COLLECTING, PREPARING, CROSSDATING, AND MEASURING TREE INCREMENT CORES

by Richard L. Phipps

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By Richard L. Phipps

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.

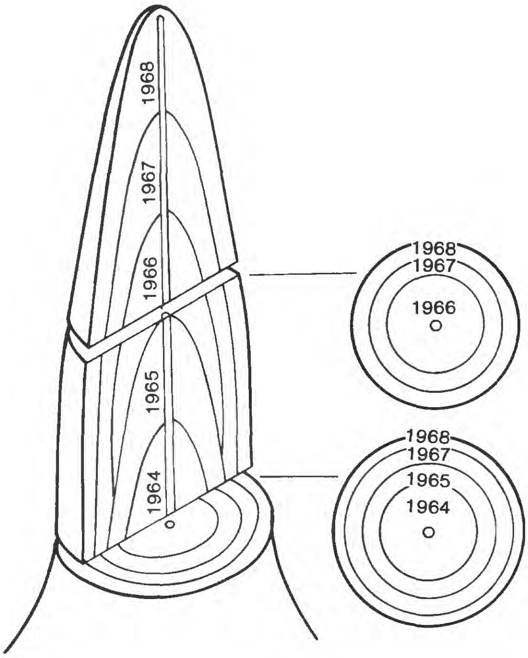
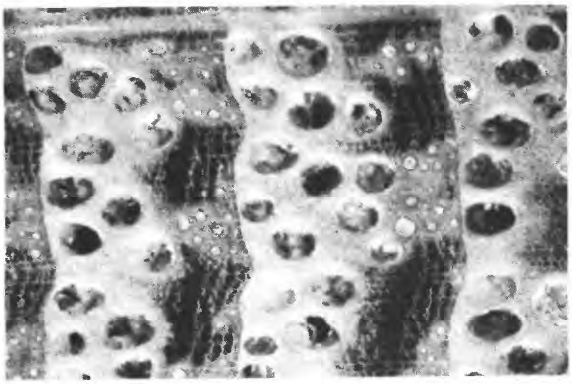


Figure 1. *-Diagram of growth layers of a single tree stem.*

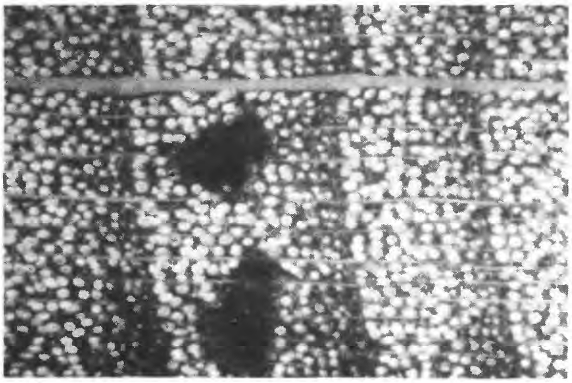
WOOD TYPES

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.

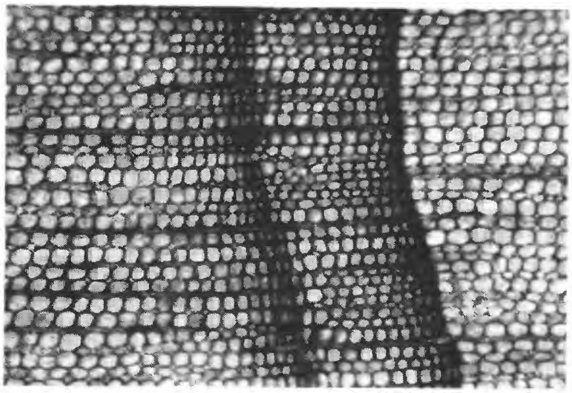
Ring-porous woods are the exception to the general rule of basipetal growth progression. In ring-porous species, growth appears to commence simultaneously throughout the tree. There is evidence to suggest that vessels of the pore zone may develop from cells that were cut off from the cambial initials 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.

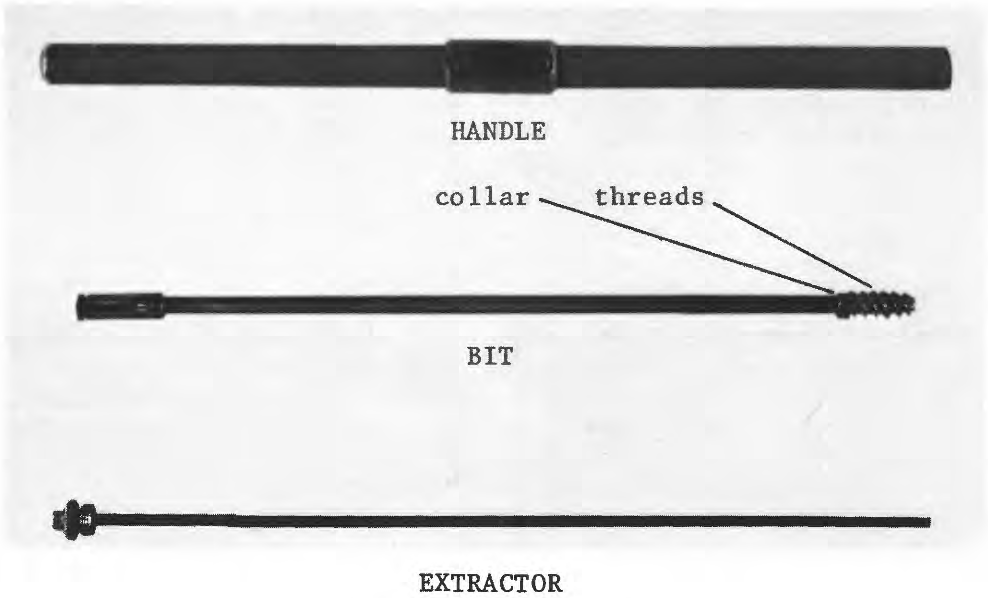


Figure 3. -*The increment borer.*

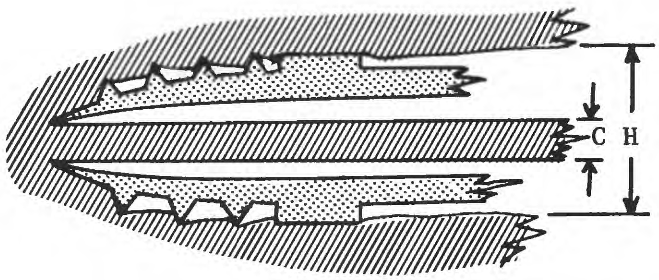


Figure 4. -*Cutting and compression of tissue with increment borer. Compression of wood tissue by borer is indicated by the difference between the size of the hole (H) and the diameter of the core (C).*

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.

Figure 6. -*End of increment borer bits from which pieces have broken away as a result of metal fatigue.*

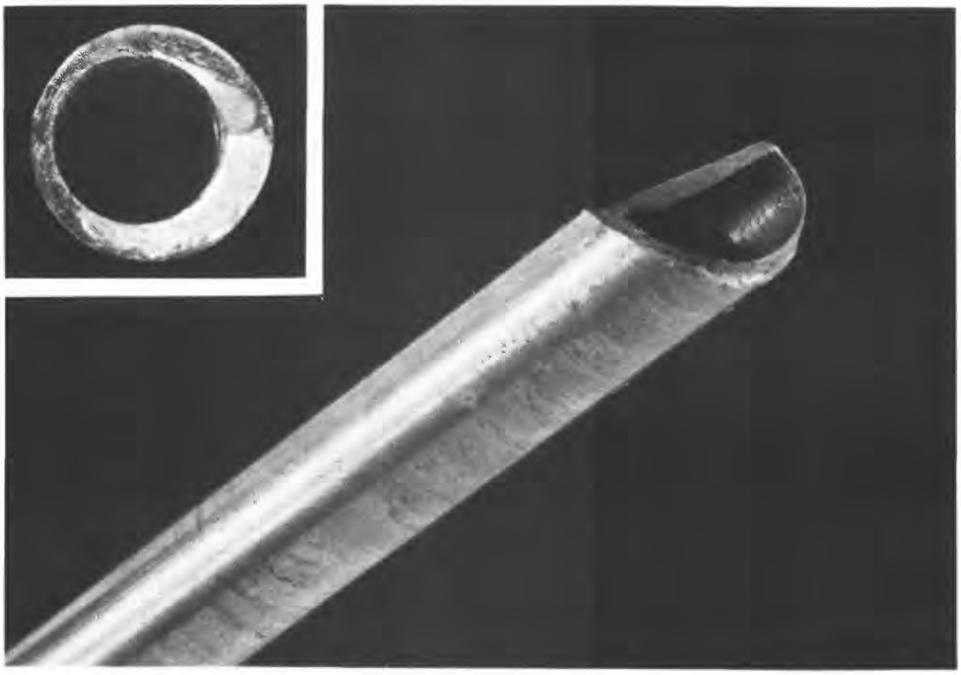


Figure 7. -*Broken bit in which hole is off center. Inset shows end view.*

If bits are properly cared for to avoid rust, corrosion, and excess heat buildup, the bit will likely succumb to metal fatigue before the cutting edge becomes dull. Breakdown of a bit by metal fatigue will likely not occur until well over a thousand cores have been taken.

COLLECTING THE SAMPLE

BEFORE STARTING THE BIT

A problem of tree coring is heat buildup caused by friction between the bit and the tree. Because heat buildup induces metal fatigue, it is advisable to reduce friction by the use of a lubricant like beeswax. Apply the wax to the threads and some of the adjoining shank of the bit (fig. 8). It is not necessary to apply wax to all of that portion of the bit that is expected to be inserted into the tree. As already mentioned, much of the friction is expected to occur in the area of the threads and collar.

The best time to apply wax is when the bit is first taken out of the tree, while the bit is still warm . However, before starting the bit in the first tree, it is important to assure that there is a coat of wax on the bit. It is not necessary that the wax melt onto the threads. It is just easier to apply an even coating to a warm than a cold bit. In coring some very soft nonporous woods, beeswax may only need be applied after several cores have been taken.

An increment borer with a Teflon-coated bit is now available. Apparently the intent is that the Teflon[1/] surface will slip through the wood more easily than an uncoated bit, and that the coating will reduce the risk of rusting. We have found that for hardwoods, such as *Quercus*, it is still necessary to coat the threads with beeswax, and that the Teflon coating wears off after only a few cores have been taken. Others tell us that the Teflon coating works and holds up quite well when sampling only conifers.

