COLLECTING, PREPARING, CROSSDATING, AND MEASURING TREE INCREMENT CORES

by Richard L. Phipps

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ABSTRACT

Techniques for collecting and handling increment cores are described. Procedures include those for cleaning and maintenance of increment borers, extracting the sample from a tree, core surfacing, crossdating, and measurement.

INTRODUCTION

Increment cores of tree rings have been used for many years by foresters, wood technologists, dendrochronologists, and forest ecologists. Anyone working extensively with increment cores develops favorite collecting and handling methods. As a result, there is a relatively large literature suggesting different methods to accomplish the same tasks. This manual is not an exhaustive review of the literature, but rather a comprehensive set of methods that my co-workers and I have developed during more than 2 decades of work with tree rings. The manual describes the use and care of increment borers, and methods of collecting, handling, crossdating, and measuring increment cores.

ACKNOWLEDGMENTS

Jane F. Hill and Cathy M. Ager both assembled material for use in descriptions of our techniques for collecting and handling increment cores. It was their conviction that the methods should be described and made available that has served as an incentive to complete this manual.

IDENTIFICATION OF TREE RINGS

TREE GROWTH

Trees in temperate regions undergo an annual cycle composed of a growth period (spring and summer growing season) and a dormant period. Trees, like other green plants, produce their own foods (photosynthates), much of which are used to carry on respiration and other life-sustaining physiological processes. As a general rule, foods produced in addition to that required to keep the tree alive are available for new growth. Thus, growth of trees may be thought of as an expression of excess photosynthates. Because various environmental factors can affect the amounts of photosynthates produced, size of the annual increment is, in part, a function of environmental conditions of that year.

Generally, environmental conditions are least limiting to food production and growth in the early part of the growing season, and most limiting in the latter part of the season. Less-limiting conditions tend to result in more rapid growth, that is characterized by larger, thinner-walled cells. Thus, the usually sharp contrast between small, thick-walled cells formed at the end of one season and large, thin-walled cells formed at the beginning of the next growing season results in a rather distinct line. When viewed on a complete transverse section, such as a stump top, the line approximates a circle. The line is the tree-ring boundary -- that is, the boundary between two annual increments. When viewed in transverse section the annual increment is referred to as a tree ring. Many authorities use the terms "annual increment" and "tree ring" interchangeably. However, I will use "annual increment" to refer to three-dimensional growth, and "tree ring" to refer to the transverse view of the annual increment.

The most recent (outside) annual increment may be thought of as a thin layer of wood just beneath the bark that completely covers the previous year's layer and extends from all stem tips to all root tips. Generally, growth of the above-ground portion of a nonporous or diffuse-porous species (see WOOD TYPES) starts in spring at, or near, the stem tips and moves basipetally (toward the tree base). The bulk of the growth near the stem tips may be occurring when environmental conditions are not appreciably limiting to growth. On the other hand, growth near the base of a large tree may be occurring enough later that environmental factors may be limiting, and fewer surplus foods are available for new growth. If environmental conditions are extreme, it is possible that so few surplus foods are produced that growth initiation will not progress to the lower part of the tree. The result is an absent ring in that portion of the tree where no growth occurred. It is not possible, however, for a ring to be absent throughout an entire tree. So long as the tree is alive and produces a new set of leaves, no matter how few, a new ring will be produced downward from the top of the tree. How far down the tree the new growth will extend depends on how much surplus food is present.

The ring boundaries of several annual increments viewed in longitudinal section may be described as a series of parabolas (fig. 1). Though very generalized, the model serves to illustrate that the width of any given annual increment decreases from top to bottom. Also, at any given height, the outer increments are more narrow than the inner increments.

