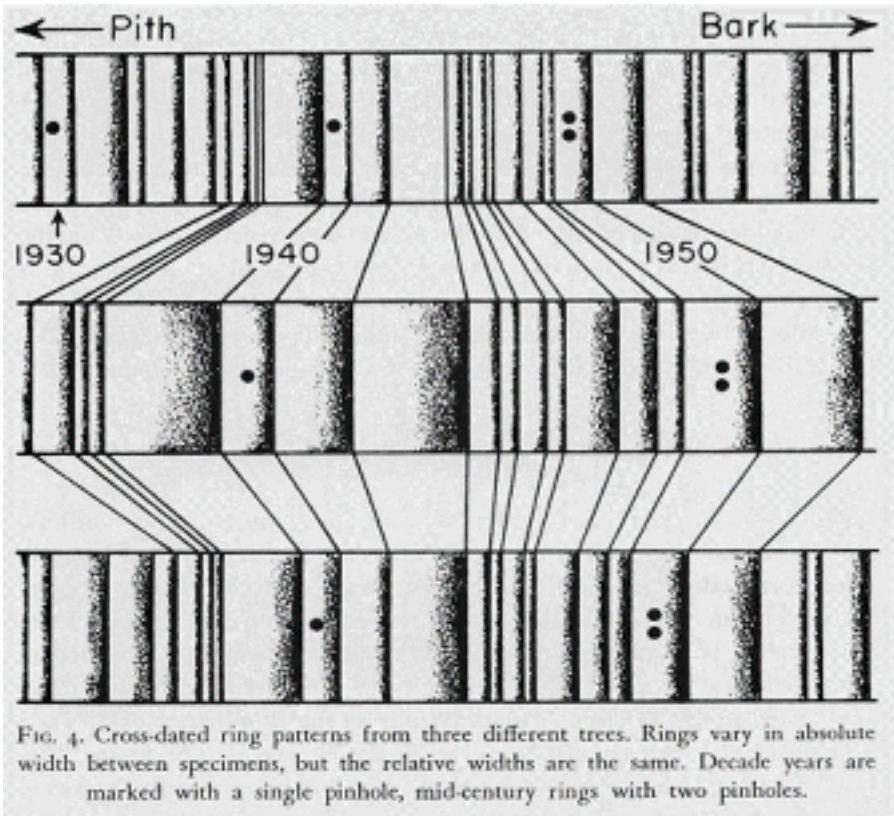


Fig.15 A systematic way of counting and marking year (Stokes and Smiley, 1968)

6.2 Missing rings

Complication may arise when some rings are missing from the location where a core was taken. Abrupt changes in climate, soil conditions, forest dynamics, etc. can produce condition when a tree is not able to produce a full growth layer completely around the stem. These missing rings can easily be detected during the process of cross dating several specimens.

6.3 False rings or Double rings

Another complication that arises in the process of cross dating is the occasional presence of false or double rings in a specimen. There are several ways of detecting false rings. The last latewood cells of a false ring are not clearly delineated but rather diffused because the latewood seems to turn back into earlywood before the final latewood is formed at the end of the growing season.

In some conifer species, resin ducts are common in the latewood, one can see that false latewood terminates at a duct, while true latewood surrounds the duct incorporating it into the annual ring. Some species like cypress and junipers have ring series in which it is often impossible to distinguish between true and false rings. When these methods of identification fail, false rings can sometimes be detected when specimens from the same site are cross-dated ring by ring.

6.4 Skeleton plot

The skeleton plot technique is used as an aid for chronologically relating a group of specimens to each other by pattern matching, and for determining exact calendar year/dates for individual rings in a sample. A skeleton plot is drawn on a strip of graph paper and labeled with the specimen number. A zero is placed at the extreme left of the paper. It is a plot drawn with vertical bars in which the length of each bar is inversely related to the width of the ring noted. In a skeleton plot a narrower ring gets a longer bar height and wider ring width gets shorter bar height. Locally average rings gets no marks on the graph. On a skeleton plot one may also note the position of peculiar wood anatomical features like false rings and partial rings. These help guide the matching of distinctive ring patterns between samples (Fig. 16).