STARTING THE BIT

It is usually desirable to examine tree rings in transverse section and to obtain as long a tree-ring record as possible. This is most easily accomplished with cores that are parallel to wood rays. First, orient the borer by aiming it toward the center of the tree, perpendicular to the axis of the trunk.

The next step is to simultaneously push the borer into the tree and turn the handle. The most common approach is to hold the borer near the center of the handle, pushing with the palm (fig. 9). The other hand may be used to steady the bit to prevent it from wobbling. Wobbling of the bit, before it

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[1/] The use of trade names in this publication is for descriptive purposes only, and does not constitute endorsement by the U.S. Geological Survey.

Figure 8. -*Beeswax is applied to lubricate the borer bit threads.*

Figure 9. -*Start the increment borer by a combination of pushing and turning with one hand while steadying the bit with the other hand.*

has been driven far enough to be well anchored in the tree, may cause the core to break. If the break occurs only at the cambium, no harm has been done. However, if the break is just inside the cambium, the outer one or two rings may be very difficult to discern. Wobbling results in a bent or even a corkscrew-shaped core (fig. 10).

AFTER STARTING THE BIT

Once the bit has been pushed and twisted enough that the threads are fully twisted into the xylem, there is no need to continue pushing. The threads will pull the bit into the tree as the borer is turned. At this point, both hands may be used to turn the handle (fig. 11).

The borer often squeaks or pops as it is twisted into the tree. These noises result when there is considerable friction between tree tissues and the bit shank. Because friction of this magnitude can result in appreciable heat buildup, contributing to metal fatigue, slow the rate of turning the handle so that the popping noise ceases and the squeaking is at least minimized.

REMOVING THE CORE

There is no advantage to twisting the bit any farther into the tree than the length of core desired. The core is removed from the bit with the extractor, while the bit is still in the tree. The diameter of the bit tube is greater than the core, except near the cutting tip; thus, there is room to insert the extractor spoon. Some people always insert the extractor with the cup of the spoon facing upward so that the spoon slides along the bottom of the tube beneath the core. But I find that if the outer end of the core happens to be resting on the bottom, the spoon may snag, and perhaps damage, the end of the core. I prefer to lightly probe with the extractor to find the side of the tube which is away from the core, and then to insert at that position.

It is best to insert the extractor with one steady, continuous motion (fig. 12). If the extractor is pushed only part way in, it may be difficult to push it farther. If it can be pushed farther, there may be a risk of damaging the core or bending the extractor. As the tip of the extractor reaches the point at which the bit tube narrows, the extractor teeth are forced into the side of the core. This is important. It causes the teeth to grip the core so that it can be withdrawn with the extractor.

The extractor spoon is mounted off center in the knob. Therefore, too much pressure on the knob while inserting the extractor will very likely bend the spoon just below the knob. Essentially all broken extractors that I have seen were broken just below the knob (fig. 13).

Do not be terribly dismayed if the extractor falls a few millimeters short of being inserted all the way. However, if the extractor stops as much as a full centimeter from complete insertion, there is a risk of either not engaging the teeth in the core tightly enough to extract the core or leaving a short piece of the core stuck in the end of the bit. If, in taking additional

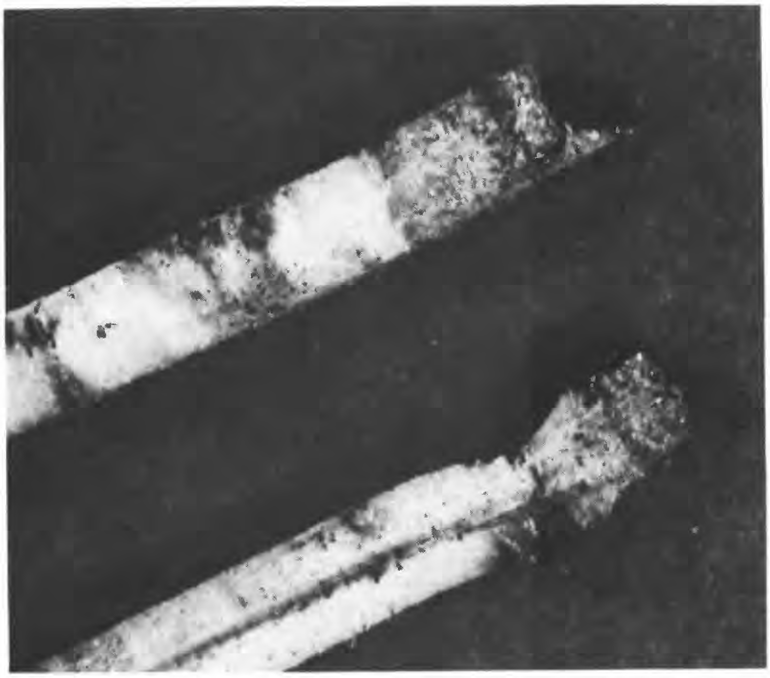

Figure 10. -*A correctly shaped, straight core, and a core with bends near the outside resulting from not maintaining a steady borer.*

Figure 11. -*Pressure need not be applied to push the borer into the wood after the bit threads have engaged the wood.*

Figure 12. -*Insert the extractor in a steady, continuous motion.*

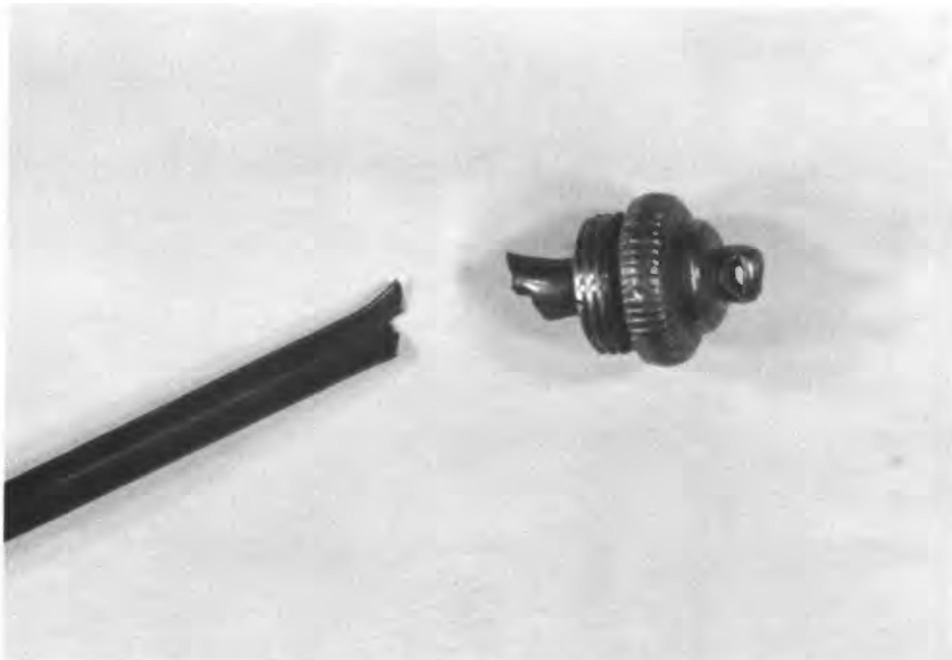

Figure 13. -*Extractor broken just below the knob as a result of forcing the extractor into the bit tube.*

cores, it is still difficult to get the extractor in far enough, the tip of the extractor spoon may be too thick. This can be remedied by filing the inside surface of the spoon tip (fig. 14). If it is still difficult to insert the extractor all the way, it is possible that the teeth are gripping the core too tightly. This can be remedied by very slightly flattening the end of the extractor spoon by a light blow with a hammer (fig. 15). On the other hand, if the extractor can be inserted all the way and fails to grip the core, the toothed end of the spoon may be too flat. In this case the end of the extractor can be closed slightly with a pair of pliers (fig. 16). Generally, adjustments to the extractor are not necessary when using a new borer. The need for adjustment is rarely encountered, but when the need arises it is usually brought about by a replacement bit or extractor.

After inserting the extractor, break the core loose from the tree before attempting to remove it. This is done by rotating the borer counterclockwise while the extractor is fully inserted. Because the toothed tip of the extractor spoon is tightly wedged between the core and the bit, the core and extractor will both turn as the borer is turned. There is a procedure for finding the center of the tree (see SAMPLING THE CENTER RING) that requires backing off the handle one full rotation (360 degrees). Because of this, as a matter of convention, I routinely back off the handle one full rotation, whether or not I am following the center-finding procedure.

If the handle is backed off before the extractor is inserted, the core may slip back through the cutting edge of the bit and not break loose from the tree. If the extractor is removed before the handle is backed off, the spoon teeth may slip off the core before the core is broken loose, or the core may break off back from the tip, leaving a portion of the core stuck in the bit.

After the handle has been backed off, breaking the core loose from the tree, remove the core from the bit with the extractor (fig. 17). If the extractor was not inserted underneath the core, but rather to the side or top of the core, place a hand under the extractor as it is withdrawn to catch any loose core pieces that may fall off the extractor spoon.

REMOVING THE BORER

After removing the core from the bit, it is very tempting to examine the core immediately. Avoid this temptation, and immediately remove the borer from the tree. As already explained, compressed tissue around the bit slowly springs back toward its original shape, increasing pressure on the borer bit. If too much time elapses while the borer is in the tree, the borer may become stuck. A few minutes may be too long. Removing a stuck bit can be very difficult.