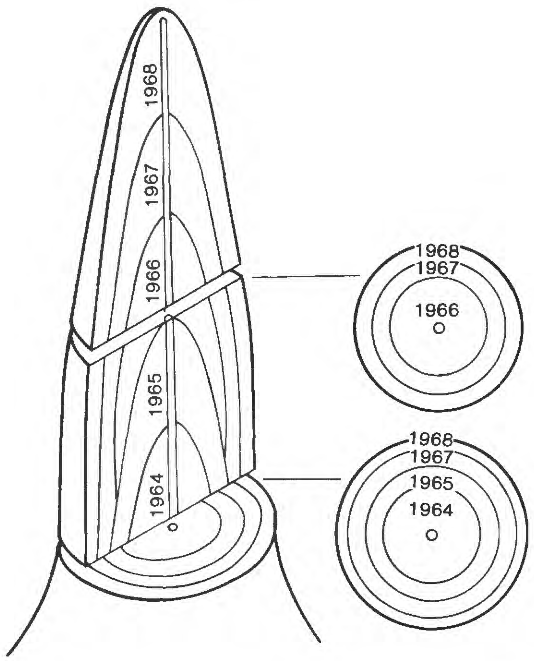
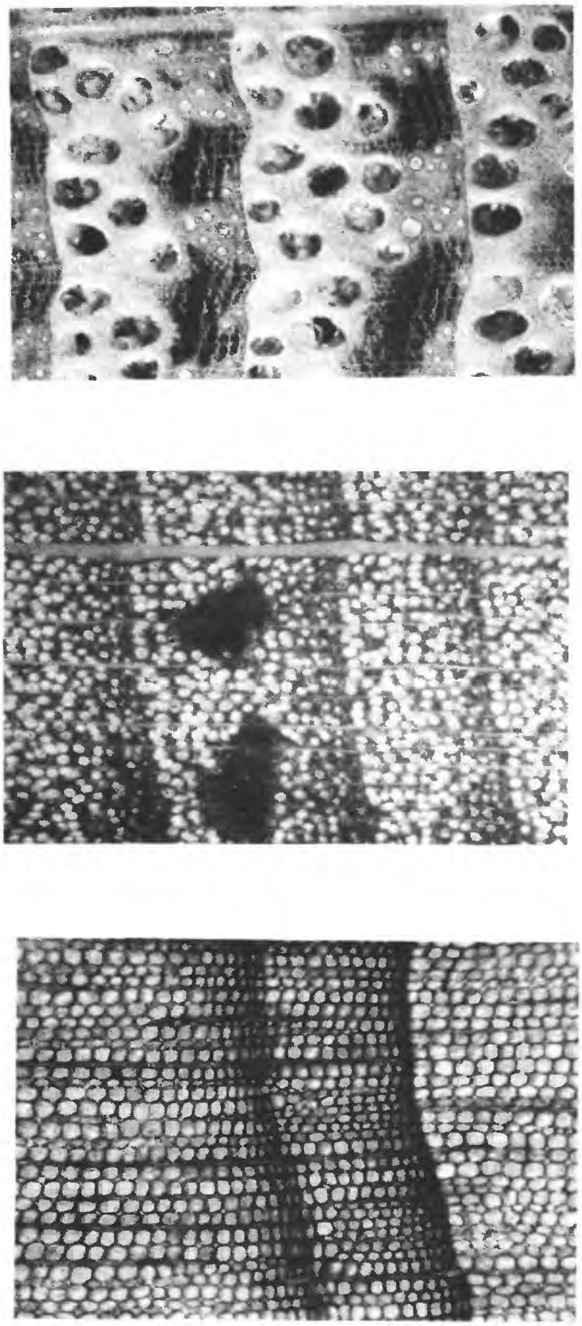


Figure 1. -*Diagram of growth layers of a single tree stem.*

WOOD TYPES

Three general wood types may be distinguished, based on the presence, absence, or types of water-conducting vessels (fig. 2). The wood of conifers (cone-bearing trees generally referred to as softwoods) contains no vessels, or pores, and is referred to as nonporous. Many nonporous woods are characterized by a distinct color difference between wood produced in the early part of the growing season (thin-walled, light-colored earlywood) and wood produced in the latter part of the season (thick-walled, darker-colored latewood). The wood of angiosperms (generally referred to as hardwoods) contains pores, and may be divided into diffuse-porous and ring-porous types. Ring-porous woods contain a band, or ring, of very large pores produced at the beginning of the growth season, that may be referred to as the pore zone (also often called earlywood). The rest of the ring (latewood) contains some small pores and, thus, appears not unlike the entire ring of diffuse-porous woods. Often there is very little color or texture variation across rings of nonporous woods, meaning that ring boundaries of these woods are frequently very difficult to discern.

Ring-porous woods are the exception to the general rule of basipetal growth progression. In ring-porous species, growth appears to commence simultaneously throughout the tree. There is evidence to suggest that vessels of the pore zone may develop from cells that were cut off from the cambial initials at the end of the growing season. Thus, what appears as growth at the beginning of the season, may not represent cell divisions but simply cell enlargement and differentiation of cells already present. Growth of the rest of the ring (latewood) may be analogous to the entire ring of diffuse-porous woods, and appears to progress basipetally. If this is true, then the pore zone of ring-porous woods has no counterpart in nonporous and diffuse-porous woods. Regardless of how limiting the environmental conditions, the pore zone almost always forms even if no latewood is produced. Thus, absent rings are extremely rare in ring-porous woods.