6.4.1 Composite Skeleton Plot

After each specimen in a group has been skeleton plotted, all plots can be compared at one time. When this is done, similarities in their ring patterns can be noted and matched so the similar patterns are lined up one under the other. When this matching has been correctly done, all of the rings formed in the same year will fall on the same vertical line. When all of the specimens have been lined up, a piece of graph paper is placed at the bottom and then composite is made by plotting the average length of all lines that are present in each year as shown in Fig.15.

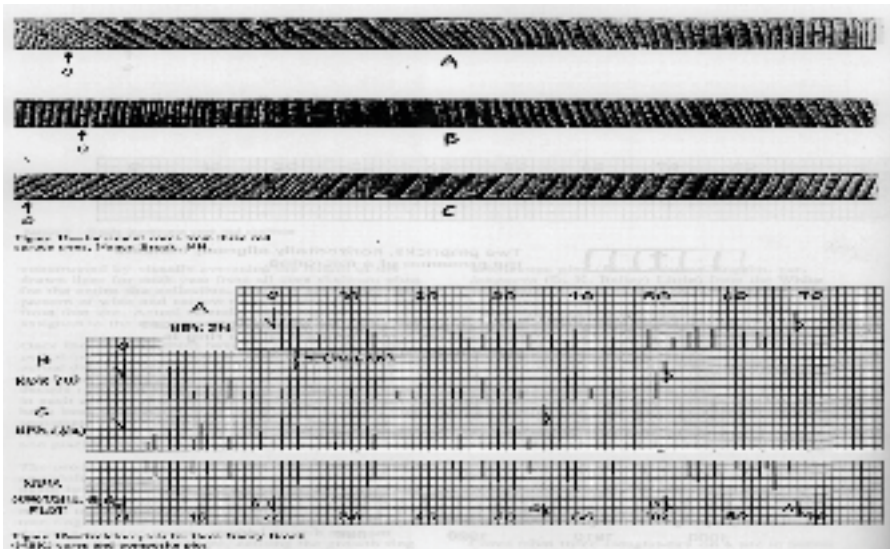


Fig.16 Skeleton plot (Stokes and Smiley, 1968)

Chapter 7

Measuring Samples

Since the invention of computers and the application of micro-chip circuitry, tree-ring measuring systems have become very accurate and affordable. Today's most precise measuring systems incorporate linear encoders that can measure ring-widths to the nearest 0.001mm. However, the single most important advice one can give to the novice regarding tree-ring measurement is, be consistent.

7.1 Measuring Tree-Rings

Individual rings are measured by moving the samples on the sliding stage under a stereoscope set up with crosshair in one ocular. Measurements are recorded in the microcomputer and subsequently on a magnetic disc by pressing a remote switch when the crosshair is lined up on the ring boundaries of successive rings.

A ring-width is measured from the edge of the first cell of earlywood to the edge of the last cell of latewood (Fig.17). The goal of measuring a ring is to take the path that most approaches a perfect radial path. In some cases, particularly with cores, the perfect radial path is difficult to determine, or the point where to begin and end a measurement is not clear. In either case, consistently using the same criteria will improve results.

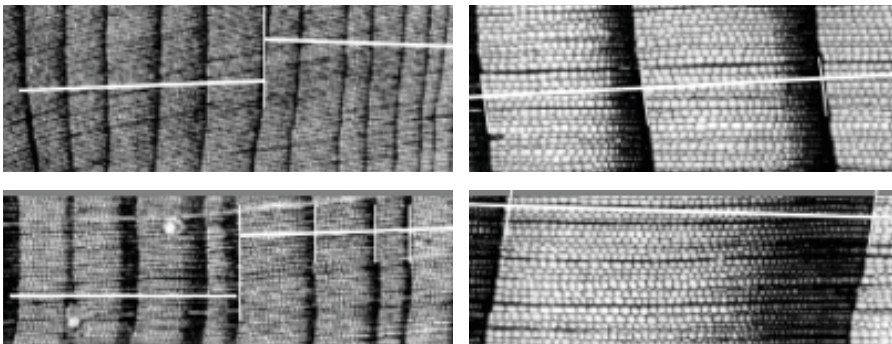


Fig.17 Ring-width measurement technique (Photo: P. Krusic).

7.2 Tree Ring Measuring System

Basic components of a modern Tree-ring measuring system (Fig. 18).