As previously mentioned, it is a good idea to apply beeswax to the threaded end of the bit while it is still warm immediately after withdrawing it from the tree. It appears that corrosion is much more harmful to the cutting edge than is fresh wood of a living tree. Borer bits and extractors replaced in the handle immediately after the bit has been withdrawn from the tree will almost always rust overnight. Moisture that is present inside the

Figure 14. -*Filing inside surface of extractor spoon to allow the extractor to slide more easily between the core and bit tube.*

Figure 15. -*Opening end of extractor spoon with hammer when the extractor jams against the core before complete insertion.*

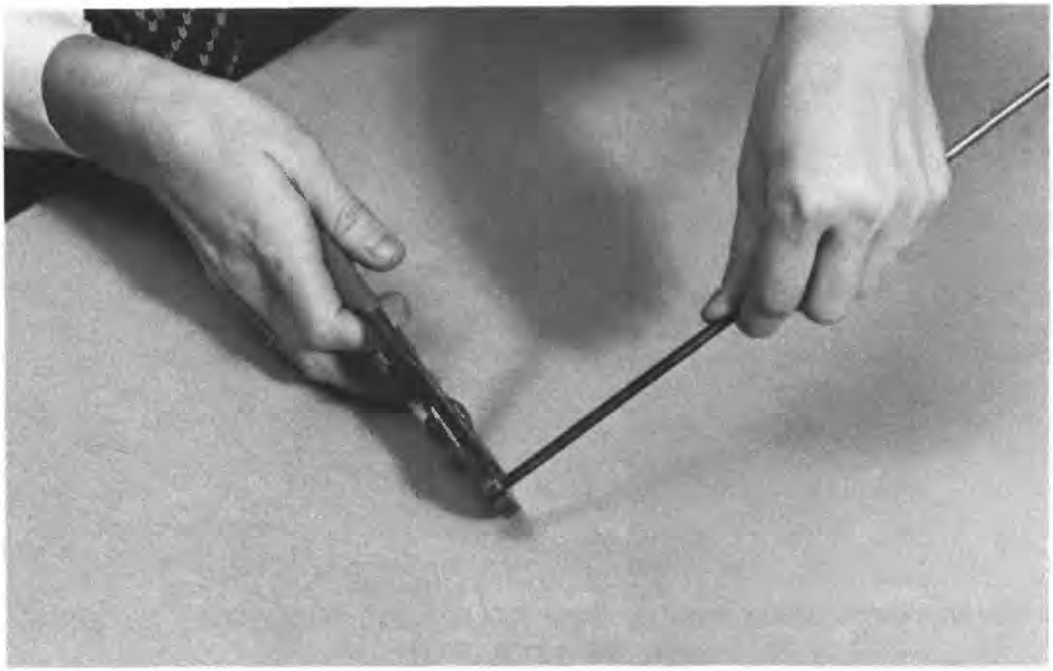

Figure 16. -*Closing end of extractor spoon with pliers when the extractor will not grip the core.*

Figure 17. -*Removing core. Use one hand to steady the extractor and catch any loose core pieces that might fall out of the spoon.*

bit as a direct consequence of boring is thus trapped in the handle and cannot evaporate into the air.

Storing the bit in the handle only after it has cooled to ambient temperature helps avoid rust. In winter weather the bit may not completely cool for 10 to 15 minutes; in summer weather, much longer. At times, it may be necessary to store the bit in the handle before it has thoroughly cooled. For example, it may be better to store the bit in the handle than risk bumping the bit into something that could damage the cutting edge. When the bit cannot be allowed to cool before storage, a couple of squirts of oil from an aerosol can into the bit tube before placing it in the handle will usually prevent rust formation. Some of my co-workers routinely place a couple squirts of oil in the tube at the end of each collection session, whether or not the bit has cooled to ambient temperature. If no rust or corrosion is allowed to develop in the bit, it may become stained, but otherwise will remain remarkably clean.

REMOVING A STUCK BIT

As described above, failure to remove the borer from the tree immediately after taking the core out commonly causes the borer to stick. Another cause is driving the bit threads out of solid wood into a rotten or hollow portion of the tree. If the borer suddenly turns much more easily, the borer threads have been driven out of solid wood. Without proceeding further, attempt to remove the borer.

Usually, a stuck bit will not have seized in the tree. Indeed, the handle may turn quite easily. In cases where the borer has been left in the tree too long, tissue has sprung back against the borer shaft with enough force that the collar at the back of the threads cannot easily be moved back through the tissue, and the threads slip.

Often a stuck borer can be restarted by simultaneously pulling and twisting the handle (fig. 18). If the borer is tightly stuck, it may be necessary to perform this operation as a very hard jerk while turning the handle about an eighth of a rotation. Usually, a series of jerk-and-turn operations will back out the borer far enough to re-engage the threads. This procedure is almost always successful in restarting a borer that has encountered a rotten spot. A borer that has become stuck in solid wood because it was left in the tree too long may be more difficult to remove.

Rarely, a borer may become stuck so tightly that no amount of jerking and turning will restart it. In all the years of working with increment borers, my coworkers and I have only encountered three instances when the borer stuck. Two of the instances involved leaving the borer in the tree too long while examining particularly interesting cores. Both borers were removed by the use of a small rope. The rope was looped around the borer handle and an adjacent tree, pulled tight, and the two ends tied together (fig. 19). The borer handle was then turned, twisting the rope. Continued twisting tightened the rope enough to pull the borer back enough to allow the threads to engage. It was then possible to remove the rope and back the borer out in the normal fashion. In the third case the borer became stuck in very soft, rotten wood

Figure 18. -*Using the jerk-and-turn method to remove a stuck borer. This procedure usually engages the threads, after which the borer can be removed in the normal manner.*

Figure 19. -*Using rope method to free a stuck borer. This method is dangerous and only used in extreme cases.*

at the center of a tree. It was not possible to remove the rope until the borer had been completely withdrawn from the tree.

The rope method of borer removal is potentially very dangerous. When tension is applied to the borer by the twisted rope, the only thing that holds the handle on the borer bit is the small clip on the handle. As the handle is turned, stand far enough to one side to be clear of both the handle and the rope if the handle breaks loose from the bit.

REMOVING A STUCK CORE

Occasionally, after removing a borer from the tree, a part of a core may be stuck in the bit. If any of the core is sticking out of the end of the bit, do not attempt to push it back into the bit or pull it back into the bit with the extractor. Break it off, then attempt to remove that remaining inside the bit by use of the extractor.

It is possible to have a very tiny plug of core left in the cutting edge end of the bit that the extractor teeth cannot reach quite far enough to grip. If the plug is not too tightly wedged, it is sometimes possible to remove it by simply starting a new core, and letting the new core push the plug loose. On the other hand, if the plug is tightly wedged it may not be possible to engage the bit threads to take a new core. In this case, there is little choice but to drive the plug into the bit from the cutting edge end. If an attempt is made to drive the plug out by inserting a wooden dowel into the bit tube, it may only succeed in wedging the plug even tighter. Further, spraying a fluid into the bit tube may only exacerbate the situation by swelling the core and causing it to become even more tightly wedged. A small, whittled, wooden peg seems to be the most practical tool to use to push the plug back into the bit (fig. 20). Use of a whittled plug in the field ensures that the peg surface contains no sand or grit that could harm the cutting edge.

Figure 20. -*Removing a core plug using a wooden peg. The first consideration is to avoid damaging the cutting edge of the bit.*

SAMPLING THE CENTER RING

Some studies require determination of tree age at sample height. This, of course, necessitates sampling the center ring. I am convinced that trees love to play games with the field scientist, particularly if the investigator is intent upon sampling the center ring. Even in nice, symmetrical tree trunks, the botanical center seems more often than not to be somewhat off from the geometric center. Consequently, one rarely hits the center on the first attempt. Further, the tree *must* be capable of moving its botanical center between the time of taking the first and second samples. I have no more plausible explanation why the center is missed on the second attempt.

Fortunately, there is a neat trick to greatly improve the chances of hitting the center on the second or third attempt. The trick was shown to me by a coworker, Robert S. Sigafoos. The trick is simple enough that surely nearly anyone could discover it on his own, but many people, such as myself, don't.

When extracting the first core, back the handle off exactly one revolution (360 degrees). This leaves the core oriented in the extractor spoon in the same way it was when attached to the tree. Then, when the core is withdrawn the arcs of the rings near the center indicate whether the botanical center is to the right or the left of the first core hole, and how far right or left the center is (fig. 21).

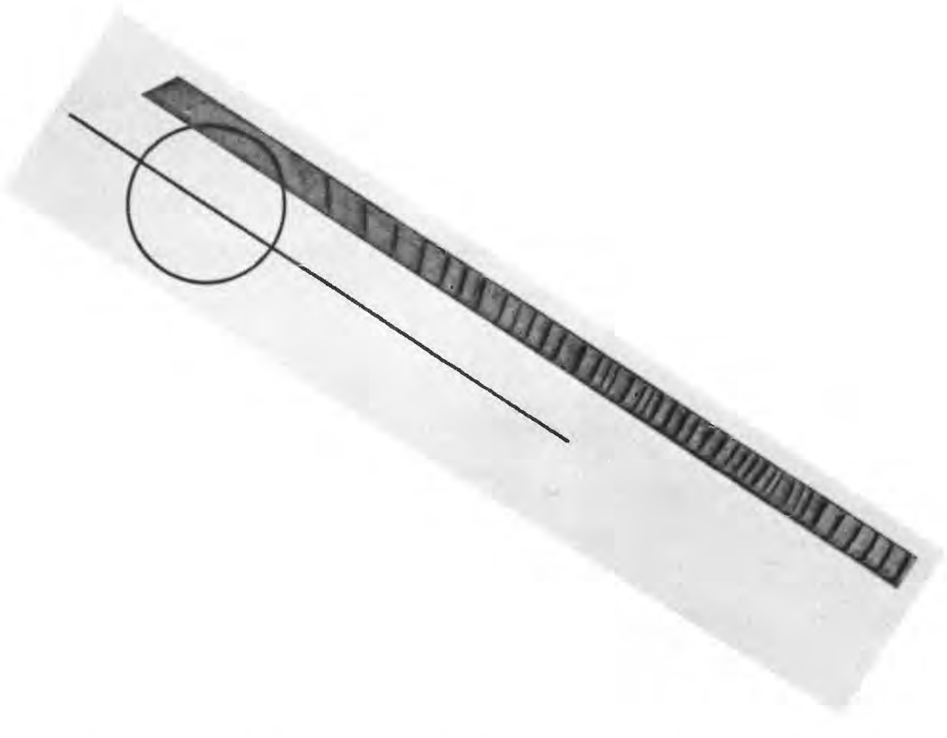

Figure 21. -*Estimating direction and distance of botanical center from increment core.*

Remove the core from the extractor spoon and place it back in the hole from which it came, leaving several centimeters of core sticking out of the tree. For the second attempt, orient the borer parallel to the first core, and the estimated distance to the right or left (fig. 22). If the estimated distance is quite short, it is also a good idea to bore either up or down a few centimeters to make sure there is good solid wood into which the borer bit can dig. If the tree is not much larger than about 60cm diameter, this method will usually yield the center ring on the second or third try.