RING-POROUS

DIFFUSE-POROUS

NONPOROUS

Figure 2. -*Nonporous, diffuse-porous and ring-porous wood types.*

PREPARING THE INCREMENT BORER FOR USE

THE INCREMENT BORER

If a nail is driven into a tree, the tissue that occupied the volume now occupied by the nail is not removed but compressed into the surrounding tissue. The larger the diameter of the nail, the greater is the amount of compressed tissue and, within certain limits, the greater is the pressure of the tissue on the nail. If a hollow nail is driven into a tree, the volume of tissue compressed is essentially equal to the volume of the nail minus the volume of the tissue that ends up inside the nail. An increment borer is very much like a hollow nail with the additional feature of threads that allow the bit to be screwed into the tree. The tissue that ends up inside the bit constitutes the core that we wish to collect.

An increment borer is composed of three parts: bit, handle, and extractor (fig. 3). The bit and extractor are stored in the handle for transport. The bit has a collar at the back of the threads. The collar compresses the tissue surrounding the bit to a diameter roughly equal to that of the outside of the bit threads (fig. 4). If, after the collar passed, the tissue immediately sprang back toward the bit shank, there would be no advantage to the collar. But, because the tissue tends to spring back slowly, it is possible to twist the bit in as far as desired, and to remove the core and the bit before the tissue applies full pressure to the bit shank.

Forestry supply houses normally stock two or more brands of increment borers in a variety of lengths and diameters. Generally, the greater the borer diameter and the shorter the length, the more strength is required to operate the borer. Notwithstanding that longer handles are easier to turn than shorter handles, the first borer purchased is typically found to be longer than necessary. The 16-inch borer is very commonly used by western dendrochronologists, whereas we find that 10-inch or 12-inch borers work very well for most trees of cutover hardwood forests of the East. Some brands of borers are available as 2-thread or 3-thread models. The pitch of the threads varies among brands and models, but, generally, one rotation of a 3-thread model will pull it farther into a tree than one rotation of a 2-thread model. It would seem that the 2-thread bit might be preferable for use in hardwoods. However, some people find that it is harder to start an increment borer than it is to turn it after it has been started, and that the 3-thread bit is easier to start than the 2-thread bit. For this reason the 3-thread bit may be preferred, even when coring hardwoods.

As with any wood-cutting tool, it is important that the bit be sharp and clean. Perhaps the most common consequences of using bits that are not sharp and clean are twisted and broken cores and cores with surfaces that have not been smoothly cut. Although many authors emphasize the importance of sharpening and cleaning, we have generally been able to maintain sharp, clean increment borer bits without sharpening and with very little cleaning.

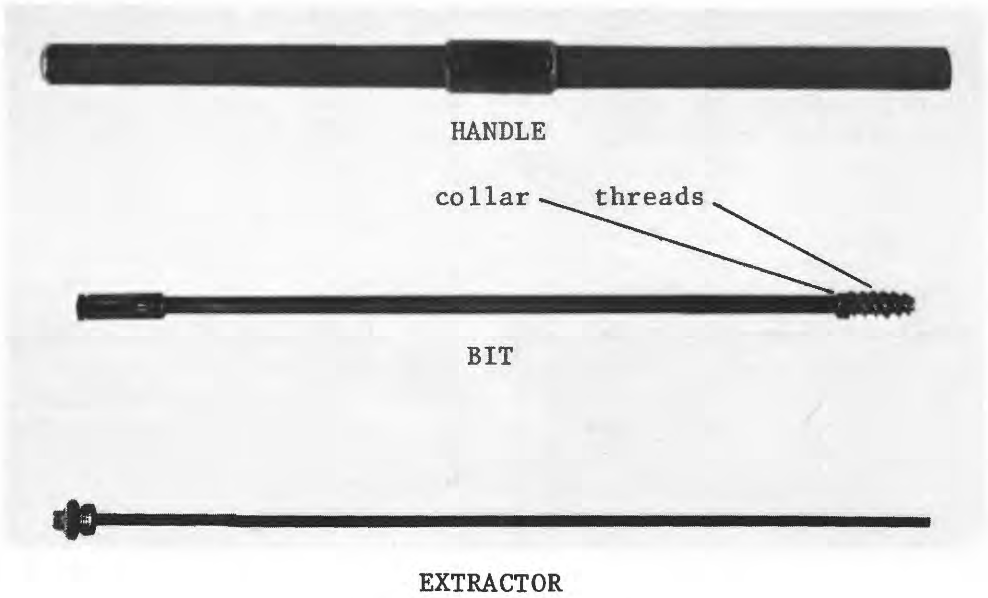


Figure 3. -*The increment borer.*

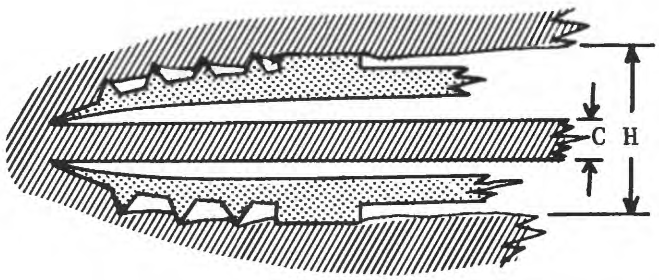


Figure 4. -*Cutting and compression of tissue with increment borer. Compression of wood tissue by borer is indicated by the difference between the size of the hole (H) and the diameter of the core (C).*

