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A MANUAL AND TUTORIAL FOR THE PROPER USE OF AN INCREMENT BORER

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ABSTRACT

An increment borer is the primary tool used to collect samples for dendrochronological analyses. These are precision instruments and users should be trained in their proper use, care, and maintenance. In this paper, I describe the various parts of an increment borer and how to keep these in working condition. I provide details on how to sharpen an increment borer, properly core a tree, check for core compression ("jamming"), extract the core, and store the core for transport. I provide tips on how to clear a jammed borer and remove a borer stuck in a tree. An important topic concerns the effects of boring on trees. The majority of studies indicate that conifers are minimally affected by both fungal decay and discoloration, whereas certain hardwood species can sustain major internal damage. Plugging the holes created by coring is unnecessary.

Keywords: increment borers, increment borer maintenance, damage from increment borers, field methods.

INTRODUCTION

The increment borer was developed in Germany *ca.* 1855 (Pressler 1866), and has changed little since its original design (Schweingruber 2001). Increment borers are used to extract cores from living and dead trees for analysis of growth trends based on inspection of the tree's ring patterns. Beginning in central Europe in the mid-1800s, growth rings were analyzed to determine growth rates of conifers to assess when and how often they should be harvested. Growth rings also helped determine whether trees were showing signs of poor growth (*e.g.* Hartig 1851; Seckendorff 1881; Pressler 1883). Investigators have since used tree rings for a variety of applications, including: silvicultural treatments on managed forests (Guilley *et al.* 1999; Bridge and Winchester 2000); reconstruction of past climate (Briffa *et al.* 2001; Watson and Luckman 2001); reconstruction of insect outbreaks (Swetnam and Lynch 1993; Speer *et al.* 2001); reconstruction of past wildfires (Swetnam 1993; Grissino-Mayer and Swetnam 2000); and reconstruction of earth surface processes (Yamaguchi *et al.* 1997; Gärtner *et al.* 2001).

Information on past environments gained from living trees is often extended back in time using tree rings from dead trees (*e.g.* Grissino-Mayer 1996), including downed logs, snags (standing dead trees), remnant wood, and buried/exposed subfossil wood (*e.g.* Lindholm *et al.* 1999). When dead trees are unavailable, timbers from historic structures can be sampled to extend the tree-ring record (Sass-Klaassen 2002; Mann 2002). Although an increment borer can be used to take cores from dead samples, these are sometimes too heavily decayed internally, causing problems with broken cores and borers irreversibly jammed with wood. Most often, a chain saw is used to obtain complete or partial cross sections from dead samples.

Current manufacturers of increment borers include Haglof® (made in Sweden), Suunto® (Finland), Mattson® (United Kingdom), and Timberline® (China). High-quality increment borers were once manufactured in Sweden by two companies, Djos® and Sandvik®, neither of which today pro-

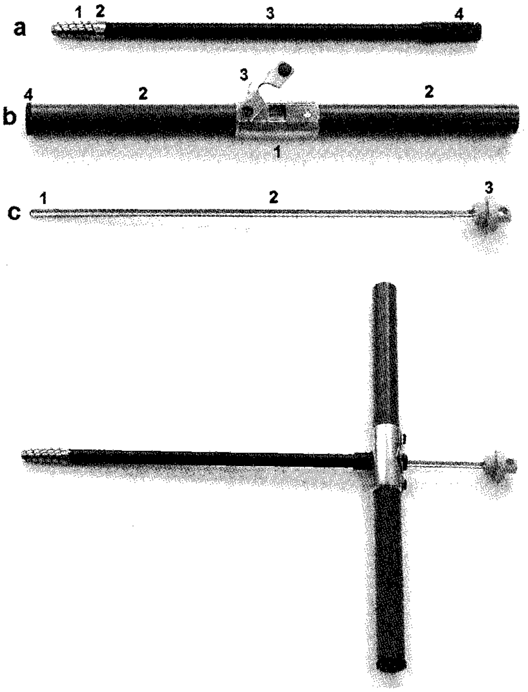


Figure 1. The main parts of an increment borer (top): the auger (a), the handle (b), and the extractor (c), and the full borer assembled (bottom). See text for details on the numbered sections.

duces borers. These borers are easily recognized by their metallic, silver augers, compared to the black, Teflon-coated augers common on contemporary borers.