Figure 22. *-Orienting increment borer parallel to, and at correct direction and distance from, first core hole in order to obtain botanical center with second core.*

PLUGGING THE CORE HOLE

The hole left in the tree after a core has been removed customarily is not plugged. Although the wound caused by boring can provide an entry point for bacterial and fungal infection, the risk of infection appears to be minimal for most tree species. Occasionally, a landowner will grant permission to core trees on condition that the core holes are plugged or sealed. A dressing, such as commonly used for cut surfaces when branches are pruned, may serve to placate the landowner, although I am not convinced that it always does more good than harm. I have noted a number of cases in which plugged holes failed to heal as rapidly as unplugged holes.

HANDLING THE CORE

FIELD EXAMINATION

Upon removing the core from the tree, it is advisable to perform a cursory field examination. Even casual observation may reveal faults in the core that may render it unusable. For example, inadvertently sampling too close to an adventitious bud or a branch trace of a long-gone branch can yield distorted ring boundaries. It is certainly better to discover the unusable core while in the field than after having returned to the laboratory.

It may be necessary to more closely examine a core in the field. For example, accurate ring counts in the field may have a bearing on further activities of the same field trip. Or, it may be necessary to determine if the core contains a predetermined number of rings.

Field counts of rings made directly on an undisturbed core as it is withdrawn from the tree are rarely reliable. More precise examination in the field can be accomplished by hand-surfacing the core and then examining it under a hand lens. The core can be surfaced by paring, or slicing, with a sharp knife. It is advisable to hold the core in some sort of clamp during the slicing operation (fig. 23). Care should be taken to orient the core in the clamp so that the exposed surface of the core will yield a transverse section of the wood when sliced. This can easily be done by turning the core in the clamp until the grain of the wood (vessels and wood fibers) exposed on the end of the core is parallel to the sides of the clamp (fig. 24).

The exposed surface of the core is then sliced with a sharp knife. I prefer to use a surgical scalpel with standard #10 disposable blades. For very hard wood, such as some oaks, the blade may need to be replaced after one or two cores, depending in part on core length surfaced. A more detailed description of slicing cores with a knife is provided below under the heading, CORE SURFACING.

The surfaced (sliced) core can be examined in the field with a hand lens. A 10X Hastings triplet works well for most purposes (fig. 25). The ring boundaries of some diffuse-porous species may be more easily distinguished after the sliced core has been allowed to air dry for a half hour or more. But boundaries of diffuse-porous species are sometimes impossible to distinguish under field conditions.

Figure 23. -*Core clamp used to hold core during surfacing, crossdating, and measuring.*

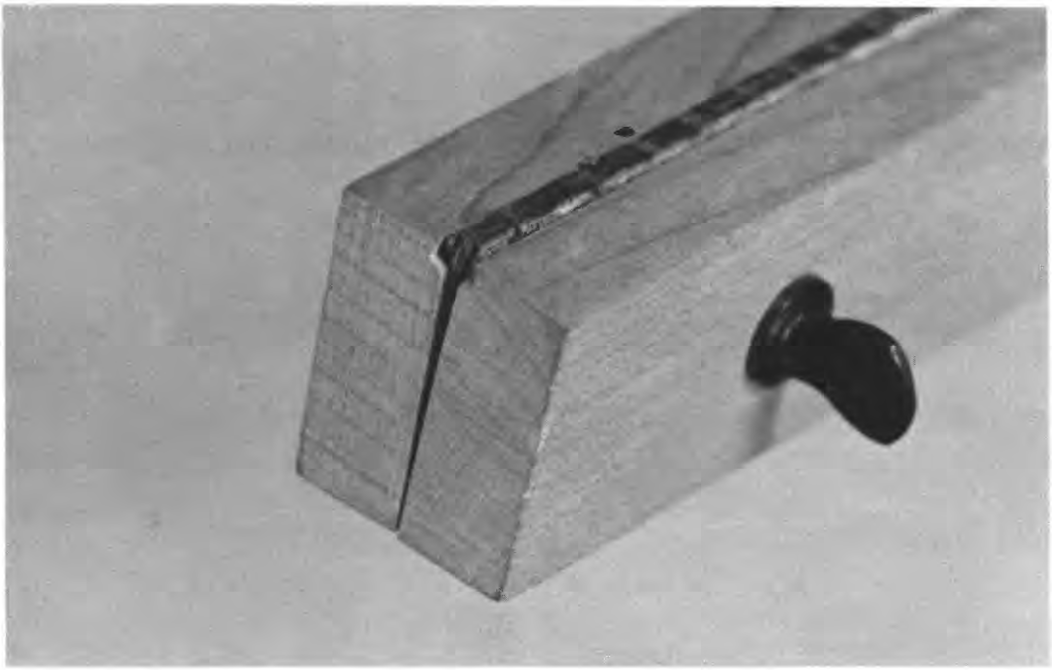

Figure 24. -*Orient wood fibers of core parallel to sides of core clamp.*

Figure 25. -*Examining shaved core in the field with core clamp and hand lens.*

STORING CORES

Many methods of storing and transporting cores under field conditions have been described in various notes in the literature. By far the most popular method is to store the cores in soda straws. Paper soda straws are preferable to the more commonly available plastic ones. The paper soda straws are rigid enough to prevent the cores from warping during air drying, yet porous enough to allow the cores to dry before developing profuse crops of mold. Further, in handling small diameter cores or broken cores that may easily slide out of the straw, the ends of a paper straw may be neatly crimped and closed (fig. 26). Of course, paper straws cannot be used if it is desired to store the core in its original, fresh, wet, condition.

The straw should be labelled with an identifying note or number. The simplest procedure is a number that is keyed to field notes containing such information as date, location, site, and tree descriptions. By convention, some workers number the end of the straw containing the bark end of the core. Knowing which end of the straw contains the bark end of the core may be helpful when removing the core from the straw.

The paper straws can be field-stored in mailing tubes that have been cut to length (fig. 27). The straws are placed in the tube such that the numbered end of the straw is at the top. These containers have been mailed without damaging the cores.

Figure 26. -*Folding ends of paper straw. Make four creases with a thumbnail, and then fold in.*

Figure 27. -*Mailing-tube straw containers.*

Much of the coring from secondary or tertiary forests results in full radius-length cores that easily fit into standard 10-inch (25cm) straws. Some cores, however, are too long to fit into a single straw. In such cases, cut the core and store it in 2 or more straws. Do not break the core. A core, particularly of a ring-porous species, will often break along the pore zone. When the core is put back together for ring-width measurement, a certain measurement error is incurred in the one or two rings containing the break. To prevent this, cut the core diagonally across a ring boundary such that a portion of the same boundary remains with each piece (fig. 28). This is done by cutting about halfway through the core, parallel to the grain, and then twisting the two pieces apart (fig. 29). The first (outer) core piece is placed in the first straw in the usual manner. The second core piece is placed in the second straw with the outer (cut) end at the numbered end.

Occasionally, if the cores are to be permanently mounted in blocks instead of being stored in straws, it may be better to leave a long core sticking out of a straw in the field than to cut it.

AIR DRYING CORES

Even if stored in porous paper straws, the cores will only dry slowly if the straws are left in the mailing-tube straw containers. When the straws are removed from the containers and spread out on a table, the cores typically dry enough within a day or two for sanding. Additional drying may be needed if the cores are to be permanently mounted.

REMOVING CORES FROM STRAWS

Cores are easily removed from straws by the use of a small-diameter rod (fig. 30). We use a 1/8-inch (3mm) brass welding rod. To remove the core, the rod is inserted from the un-numbered end of the straw. If the rod is inserted from the numbered end containing the bark end of the core, the rod may cause the bark of some species to flake and jam the straw. The rod may be inserted into straws with crimped ends (fig. 26) without uncrimping the straws.

MOUNTING CORES

Most laboratories customarily permanently mount their cores in grooved, wooden blocks. Most of our cores are not mounted. Our cores are removed from the straws and placed in core clamps for surfacing, crossdating, and measurement, then replaced in the straws for permanent storage. We mount cores, however, if (1) the cores are fragile or broken into many pieces, as is common with eastern hemlock, *Tsuga canadensis*, or (2) it is expected that the cores will be repeatedly handled. It is always possible to mount a core at a future date, but it is very difficult to unmount a core once it has been mounted.

Most laboratories that customarily mount their cores prefer to air dry the cores before mounting. Fresh cores almost always pull apart in the mounting block while the core and the mounting medium are both drying. The cores must be very dry before mounting to avoid the breaks that usually make measurement a bit awkward.