BIT CLEANING

Rust provides the roughened surface on which debris can accumulate. Thus, a bit that has accumulated debris almost certainly has some rust and corrosion, often impairing core removal from the bit. Almost as certain, the cutting edge will have been damaged by corrosion. If damage is not advanced enough to have seriously dulled the cutting edge, the bit can be cleaned and put back into use. A cleaning kit for .22 caliber rifles works very nicely for cleaning increment borer bits (fig. 5). When using a kit for the first time, determine that the swatch holder is not too wide to easily fit through the cutting-tip end of the bit tube. If the swatch holder is too wide, it can usually be filed down enough to fit the tube and still be strong enough to hold the swatches. The powder solvent usually contained in the cleaning kits works very well to cut the stains caused by the interaction of oak tannins with the iron of the bit. Though it is not necessary to remove all of the stain, except in special cases where clean, unstained cores are needed, it is desirable to remove enough residue to leave a smooth, rust-free tube surface.

Always insert the cleaning rod from the butt end of the bit (never from the cutting-edge end). A swatch should not fit tightly when inserted into the bit. Because the bit tube narrows near the cutting-edge end, a swatch inserted in the butt end will fit tighter as it is pushed toward the cutting-edge end.

Figure 5. *-Cleaning kit modified from a commercial kit for .22 caliber rifles. The swatch holder has been filed to easily fit the cutting-edge end of the borer bit, and the rod attached to the handle has been shortened.*

SHARPENING THE CUTTING EDGE

If the cutting edge has been dulled by corrosion, it is possible to touch up the edge with sharpening stones. Forestry supply houses carry bit-sharpening kits that include a wedge-shaped and a cone-shaped sharpening stone useful for this purpose. Various authors give instructions as to the proper methods of sharpening and cleaning increment borer bits. Maeglin (1979) includes instructions for building a simple jig to hold the bit in order to hone the cutting edge at the correct angle. Sharpening is a tedious, time-consuming task and is ordinarily not performed in the field. If the cutting edge has been nicked or chipped by mishandling, sharpening stones are of little use. In such cases the bits must either be discarded or returned to a forestry supply house to be machine-sharpened.

When a bit is sharpened by machine, a certain amount of the end of the bit is removed. This in turn changes the position of the cutting edge in relation to the threads and the inter-thread surface. No matter how carefully a new edge is machined, the bit is not the same as the original. If properly cared for, a bit may never need to be sharpened. This seems preferable to improper care and sharpening.

METAL FATIGUE

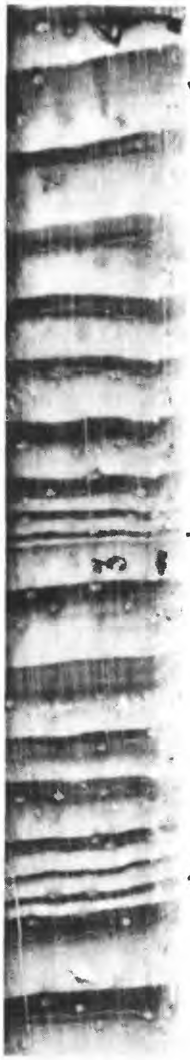
Considerable friction develops between the tree tissues and the increment borer bit, particularly in the thread section. No matter what measures are used to reduce friction (discussed below), it cannot be totally avoided. Friction causes heat that eventually takes its toll in metal fatigue. Commonly, the first visible signs of metal fatigue are cracks at the cutting edge. There may be 3 or 4 or more cracks, each extending as much as several millimeters back from the cutting edge. Eventually, as cracks lengthen during bit use, a chunk of the bit between adjacent cracks will break out, thus terminating the usefulness of the bit (fig. 6). When a chunk breaks out it may cause a domino effect resulting in the whole end of the bit crumbling away during one twist of the borer handle. No one likes to leave chunks of metal in a tree. Therefore, cease using a bit when cracks are first noted. Because there is always a chance that a bit may break, it is advisable to carry an extra bit.

BIT BREAKAGE

No matter how carefully increment borers are used, bits occasionally break (see also METAL FATIGUE). If the bit is relatively new and has been properly used, breakage may be due to a fault in its manufacture. A common fault is that the hole in the bit is not exactly in the center of the bit thoughout its length (fig. 7). A break resulting from this fault will occur nearly equidistant from each end of the bit, and the hole at the break is obviously off center. Often, faulty bits will be replaced by forestry supply houses when returned to them.