- 1) A Computer set with measuring software program installed, such as J2X, Tellorva or TSAP win.
- 2) Linear measuring stage with Digital Read-Out (DRO)
- 3) Stereomicroscope with cross-hair reticle, boom stand, and illuminator



Fig. 18 A complete measuring micrometer stage

7.3 Measuring program J2X

The Following steps will help you to operate the measuring system. For detail description of the J2X measuring program and operator's instructions go to <http://www.voortech.com/projectj2x/docs/userGuide.htm>.

1. First, switch on the DRO/Display. The string "SFE 1.01" will print out on the display panel. Press "DISPLAY ON" which will change the string to the 0.000 (Fig. 19).



Fig.19 DRO set to 0.000

2. Open the program, then click **Setup** from the menu bar and check that the program settings are correctly initialized. If not, then you have to configure the program settings as shown in the Fig. 20.

The example provided here conforms with the system used for making this document. Depending on the configuration of components that make up your system, the settings may be different. To choose the proper settings for your system see the J2X Users Guide web document downloadable from the Voortech website.

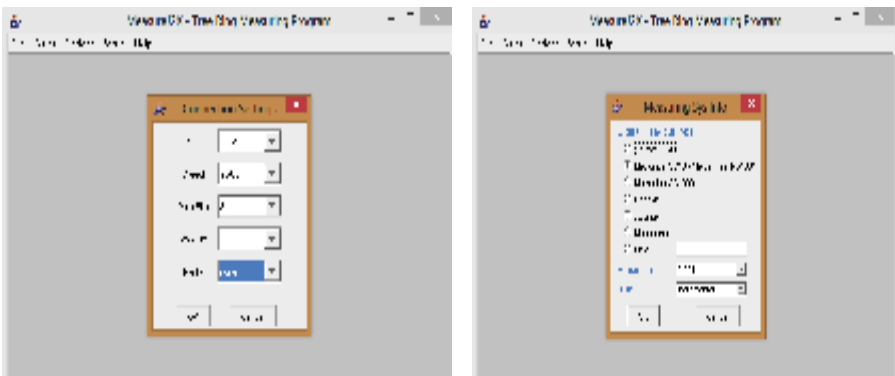


Fig.20 Measuring program setup

3. In **Series** menu bar, click on “New” and enter a maximum 8 character ID for the specimen, and the start year of the first measurement as shown in Fig 21.

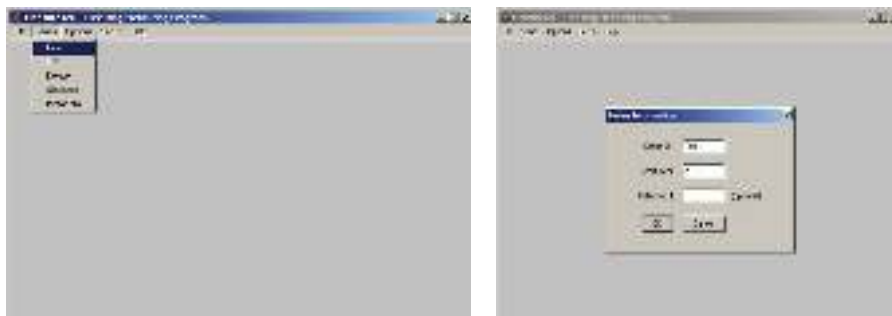


Fig.21 Input series ID with start year, sample ID should not be more than 8 digits

4. Once you have entered the core ID and initial year, click on “OK” and then Fig.22 should be the next screen. Use the “Mode” button to change the direction of measurement. There are four choices, “APP-Fix LYOG” (Append-Fix, Last Year of Growth) permits the user to measure samples from the bark to the pith. APP-Fix LYOG mode decrements the start year by one after every measurement. APP-Fix FYOG (Append Fix, First Year of Growth) is the opposite measuring mode, where with each successive measurement the start year is incremented by one (e.g., measuring from pith to bark). The other two modes, Ins-Fix FYOG and Ins-Fix LYOG, are modes used to insert values post-measurement (see: <http://www.voortech.com/projectj2x/docs/userGuide.htm>). Once the appropriate mode is selected, zero out the display and click “Measure”. Then, to send the display value to the program presses the “print” button on the remote switch as shown in the Fig 22. Be sure to set the initial value to zero (0.0) before making your first measurement (Fig. 23).