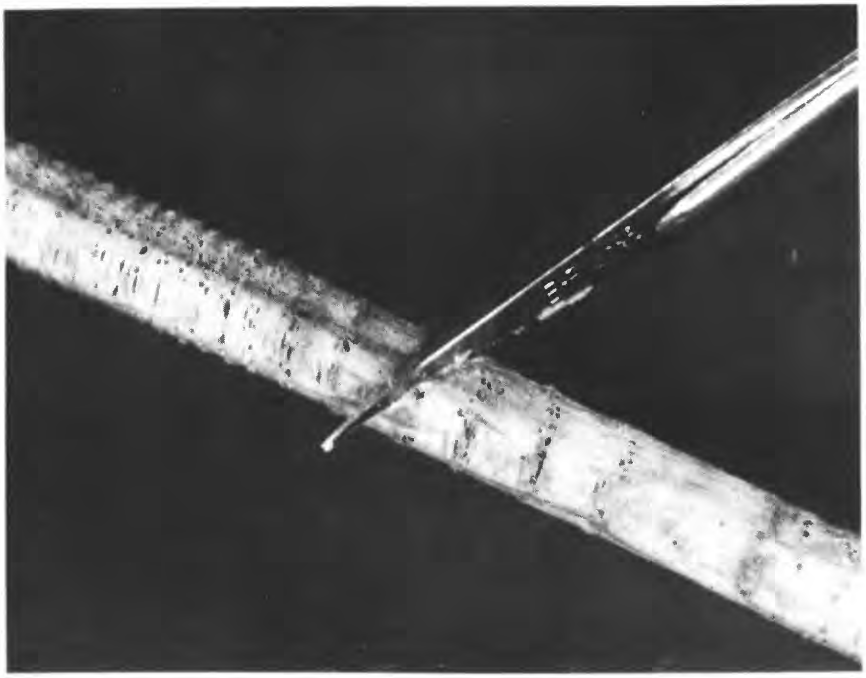

Figure 28. -*Diagonally cut core showing part of same ring boundary on both pieces.*

Figure 29. -*Breaking apart a partially cut core after a diagonal cut has been made about half way through the core.*

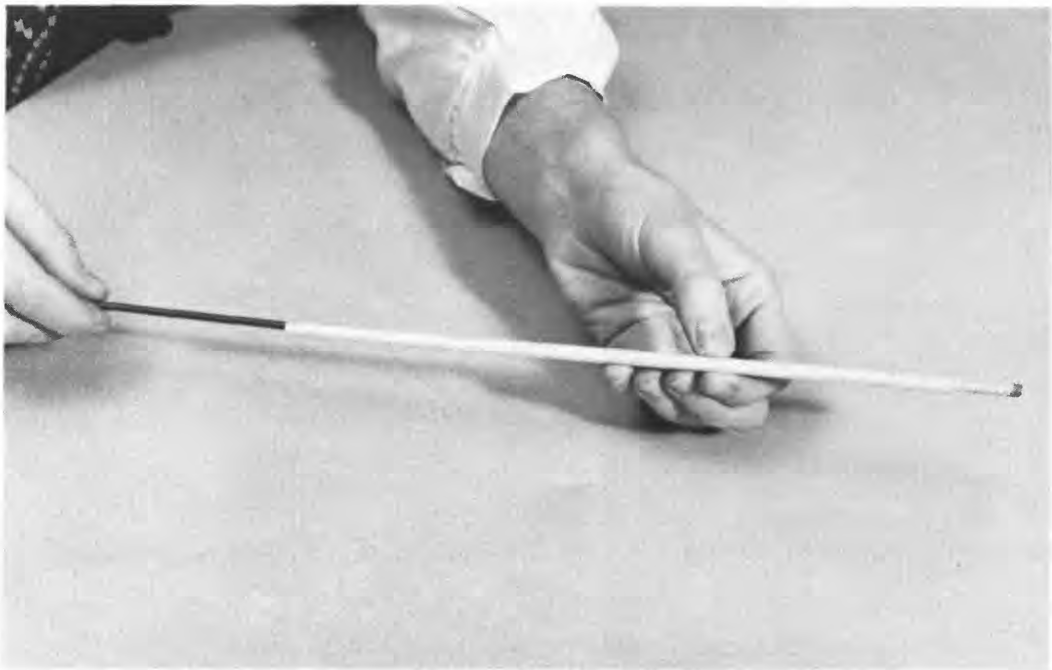

Figure 30. -*Removing a core from a straw with a 1/8-inch welding rod.*

There are advantages to mounting only one core per block, rather than the common practice of mounting 2 to 4 cores side by side in a single block. Some of the subtleties of sanding (surfacing) are more easily accomplished if each block contains only one core with very little block material on either side. A block about one centimeter square works very well. One surface of the block can be grooved with a router to the specific dimensions of the cores to be mounted (fig. 31). The groove should be shallow enough to allow sufficient core to protrude above the block to produce a reasonably wide finished (sanded) surface.

It is important to orient the core in the mounting block such that the wood grain (vessels and fibers) will be at right angles to the finished surface. It is thus important that the core is not twisted appreciably. Any glue commonly used in cabinetry can be used as a mounting medium. Some means of holding the core in the block should be provided until the glue dries. Rubber bands work very nicely (fig. 32).

In working with material in which the ring boundaries are particularly difficult to discern, it may be preferable to hold the cores in clamps rather than permanent mounts. Sometimes it is found that resurfacing the cores at a slight angle to a perfect transverse section enhances boundary distinction. A clamped core which has a particularly obstinate surface may be turned over, allowing the opposite side to be surfaced.

Figure 31. *-Core permanently mounted in block.*

Figure 32. *-Holding core in mounting block with rubber bands while the mounting medium sets.*

TWISTED CORES

In twisted cores, the grain of the wood changes angle along the length of the core (fig. 33). The wood was not twisted while still in the tree, nor does twisting occur as a core dries. Pronounced twisting is caused by the core dragging in a very dirty or rusty borer bit tube, or by a dull, burred, or improperly sharpened cutting edge. However, particularly with some soft conifer woods, it is sometimes impossible to avoid minor twisting, even when using clean, sharp borers.

If the core is severely twisted, it is often necessary to treat the core to straighten it. Simply soaking in plain water may be sufficient. However, it may be necessary to soften the core with live steam. After the core is softened, it may be straightened and held in a core clamp while it dries. Recheck the core from time to time as it dries to ensure that the core has not shrunk enough in drying to loosen itself in the clamp and perhaps partially retwist.

If total twist is less than about 45 degrees, it may be better to leave the core twisted. In such cases, mount the core so that the approximate midpoint of the core length is oriented correctly and each end is twisted about equal amounts in opposite directions.

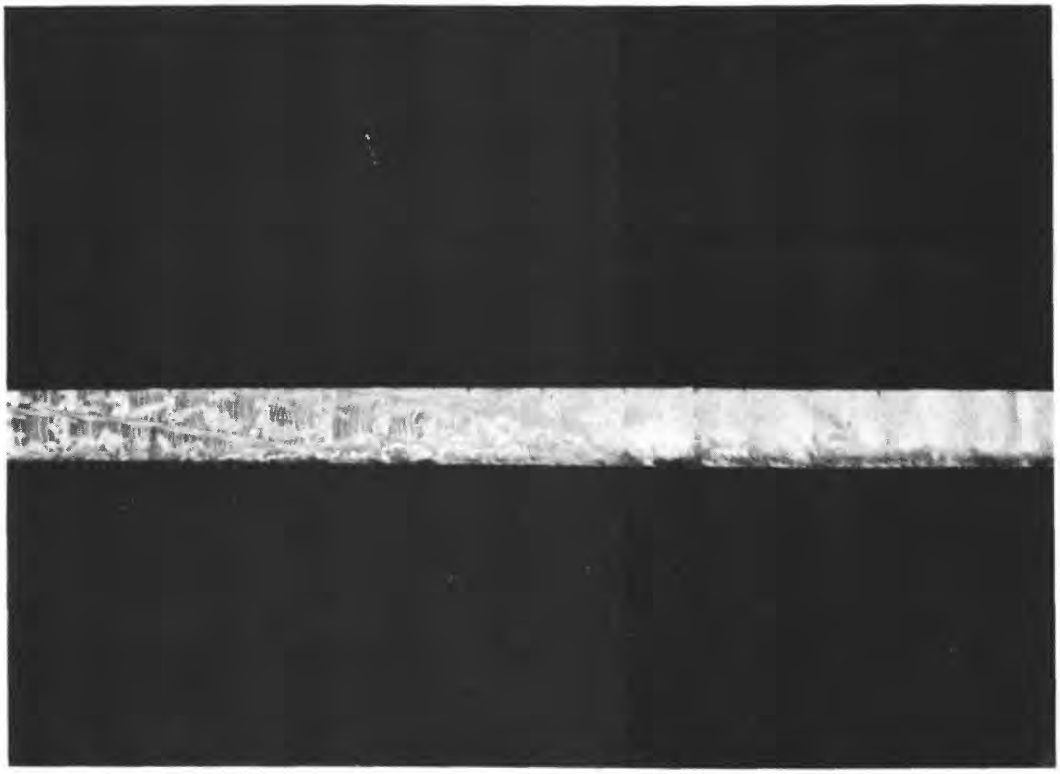

Figure 33. *-A badly twisted core. Surface of left part of core is nearly transverse, that of right part of core is radial.*

SURFACING THE CORE

Attempts to read ring boundaries on unsurfaced material are generally not reliable. Even in conifers in which most boundaries appear distinct on the unsurfaced core, there is risk of missing very tiny rings or misidentifying false rings.

SLICING

Slicing of cores with a knife or scalpel is normally most successful when the material is fresh. Cell walls are not easily cut cleanly once the material has dried. Softening, as with live steam, will generally not yield as clean a cut surface as will fresh material.

The blade used for surfacing must be nearly as sharp as a sliding microtome blade. A good experienced wood carver may have knives sharp enough to do a respectable job, but this is rare indeed. Surgical scalpels with disposable blades have proven to be very practical.

Pare off thin layers of wood to produce the desired surface. Do not push the blade through the wood, slice. In executing a single slice, the portion of the blade in contact with the core should progress from blade heel to toe (fig. 34).

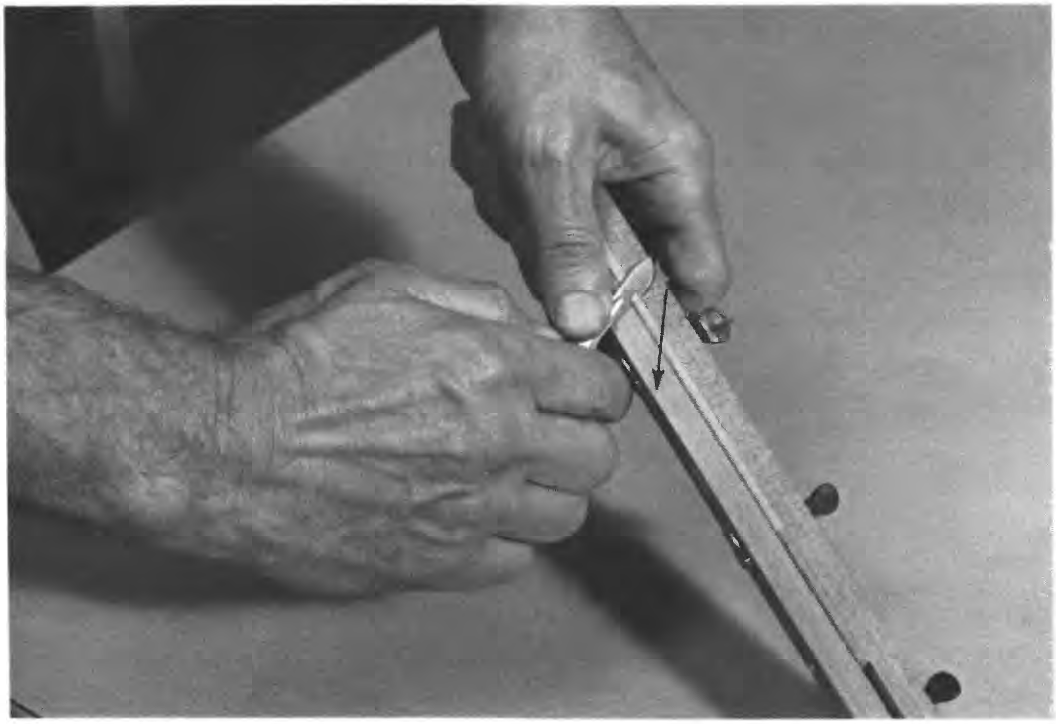

Figure 34. -*Slicing an increment core with a surgical scalpel. Direction of blade movement is indicated by the arrow.*

Properly sliced surfaces have an advantage over sanded surfaces in that vessels (angiosperms only) are left open and not filled with sawdust. Ring boundaries of some difficult diffuse-porous material are sometimes more easily discerned on a sliced than on a sanded surface.