In crossdating, extreme-sized rings (both wide and narrow) are identified, and the number of rings between extremes is counted. In practice, a list is composed of the unusual, or outstanding, features of rings of each surfaced sample. In addition to listing unusually wide and narrow rings, other features such as false rings and parenchyma banding are listed. Abnormal features such as frost rings, scarring, and wound tissue are also noted (fig. 40). Finally, as with the skeleton-plot method, comparisons are made among samples. The product of this effort is a list of key years for the collection that includes years of wide, narrow, missing, and false rings, and sometimes other features. This final product is filed for future reference when dealing with the same, or related, species from similar, nearby habitats.

The extreme-ring match-mismatch method is considerably less time consuming than the skeleton-plot method for areas where environmental factors are not severely limiting. However, as the severity of limiting factors and the consequent number of very narrow rings increase, the difference between the extreme-ring and the skeleton-plot methods becomes less and less.



	1940	
wide latewood . . .	1939	. . . wide latewood
	1938	
	1937	
	1936	. . narrow latewood
	1935	
	1934	
	1933	
	1932	
very narrow	1931	. . . . . (missing)
narrow latewood . .	1930	. . narrow latewood
	1929	
wide latewood . . .	1928	. . . wide latewood
	1927	. . narrow latewood
	1926	
	1925	
	1924	
narrow.	1923	. . . wide latewood
	1922	. . narrow latewood
	1921	
extra wide.	1920	

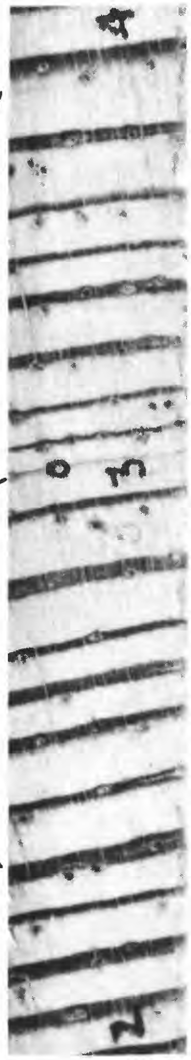


Figure 40. *-Two extreme-ring lists and accompanying core segments. Note matches between lists for large as well as small rings.*

GRAPHIC CROSSDATING

Just as skeleton plots and extreme-year lists may be compared among samples to accomplish dating, graphs of ring-width measurements may be compared to allow crossdating. However, one should be cautioned that graphic crossdating is less rigorous than other methods that more directly involve the wood samples. Apparently, many more anatomical features are used to distinguish individual rings than is reflected in a skeleton plot or an extreme-year list. Because information included in skeleton plots or extreme-year lists can be described, computer programs for crossdating have been written. But, because computer programs do not contain many of the anatomical subtleties that can be seen on the cores, many professional dendrochronologists feel that computer crossdating is most valuable as a final check of hand crossdating. Computer crossdating and graphic crossdating are, thus, analogous in this respect.

In performing comparisons among graphs, procedures similar to the extreme-year method might be followed.

DATING INDIVIDUAL SAMPLES

The crossdating procedures have been described above in terms of dating large collections of samples in which the outside date of the samples was known. Crossdating can also be utilized in situations where it is not possible to obtain large collections and where the outside date is not known. For example, it may be desirable to obtain from only a few samples the exact date of a growth release following lumbering or fire. Or, it may be desirable to determine the cutting date of a log used as a structural beam in a building.

In situations like this, crossdating is done as previously described, except that it is performed entirely with existing, previously dated chronologies. If there is no dated chronology with which to establish absolute dates, and if enough samples can be obtained that the samples can be compared with each other, a floating chronology could result, in which the samples are dated only with respect to each other.

CROSSDATING AND DISTANCE BETWEEN SAMPLE SITES

If considerable similarity exists in conditions among trees at a given site, then many more than just the most extreme-sized rings will match among tree patterns. With increasing distance from that site, patterns of trees of the same species from similar habitats will show fewer and fewer matches as matches become increasingly restricted to the more extreme-sized rings. In other words, when sites are close together and the patterns among sites are quite similar, a significant number of matches of individual years can be noted in a relatively short span of years. With increasing distance between sites, a greater span of years would be required to achieve the same number of yearly matches. Pattern similarities among trees at any given site are a function of what may be called the climatic sensitivity of a tree-ring collection from that site. Thus, the maximum distance between sites from which tree-ring collections may be crossdated with each other can be regarded as dependent upon the climatic similarities of the sites and the climatic sensitivities of the collections.