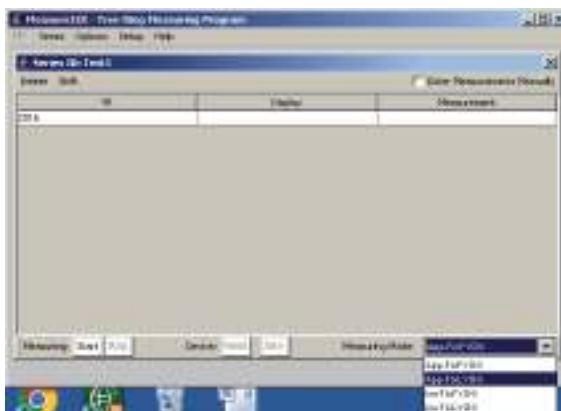


Fig.22 Measuring mode should be App-fix Last Year of Growth if measurement is taken from bark towards pith



Fig. 23 Initial value should be set to zero before beginning measurement.

- Place the specimen that you want to measure on the stage sample table and be sure to set the initial value to zero. If you are measuring from bark to pith, align the center of the cross-hair with the edge of the latewood of the last ring and rotate the dial/crank till the same point on the cross-hair reaches the edge of the earlywood in the same ring. Now press the “print” button to send the measured ring width to the measuring program (Fig. 24).

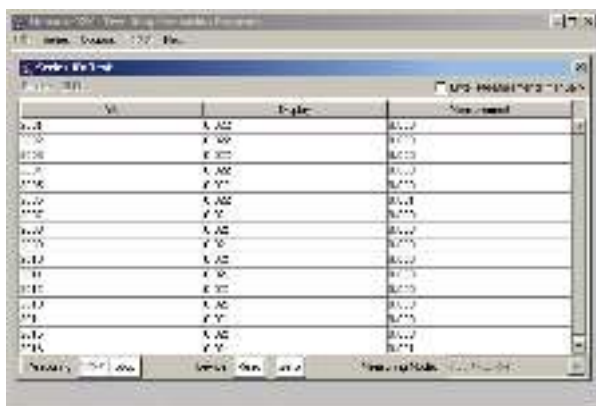


Fig. 24 Example of measurement from 2016 to 2001

- Continue till you have measured all the rings in the specimen. To save the measured specimen, click “Done” and CLOSE the measuring window. Then open the **File** tab and save your measurements in a new file with any name you want. That is the procedure for measurement and saving the first specimen. For the rest of the specimens, you repeat the same steps, however remember to save the data in the same file. Each time you save new data to the same file the program flashes a warning (Fig.25). Each time the program saves data it rewrites all the data that was already in the file and the new data just measured is appended to the end. This re-writing and saving habit has changed with older versions of the program, so check J2X Measurement users manual before use.



Fig. 25 How to overwrite file name and continue measurement

Sometimes, while measuring a ring width, you might press the print button twice instead of once or make some mistake in measuring. When that happens, click “Done”, highlight the bad measurement and delete it by pressing the delete button. To continue the measurement, click the “measure” button and position your sample at the proper place. Press “OK”. Reset your measurement to zero (0.0) by pressing in the remote switch “zero button” and then the “print” button. Now, you are ready for measuring again.

7. If you want to see how many samples you have measured: open the **Series** tab and go to the “Statistics” (Fig. 26). Here you may select “records” to edit and/or delete.