Slicing cores is almost an art. Do not expect to get high quality surfaces without considerable practice. Because good sanding techniques are much more easily learned, many people quickly abandon attempts to develop good sliced surfaces.

SANDING

Anyone who has experience in woodworking or furniture refinishing knows that it is relatively easy to smoothly sand the side of a board, but quite difficult to smoothly sand the end of the board -- the "end grain." The end of the board, like a core, is close to being approximately a transverse section of the wood. Sanding a core is sanding end grain.

Sanding can be done by hand or by machine. A sanding disc on an electric drill can be used. However, a sanding disc on a drill press is often preferred (fig. 35). The drill press usually provides both higher speeds and a greater range of speeds than an electric drill, and a more uniform surface may be easily achieved.

Figure 35. *-Preparing a sanded surface on an increment core using a sanding disc mounted on a drill press.*

The most practical sandpaper grits for use on cores are finer than those normally available in ready-cut sandpaper discs. Therefore, we buy sheet sandpaper and cut the discs. We normally stock grits 220, 280, 320, 400, 500, and 600. For each core, only two or three grits of sandpaper are typically used, starting with a coarse grit and ending up with 500 or 600.

Each grit should remove the scratches of the previous grit. When first attempting to sand cores, the core should be scanned under a dissecting scope after each step. Scratches that obscure ring and cell boundaries are obvious when viewed at 15 to 30 power. Sometimes it will be necessary to repeat a previous grit, or to use an intermediate grit.

The objective of sanding is to prepare a surface similar to a cut surface. The purpose of the coarsest sanding is to prepare a flat surface. The purpose of the finer sandings is to reduce and finally remove the burred edges of the cell walls to sharply and clearly define them.

As a final step, buff the core with a lamb's wool pad (fig. 36). When viewed under a dissecting scope, the difference between final sanding and buffing is remarkable. Buffing not only does some polishing, but also removes some of the sawdust clogging the vessels. Considerable pressure between core and pad may be applied during buffing. However, if there is concern that the sawdust remaining in the vessels may act as an abrasive during buffing, lightly dust the core surface before applying appreciable pressure.

Figure 36. *-Using a lamb's wool buffing pad to polish and dust a surfaced increment core.*

ENHANCING INDISTINCT RING BOUNDARIES

The literature abounds with methods to enhance identification of indistinct ring boundaries. Many of the notes refer specifically to problems with rings of diffuse-porous species. There is no way that we could have tried every method, but we have tried many. We have rubbed various types of oils, kerosene, and even perspiration on the surfaced material. We have tried a variety of stains, including some used in microtechnique. We have tried shoe polish, and we have even tried lightly burning the surface and then resanding.

We have found nothing that is a marked improvement on a properly sanded surface. As already noted, some ring boundaries may be easier to distinguish on cut than on sanded surfaces. More often than not, though, we find that we must touch up a cut surface with some sanding to produce the best surface.

Even the best surface can be enhanced by lighting and magnification. There seems to be no "best" combination of lighting and magnification. Experimentation with the specimen seems to be the only answer. Sometimes light at a very low angle will cast shadows in the vessels, emphasizing differences in vessel size. High-intensity light, such as achieved with fiber optics lamps, may be helpful, as may various light filters. Sometimes features not found at high magnification will be more obvious at low magnification, and then confirmed at higher magnification.

Techniques for enhancement that work well for one person may not seem the best to someone else. In dealing with particularly difficult material it is advisable to try techniques suggested by others. Expect, though, that you may need to develop your own techniques.

CROSSDATING

Crossdating is the procedure by which absolute dates are assigned to each tree ring. Basically, crossdating amounts to matching ring-width patterns among wood samples. Using accepted crossdating procedures ensures that anomalies such as missing and multiple rings are identified. Correctly crossdated material produces absolute dates for each ring. Simple ring counting does not involve crossdating, and thus, does not necessarily result in absolute dates. Ring counting can provide the same dates as crossdating, but only in situations where the absolute date of at least one ring is known (usually the outside ring), and one and only one ring is present for each year. It is not possible to know how many missing or multiple rings will be found in material of a given species in a given habitat until a number of collections of material from an area have been checked.

MARKING DATES OF RINGS

Most dendrochronologists find it convenient to mark rings as reference points. It can be exasperating to be 300 rings into a core and then lose count. A common marking system is to use dots: One dot for a decade, two dots for a half century, and three dots for a century (fig. 31). Some people make pin pricks made with the point of a dissecting needle. Others dot the rings with a finely pointed drafting pencil when making an initial ring count. Then dating errors discovered in the crossdating process are corrected by simply erasing the incorrectly placed dots and replacing them in the correct rings. In large rings, it is possible to write a number within the ring boundaries (for example, 3, to represent 1830). It may also be helpful to make some sort of mark or notation indicating the location of missing rings.

MISSING RINGS

A missing ring is exactly that. A tree ring is formed each year after bud break. So long as the tree remains alive it will break buds, and thus form a ring each year. However, if environmental conditions limit food production by the tree, ring formation may not extend from the buds all the way to the ground (see TREE GROWTH). Outer rings tend to be more narrow than inner rings, and reduced growth of rings that are normally narrow increases the chances of a missing ring. Thus, the probability that rings will be missing is greatest in the outer rings of environmentally stressed older trees.

Because of the direct relationship between missing rings and limiting factors, missing rings are quite common in semi-arid sites. Also, because trees on sites where environmental factors are not particularly limiting to tree growth tend to produce large rings, it may be generalized that the larger and more uniform the rings, the less likely are missing rings. Many of the more luxuriant forests of eastern North America have very low probabilities of missing rings for those years in which the trees have been in the forest canopy. But even in luxuriant forests missing rings may be common in sub-canopy and understory trees, especially in shade-intolerant species.

DISCONTINUOUS RINGS

Rings that are missing on some radii while being present on other radii at the same height are "discontinuous" (fig. 37). Discontinuous rings result from situations in which growth of a given year extends farther down the tree on one side than on another. It is unlikely that a ring will be discontinuous on a single increment core. But, a given ring may be present on one core and absent from a second core of the same tree.

FALSE RINGS

A false ring superficially appears as a separate ring, but is, in fact contained within an annual increment. The obvious difficulty is that if a false ring is misidentified as a true ring, then the tree-ring dates from that point backwards in time will be incorrect.

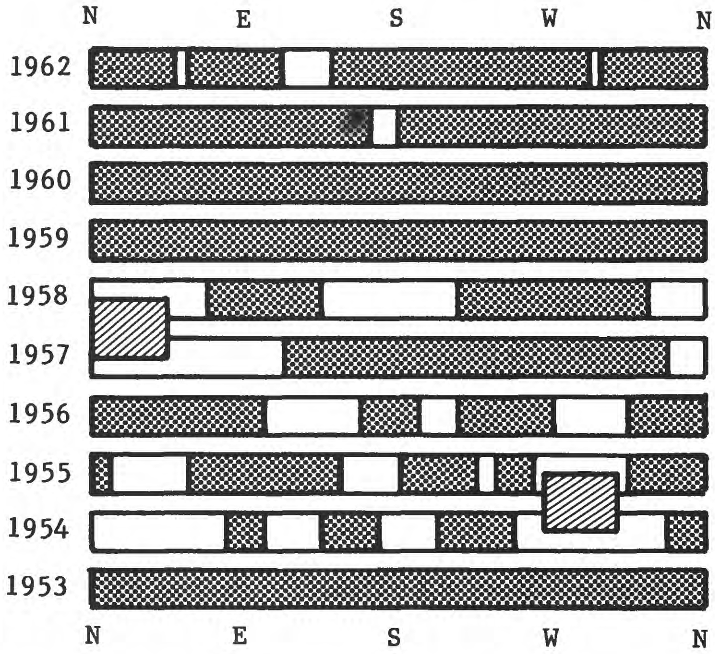

Figure 37. *-Diagram of a series of discontinuous rings from a transverse section of a suppressed, subcanopy red maple* (Acer rubrum). *Two segments (diagonal lines) could not be dated from the section.*

As environmental factors become more limiting during the normal course of a growth season, growth rates decrease, cells become smaller, and cell walls become thicker. This is the normal transition from earlywood to latewood. If, some time after latewood formation has begun, environmental factors become less limiting and growth rates increase, then subsequent growth may again be of the earlywood type. Breaking of a drought is a common cause of renewed earlywood growth.

Upon cursory examination, the transition from latewood back to earlywood may appear as a true ring boundary, thus falsely causing a single annual increment to appear as two rings. More than one false ring may occur in a single annual increment, hence, the term, multiple ring.

Close examination shows that at true boundaries, that is, those formed when growth completely ceases, there is an abrupt change in appearance between the last-formed latewood of one year and the first-formed earlywood of the next year. On the other hand, the transition from latewood of a false ring to subsequent earlywood is much more gradual (fig. 38). In some cases, most notably some diffuse-porous species with only subtle differences between earlywood and latewood, it may be very difficult to distinguish between true and false rings. For this reason, it may be very difficult to work with some diffuse-porous species in certain habitats. For example, rings of gum trees (*Nyssa*) from some habitats are relatively easy to work with, but from others are nearly impossible.