On the other hand, pattern similarities among trees at a site can be considered somewhat analogous to distance. From sites where environmental factors have only minor limits on growth, only the years of the more extreme rings may be expected to show matches. Thus, with increasing distance from such a site, the point would quickly be reached beyond which the trees would not be old enough to have a significant number of extreme-year matches between sites.

WHEN CROSSDATING IS NOT NECESSARY

Dendrochronologists might say that one must always crossdate, while foresters might think crossdating is not really necessary. Both may be correct for specific applications. For example, the dendrochronologist always deals in terms of absolute dates. No matter how unlikely missing and false rings may be in a particular collection, the dendrochronologist cannot take a chance, but must crossdate to be absolutely certain that every year is correct. On the other hand, the forester usually deals with far fewer years, and often in applications where approximate age is acceptable.

These examples represent the extremes. There are many examples of uses of tree rings in which an accurate date is desirable, but where crossdating is impossible, or where it is desirable to avoid the time-consuming process of crossdating if acceptable results can be obtained without it. For example, suppose the exact date of a fire scar is desired. The outside date is known, and a ring count indicates fewer than 30 rings from the outside to the scar. Careful examination reveals large rings with very little variation among rings and no evidence of false rings. Little ring-to-ring variation and no small rings suggest that no rings are missing. Because of the short record and little width variability, crossdating is not possible. All indications are that a simple ring count will provide accurate dates. A statement might accompany these ring-counting results to the effect that dates were derived by ring counting, and that examination suggested that missing and false rings were highly unlikely.

In addition to ring-to-ring variability and length of record, the type of species should be considered in deciding whether or not crossdating must be undertaken. Both missing and false rings are quite rare in ring-porous species, such as oak (*Quercus*), ash (*Fraxinus*), and elm (*Ulmus*). Under extreme growth conditions, oak may not form any latewood, but it almost always has at least a few scattered tracheae (vessels) representing earlywood of each year. False rings in which a new pore zone (earlywood) is formed appear to occur in ring-porous species only when the tree has been completely defoliated and then develops a new flush of leaves. Complete defoliation may result from insect damage and from inundation of the root system for several days. If defoliation occurs early enough in the growth season, a new flush of leaves will likely develop.

MEASUREMENT EQUIPMENT

In a number of past studies, ring widths were measured with millimeter rules. Measurements were usually to the nearest millimeter or half millimeter. Measurements with this accuracy have generally not been found to be precise enough for most applications. Most equipment now in use allows measurement to the nearest 0.01mm. Equipment is commercially available, but some laboratories prefer to have their equipment custom built. Most equipment consists of a mechanical stage on which the wood sample is placed and a dissecting scope with occular crosshairs. In viewing through the stationary microscope, the crosshairs are a reference point for the material that is moved underneath the microscope via the mechanical stage.

A measurement stage may be hand-driven with a crank, and stage position may be sensed with a dial-gage micrometer (fig. 41). The stage was constructed from aluminum stock, though it might be possible to use a hardwood such as sugar maple (*Acer saccharum*). A more elegant version is also available from commercial sources.