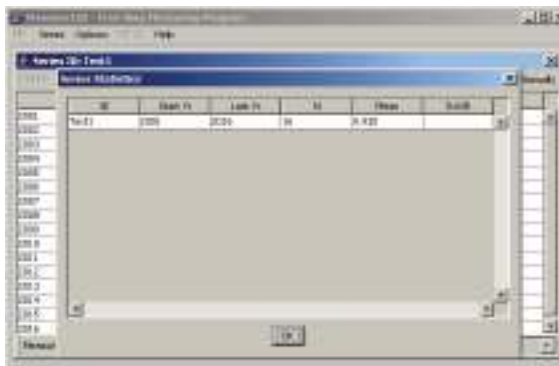


Fig. 26 The summary of measurements from start to end year

8. After you have completed all measuring, the file is saved as a simple text file in your designated folder.

Chapter 8

Important software used in dendrochronology

8.1 BBEdit

BBEdit is a Text Editor, used to edit any text file. *BBEdit* is only available for Macintosh computers. Labs operating with Windows computers may use *Notepad*. To open a file in *BBEdit*, goto the **File** menu and select “open”, which will navigate you to your file. Once you open the file, the raw data will be shown as in (Fig. 27). Be very CAREFUL editing measurement files by hand using a text editor. The position of every character and number in these files is strictly defined. Changing the format of these files can cause other programs like COFECHA and ARSTAN to skip or incorrectly read in your data. For editing raw measurement files we recommend using EDRM or the measuring program used to create them just to be safe.

```
BR485 1925 568 312 434 438 298
BR485 1930 144 330 244 542 430 700 422 254 666 1262
BR485 1940 898 362 628 1218 1304 1478 1240 1518 1394 1404
BR485 1950 1198 1260 1404 1856 2080 2396 2608 2886 3074 3212
BR485 1960 3710 3434 2198 2582 2396 2492 2152 1842 1600 1606
BR485 1970 1930 1640 1602 1442 1028 1236 1528 1504 1542 1192
BR485 1980 1512 1046 1586 1264 1640 1370 1196 1006 872 796
BR485 1990 700 1044 998 1070 1518 1158 1242 1438 1728 1580
BR485 2000 1424 2158 2190 -9999
```

8.2 COFECHA

COFECHA is a computer program that assesses the quality of cross dating and measurement accuracy of tree ring data. It is widely used in dendrochronology. Inspection by COFECHA adds a degree of confidence that tree ring samples have been cross-dated correctly and measured accurately. However, the final decision on the quality of crossdating lies with dendrochronologists. For detail on this program, refer to the tutorial for the computer program COFECHA (Grissino-Mayer, 2001). This manual describes uses, steps, interpretation of diagnostics and many of the various options available within the program.

Figures 27-32 illustrate some of the features in program COFECHA that are informative on the usage of COFECHA based on tree ring data from trees in in Bhutan.

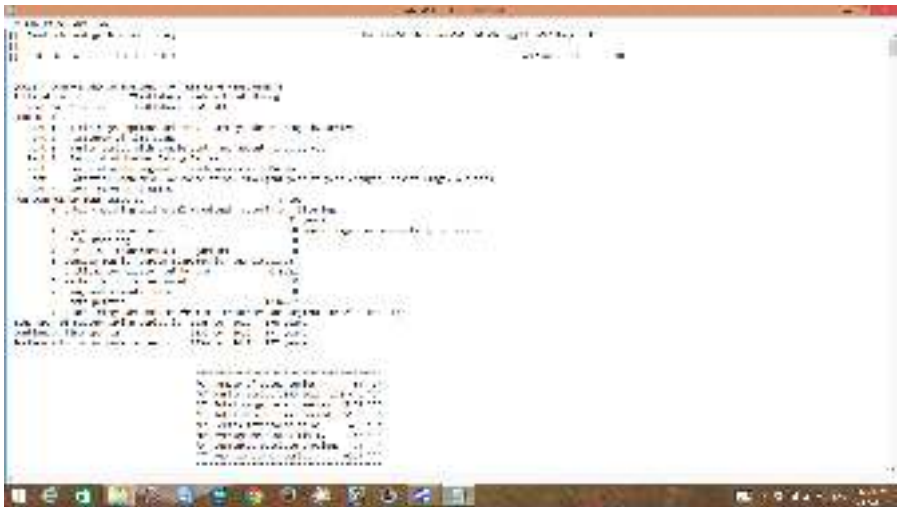


Fig. 28 COFECHA output page 1 - table of contents, run control options for analysis and summary statistics of the COFECHA run.