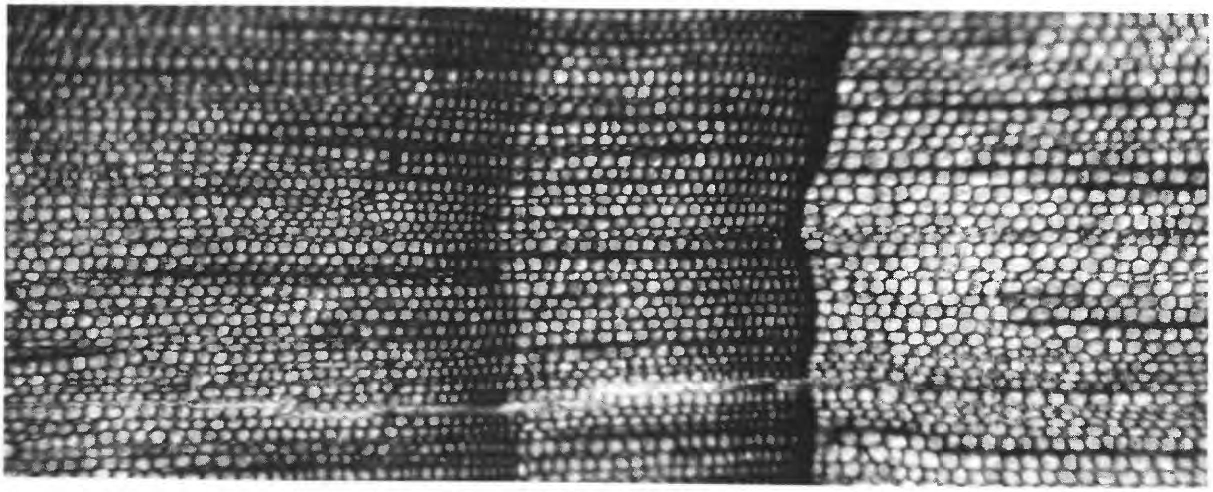

Figure 38. -*A false ring boundary and a true ring boundary.*

SIMILARITIES IN RING PATTERNS

Crossdating determines absolute tree-ring dates by matching ring-width patterns among samples, or between samples and data of previously dated tree-ring series.

Crossdating would be simple if all trees in a given area contained the same pattern of wide and narrow rings. They do not. An understanding of limiting factors may be helpful in understanding why tree-ring patterns exist and why patterns vary among trees. In order to successfully crossdate patterns, there must be some similarities. Similar growth patterns suggest that growth is responding to something in common among trees, namely, regional climate. But, factors must be limiting to growth in order to be correlated with growth. Therefore, the more limiting the environmental factors (including regional climatic factors) to tree growth, the greater the chance of similar ring-width patterns. Conversely, the more easily tree-ring patterns may be crossdated, the more environmental information the tree rings contain.

Climatic factors may not be extremely limiting to canopy trees of many luxuriant, closed-canopy forests, such as much of the humid, eastern deciduous forest. In such situations, growth appears to be as limited, if not more limited, by crowding, shading, and overtopping of individual trees. Under these circumstances, shade-tolerant species, that appear less sensitive to shading and crowding, may be found to be more easily crossdated than shade-intolerant species. Further, because all trees in the understory are more sensitive to crowding, it may be found that canopy trees are much easier to work with than sub-canopy or understory trees.

SKELETON-PLOT CROSSDATING

Where environmental factors are severely limiting to growth, and missing, false, and discontinuous rings are commonplace, some variation of the skeleton-plot method developed at the Laboratory of Tree-Ring Research at the University of Arizona is a most practical means of crossdating. Skeleton plotting may be performed on surfaced material before measurement or on ring-width measurement data. It was originally intended to be performed directly on the samples before measurement. As a practical matter, dating before measurement eliminates the necessity to correct the measurement data for missing and false rings.

Proper surfacing of samples and adequate light and dissecting scopes to view the samples are essential. Very tiny rings, perhaps with only a few cells per radial file, and false rings just cannot be positively identified without proper surfacing and adequate equipment for viewing.

A skeleton plot is a plot of vertical bars in which the length of each bar is inversely related to the width of an individual ring relative to the rings on either side. A long bar represents a very narrow ring and a short bar represents a wide ring (fig. 39). For material from sites in which environmental factors are severely limiting to growth, narrow rings are more important for crossdating than are wide rings. Perhaps this is why most

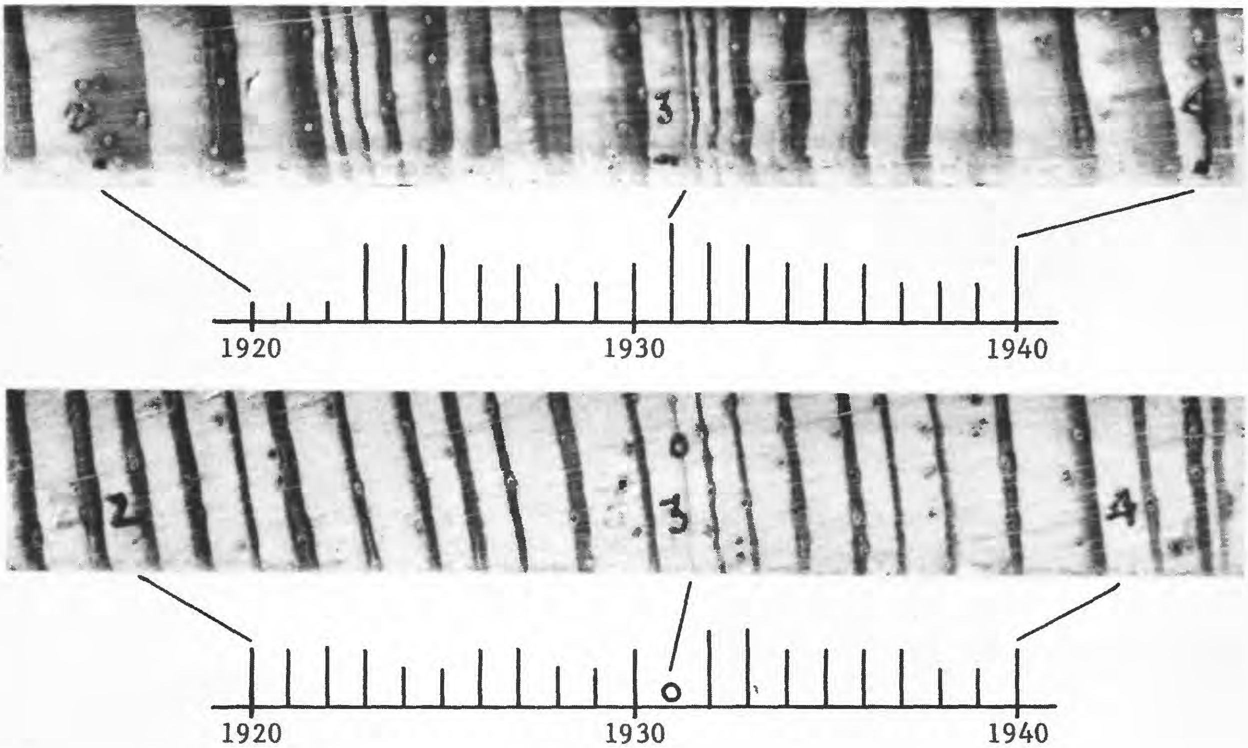

Figure 39. *-Segments of two skeleton plots and corresponding core segments. Note similarities of skeleton plots though one tree displays greater growth than the other.*

people who work with skeleton plots prefer to give small rings the importance of the longest bars. Each bar represents the width of a ring relative to a few rings on either side. In practice, it may be desirable to distinguish more than two sizes of rings. For example, it may be convenient to distinguish very wide, wide, average, narrow, and very narrow rings.

Comparison of skeleton plots for the various samples of a collection should reveal pattern similarities. Close examination may indicate, for example, that some samples contain a tiny ring at a point where others do not, suggesting a missing ring in some samples. Or, two rings may be represented at a given point on some cores where only one is represented on others. This might suggest that a false ring has been misidentified as a true ring. If the collection is large enough, crossdating should provide a high probability that all missing and false rings have been identified. This is based on the assumption that each year is represented by a ring in at least one sample, and that each false ring can be positively identified on at least one sample. It is easy to see, though, that as the frequency of missing and false rings increases, so does the probability that something can be missed in the entire collection. It is, therefore, important to crossdate the final chronology with a published, dated chronology.

In chronologies constructed from living material, all samples normally have the same outside date. However, because the sampled trees are likely to be of varying ages, the number of samples containing a given ring will decrease as ring age increases (older, center rings). For example, in a collection of 30 samples, all samples might contain rings back to 1700, with fewer and fewer samples containing successively earlier rings, and finally with only one sample containing rings predating 1600. For this example, it might be decided that because only a few samples contain rings prior to, say, 1680, crossdating of rings predating 1680 is unreliable. Therefore, it could be stated that the collection was crossdated back to 1680, and that dates prior to 1680 were based only on simple ring counts.

Skeleton plotting is very time consuming but easily justified in situations where missing and false rings are common. More detailed information regarding skeleton plotting can be obtained from Stokes and Smiley (1968) and the Tree-Ring Bulletin.

EXTREME-RING MATCH-MISMATCH CROSSDATING

In situations where missing rings are not common and, thus, where environmental factors are not severely limiting to growth, crossdating may be accomplished by concentrating on rings of extreme size. An old axiom of plant ecology is that vegetation distribution is controlled by the extremes, not the means of environmental factors. This can be restated with regard to ring widths of trees in situations where environment is not severely limiting to growth by stating that environment has the greatest chances of being limiting to tree growth during years of extreme conditions. This might explain the crossdating importance of extremely narrow rings. Contrary to the general rule of thumb applied in areas of severely limiting conditions, extremely wide rings are as important for crossdating purposes as are extremely narrow rings.

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.