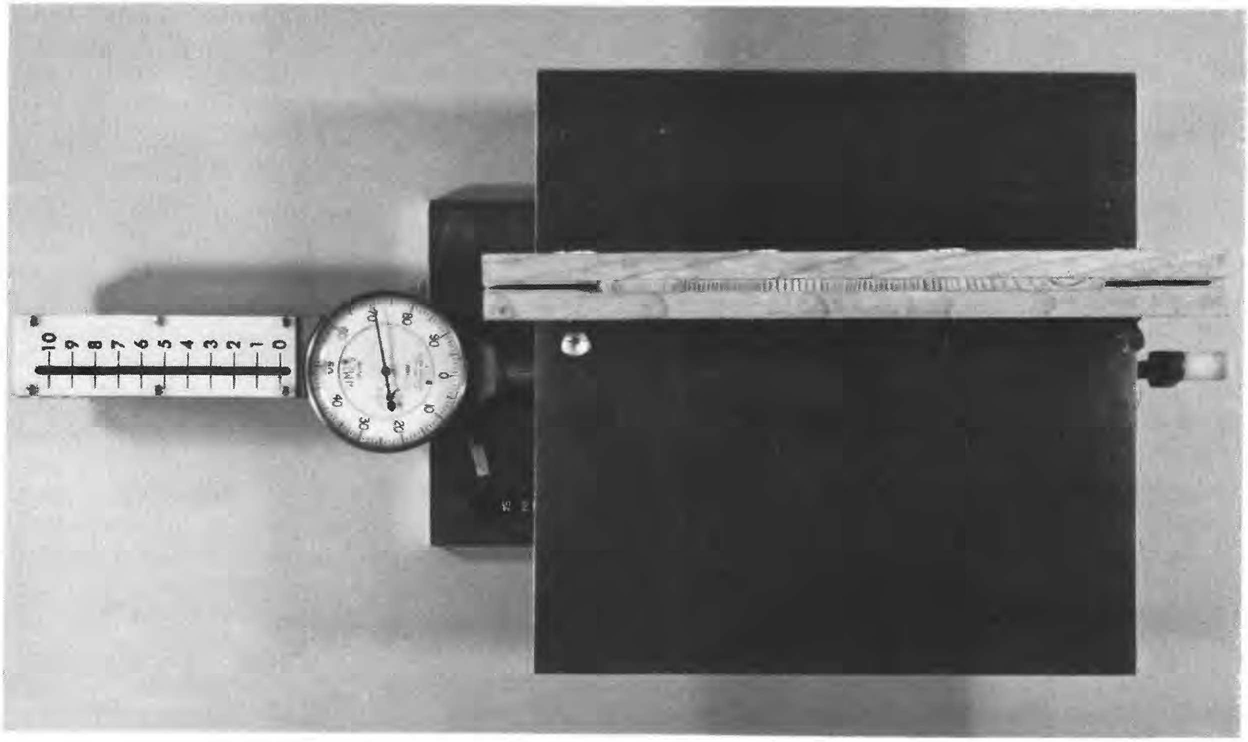


Figure 41. -*Hand-operated mechanical stage for measuring ring widths.*

More expensive measurement stages may include some provision for driving the stage electrically, and usually also include some means of electrically sensing stage position. A popular commercially available model senses stage position with a linear transducer, and includes hardware for hooking this to a microcomputer. Our equipment (fig. 42) is designed such that the stage is driven by a stepping motor geared to the drive screw. Each pulse of electricity to the motor moves the stage exactly 0.01mm. Stage position is then monitored electronically by counting pulses to the drive motor.

PROCESSING AFTER MEASUREMENT

A series of raw ring-width measurements normally contains considerable trend, referred to as the growth trend. For many applications of tree-ring data it is necessary to de-trend, or standardize, the data before proceeding with further data processing (fig. 43). It is not the purpose of this treatise to describe or explain standardization. The reader is advised to consult with other sources, such as the textbook by Fritts (1976).