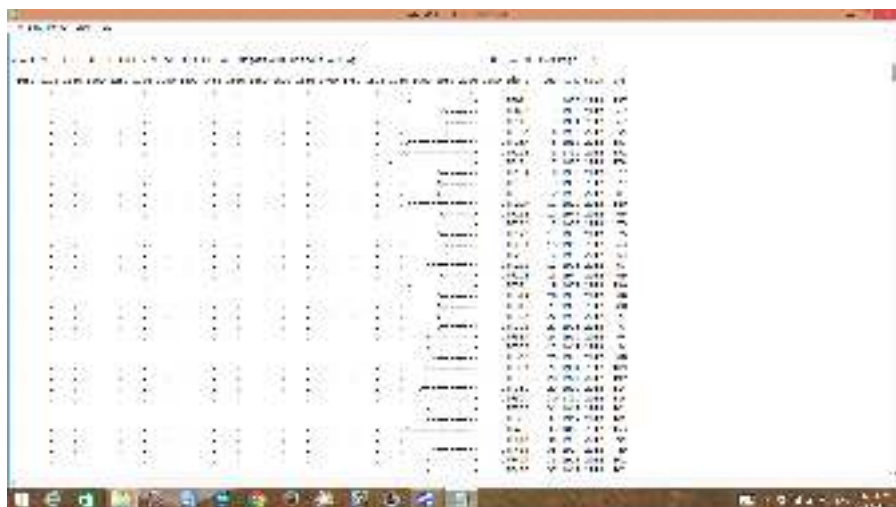


Fig. 29 Time plot of the tree ring series and graphical length of each core

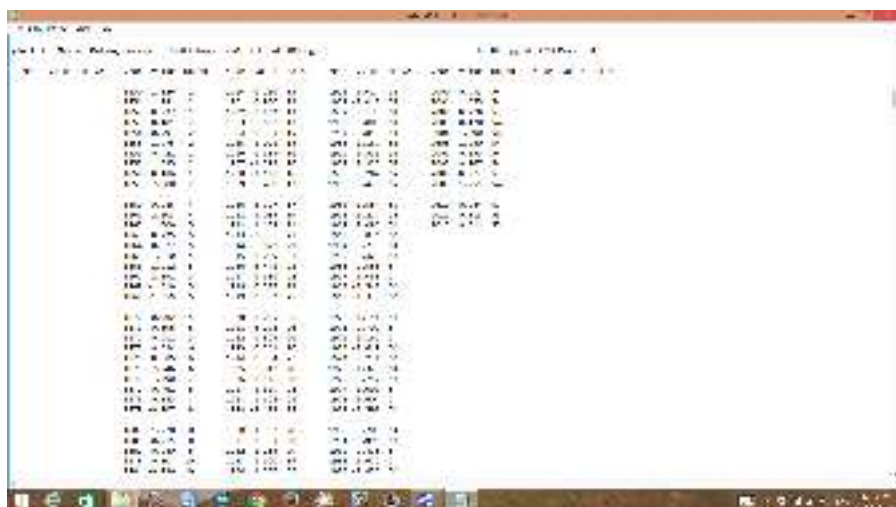


Fig. 30 Master dating series showing index values and sample depth for master

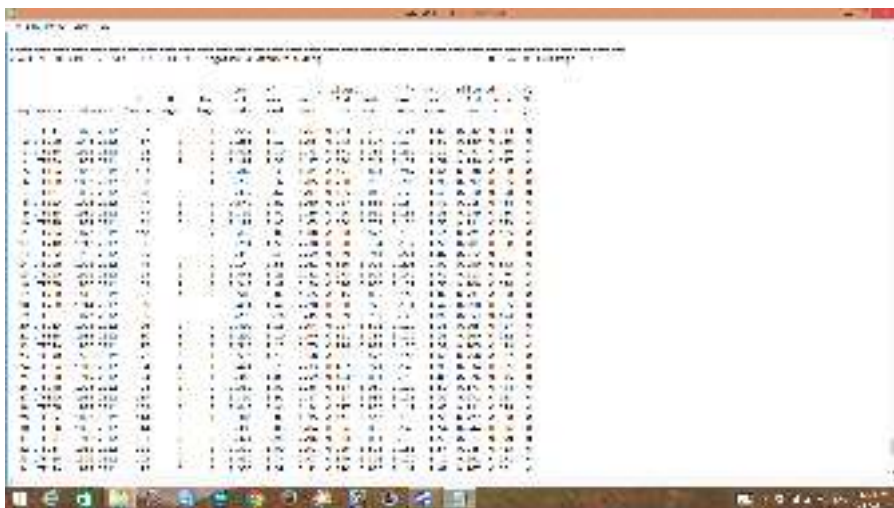


Fig 31 Descriptive statistics that shows correlation of each core with master chronology and and mean sensitivity



Fig 32 Contd: Descriptive statistics that shows correlation of each core with master chronology and mean sensitivity.