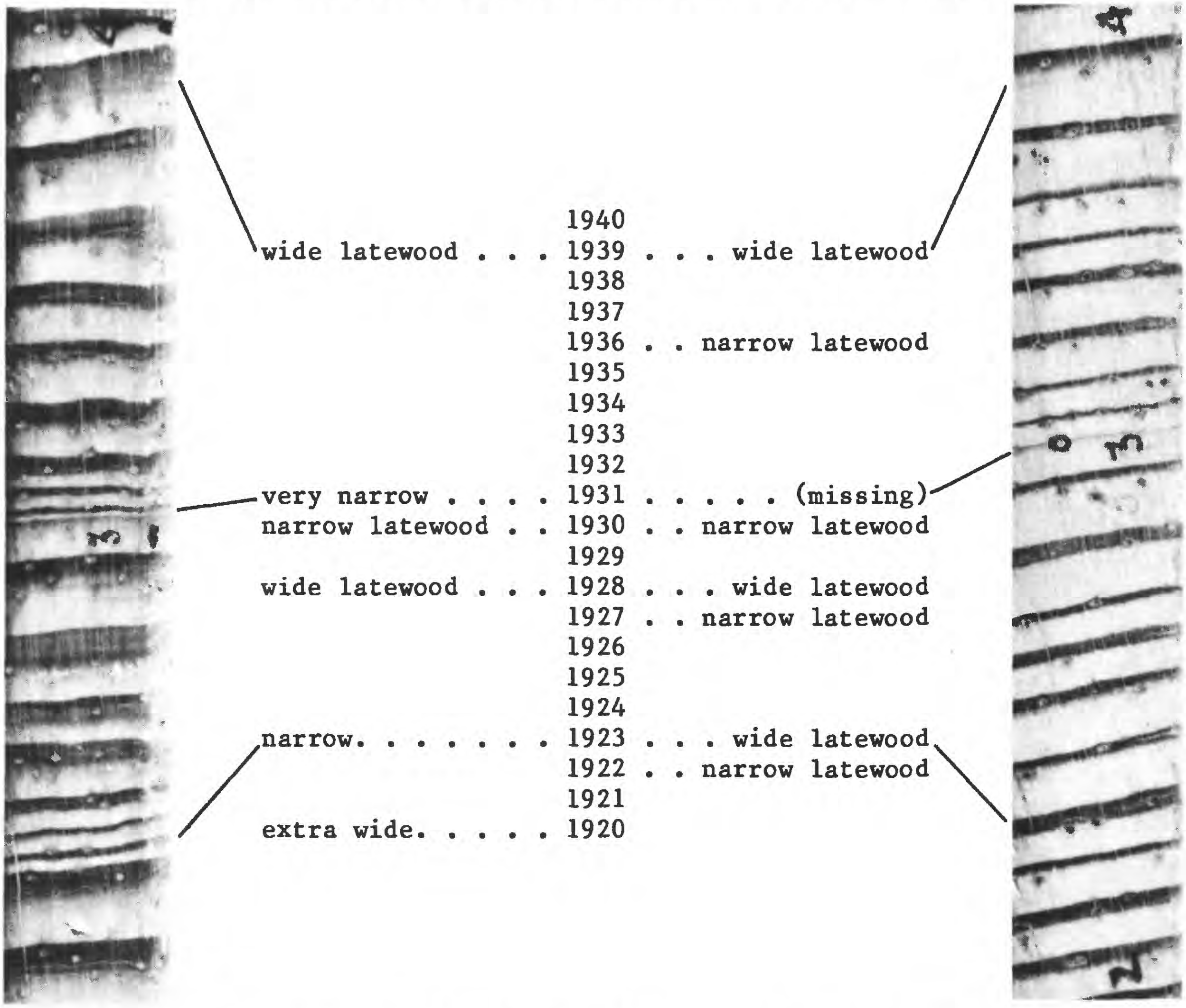

Figure 40. -*Two extreme-ring lists and accompanying core segments. Note matches between lists for large as well as small rings.*

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.

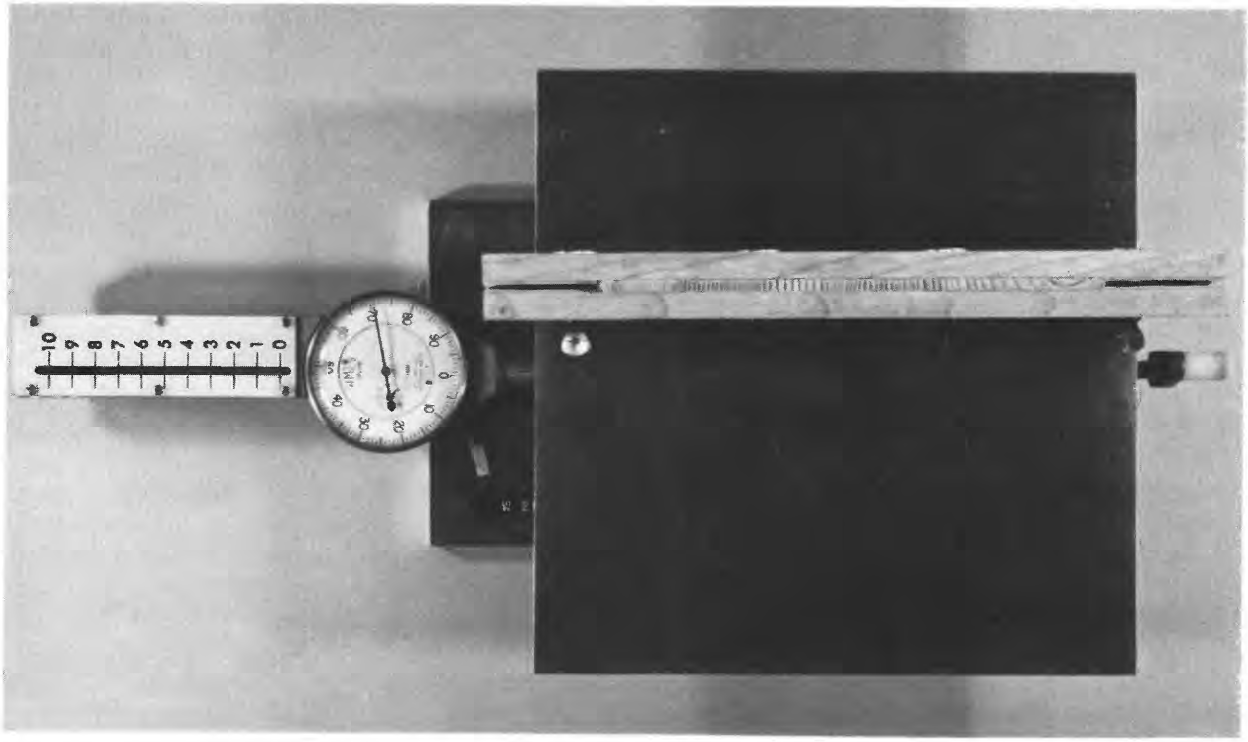

Figure 41. -*Hand-operated mechanical stage for measuring ring widths.*

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.*

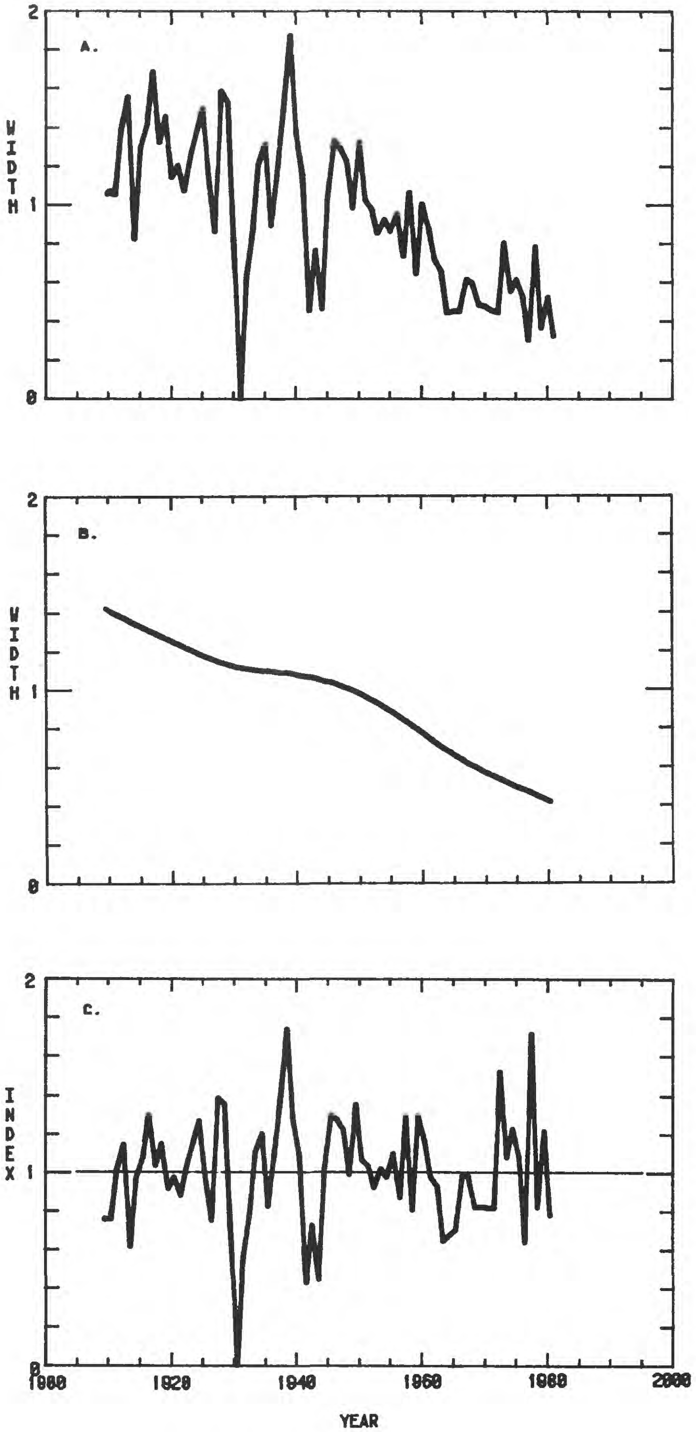

Figure 43. -*Graphs derived from ring-width measurements of a single core.*
A. Raw ring widths.
B. Growth trend curve derived by applying cubic smoothing spline to raw ring-width data.
C. Standardized indices of ring width derived by dividing raw ring widths by corresponding values from the growth trend 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.