Figure 42. -*Automated equipment for measuring ring widths.*

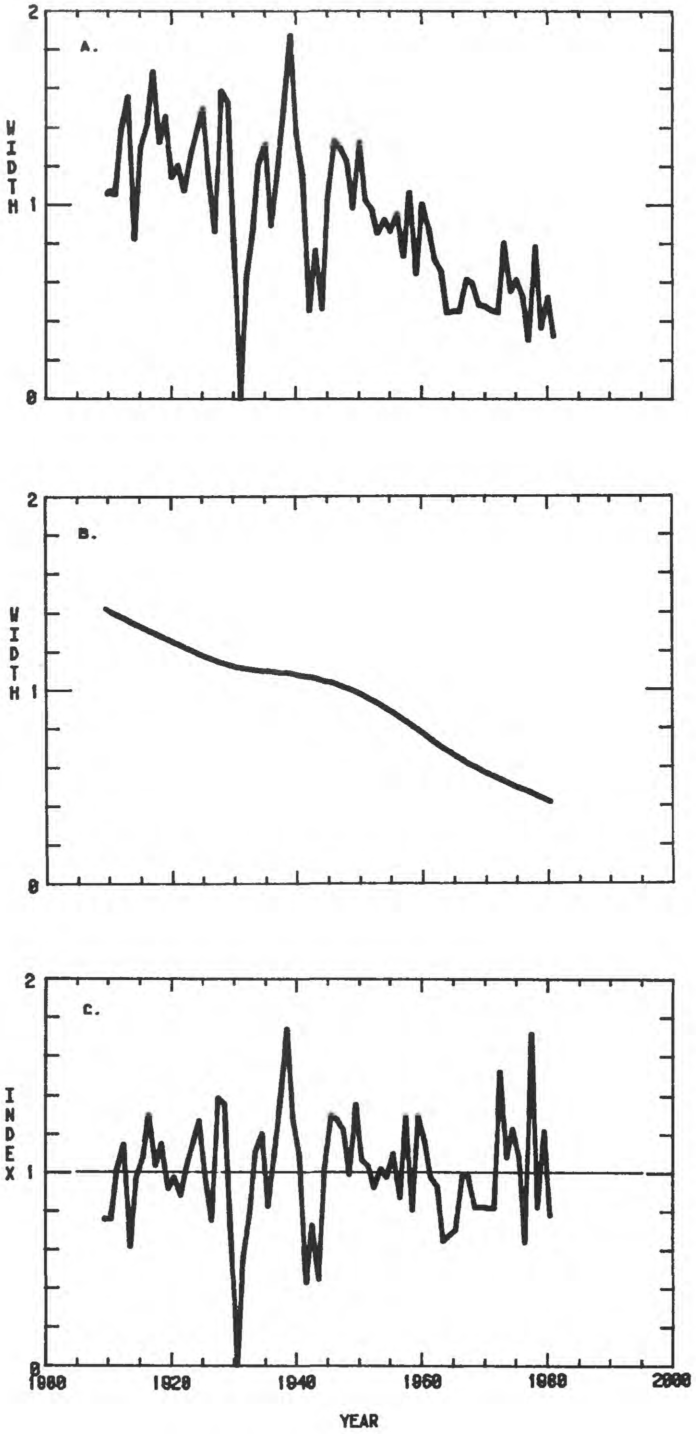


Figure 43. -*Graphs derived from ring-width measurements of a single core.*

A. *Raw ring widths.*

B. *Growth trend curve derived by applying cubic smoothing spline to raw ring-width data.*

C. *Standardized indices of ring width derived by dividing raw ring widths by corresponding values from the growth trend curve.*

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GLOSSARY

Angiosperm.--Flowering plant. Most angiosperm trees of eastern North America are deciduous and are gererally referred to as hardwoods.

Annual increment.--A broad, or general, term referring to the three-dimensional sheath of xylem (wood) added to stems and secondary roots each year. The annual increment has the appearance of a ring (tree ring) when viewed in transverse (cross) section. "Annual increment" may also be used with specific types of growth measurements; hence, "annual volume increment," "annual radial-growth increment," "annual increment of height growth," and so forth.

Annual ring.--See "tree ring."

Basipetal.--Proceeding from top toward the base.

Cambial activity.--The process by which cambial initials divide and form derivatives that differentiate into phloem cells outward from the cambium or xylem cells inward from the cambium.

Cambium.--A tissue in many higher plants, including trees, in which cells divide and form new tissues. The cambium is located between the inner bark (phloem) and wood (xylem).

Canopy.--The uppermost level of tree crowns in a forest. All tree crowns in the canopy level are exposed, at least in part, to direct sunlight.

Conifer.--Any cone-bearing plant. Most coniferous trees, such as pine (*Pinus*) or hemlock (*Tsuga*), retain their leaves, or needles, throughout the year. Conifers are often referred to as softwoods.

Deciduous tree.--Tree, such as oak (*Quercus*) or baldcypress (*Taxodium*), that normally produces new leaves every spring, loses them in the fall of the same year, and overwinters in a leafless condition.

Diffuse-porous wood.--Wood in which the vessels (pores) are of fairly uniform size and distributed throughout each annual increment, as in maple (*Acer*) or beech (*Fagus*).

Earlywood.--Inner part of an annual ring that is produced in the early part of the growing season. Earlywood of diffuse-porous and nonporous woods, relative to latewood, is generally lighter colored, due to larger, thinner-walled cells. The pore zone of ring-porous woods is often referred to as earlywood.

Growth.--Increase in size by addition of new cells or cellular material.

Growth ring.--See "tree ring."

Growth trend.--A time trend of growth, often described in terms of ring width or ring area.

Increment borer.--Instrument used to remove increment cores from a tree.

Increment core.--Pencil-shaped wood sample removed from a tree with an increment borer. An increment core is also referred to as a tree core.

Latewood.--The outer part of an annual increment. See "earlywood."

Nonporous wood.--Wood of conifers, such as pines (*Pinus*), that does not contain vessels (pores).

Phloem.--Food-conducting tissue that constitutes most of the inner bark and is located between the cambium and the outer bark.

Pore zone.--The inner part of the annual ring of ring-porous woods, that contains all of the larger vessels (pores). The pore zone is often referred to as earlywood, though it may not be analogous to the earlywood of diffuse-porous woods.

Ring.--See "tree ring."

Ring width.--The width of a tree ring at any given radius of a transverse section. An increment core is usually considered to contain all, or a portion, of a single radius.

Ring-porous wood.--Wood in which the vessels (pores) are of two distinct sizes, the larger being only in the inner (pore zone or earlywood) part of the annual increment, and the smaller being analogous to the vessels of diffuse-porous woods. Oaks (*Quercus*) and hickories (*Carya*) are examples of trees producing ring-porous wood.

Tree ring.--Two-dimensional transverse section of an annual increment. A tree ring is also referred to as ring, annual ring, or growth ring.

Xylem.--Water-conducting tissue of most plants; hence, the supporting tissue (wood) of trees. Xylem develops inward from the cambium.