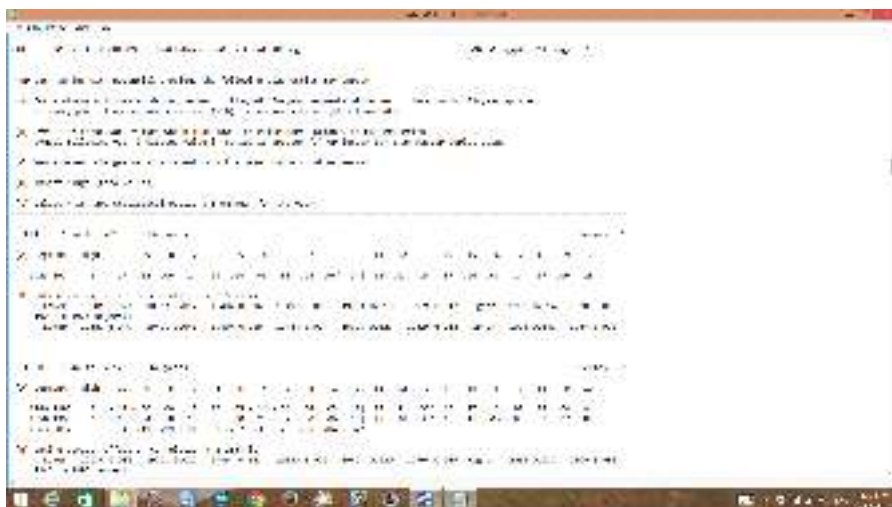


Fig. 33 Potential problems – displays core-level analysis that how each core is dated against master chronology, effect of worst and best segments on overall correlation, outliers and standard deviation for further rechecking of samples and ring measurements.

8.3 EDRM: decade format file, editing program

EDRM is a tree-ring data editing program that helps you to make changes to the values in a decade format file without disturbing the data format. Because decade format is a strict format it is important not to disturb the position of values in the file. Other programs that read this format will either crash or produce spurious results if this format is changed. In order to make changes to data saved in decade format files, programs like J2X and EDRM are very useful as they can produce edited files in the correct format.

Steps to run EDRM for editing

- 1) Enter the file name e.g. bu593 as shown in the Fig. 33.
- 2) Give new file name e.g. bu593.cor and hit enter.
- 3) The program will ask about the precision of your measurements.

In most cases, you have to choose 3 because the measurements are made at a resolution of 0.001mm.

- 4) Next step the program will provide you with different editing options for each series in the file. Based on the correction you want to make, you can select and do the necessary correction.

```

-----
Output from !edrmFAT
-----
This program creates from an existing file of time series, a new file with
the capability for editing each time series as it is copied to the new file.
In editing a given time series, you may insert, change or delete values;
truncate the series at the beginning and/or end; and adjust the dating
of the series. Any combination of these steps may be done. Each series
may be copied intact, edited and copied, or omitted in the new file.

MEASUREMENTS TO BE EDITED
... Name of EXISTING file => ba485

First 6 lines file ba485
BA485 1925 568 312 434 438 298
BA485 1930 144 330 244 542 430 700 422 254 666 1262
BA485 1940 898 362 628 1218 1304 1478 1240 1518 1394 1404
BA485 1950 1198 1260 1404 1856 2000 2396 2608 2886 3074 3212
BA485 1960 3710 3434 2198 2582 2396 2492 2152 1842 1600 1606
BA485 1970 1930 1640 1602 1442 1028 1236 1528 1504 1542 1192
.....1.....2.....3.....4.....5.....6.....7.....8
Format is M Is this correct? <Y>/N =>

EDITED MEASUREMENTS
... Name of NEW file to create => ba485.cor

Format for new edited data file:
<C> Compact format
M: Measurement .01 precision
3: Measurement .001 precision
FORMAT for edited file => 3

Line from original file:
BA485 1925 568 312 434 438 298
Copy as title or header on new file? Y/<N> =>
No 1 BA485 Interval 1925 2002 78 years

C: COPY as is F: new FIRST year U: new LAST year
I: INSERT value E: ELIMINATE value R: REPLACE value
(: Cut from BEGINNING ): Cut from END P: DISPLAY data
T: Take remaining series O: OMIT series N: New identification
X: Exit program Q: Re-edit series K: COPY and re-edit
S: Copy all until .. Select => p
Around what year? =>

```

Fig.34 measurement series edited using edrm Acknowledgements

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