CONSTRUCTION OF AN INCREMENT BORER

The increment borer consists of three parts (Figure 1; Phipps 1985): the main threaded auger (a), the handle (b), and the extractor or spoon (c). The auger consists of the threaded bit (a1), raised lugs that help widen the hole during coring (a2), the main hollow shaft (a3), and the squared end that fastens onto the handle (a4). The handle consists of a central connector (b1) onto which each individual handle (b2) is fastened, a clip used to fasten the auger (b3), an end cap which can be removed for cleaning (b4), and an internally-located cork (not shown) to protect the threaded tip of the auger. The open end of the handle is threaded for fastening the extractor during storage. The extractor consists of a serrated tip (c1) used to grasp the core upon insertion into the auger, the main spoon (c2) on which the core rests, and a threaded cap (c3) with hole (and sometimes a ring).

Increment borers come in various lengths from 100 mm (4 in.) to 700 mm (28 in.) in increments of 50 mm (2 in.), although lengths up to 1,000 mm (39 in.) can be specially ordered. The length required for a particular study should be carefully evaluated before purchasing. For example, if softwood trees less than 300 mm (12 in.) in diameter are to be studied, you should purchase a 350 mm (14 in.) borer. This will allow you to core straight through the tree and obtain a core that represents the complete diameter of the tree.

Increment borers are also available in two thread styles, a 2-thread design or a 3-thread design. Choosing which to use depends largely on the type of wood that will be examined. Two-thread designs turn slower (8 mm (0.33 in.) per revolution) and are therefore more suitable for coring hardwoods. Engaging the threads in the tree trunk, however, is more difficult on a 2-thread design. Three-thread designs turn faster (12 mm (0.48 in.) per revolution) and are more suitable for softwoods.

Increment borers are available in different inside diameters that determine the width of the core. The two most common diameters are 4.35 mm (0.169 in.) and 5.15 mm (0.20 in.). Generally, 5.15-mm-diameter borers are stronger mechanically because of their larger size, thus prolonging their lifetime. Furthermore, 5.15-mm-diameter cores provide a wider viewing surface on the cores. Increased physical effort is required to turn the larger-diameter borers, especially on hardwoods, because of the increased surface area in contact with the wood. Diameters of 8 mm (0.32 in.), 10 mm (0.40 in.), and 12 mm (0.48 in.) are also available and are appropriate for studies where larger quantities of wood are required, such as chemical studies and analyses of cell dimensions (Jozsa 1988).

CARING FOR INCREMENT BORERS

The increment borer is a precision scientific instrument. When stored, the auger and extractor should be lubricated inside and out with a protectant such as WD-40® (Jozsa 1988) to prevent any chemical deterioration (such as oxidation of the steel). The tip must be kept sharpened to obtain a smooth, unbroken core. A dull tip will shred the wood cells rather than slicing them cleanly, causing the core to appear ragged. A dull tip will also cause more friction upon the core, causing breakage, twisting, and possible "jamming" inside the borer. "Jamming" occurs when the outer wood on the core stops inside the auger, thus causing additional wood that enters the auger to become compressed behind it. The tip of the extractor should also be kept sharpened to ensure it slides smoothly under the core upon insertion. When storing or transporting, the auger should be carefully and slowly inserted into the handle to prevent excessive contact with the threads of the handle. This ensures the threaded tip of the auger and the threads inside the handle stay sharp. To ensure the auger surface stays smooth, coarse abrasive paper should not be used on its exterior during cleaning. The Teflon® coating, however, will wear off slowly over time. The clip should be periodically inspected for tightness and replaced if it becomes too rounded on its edges. A clip with rounded edges or a loose clip may cause the handle to detach from the auger during removal from the tree.

The borer tends to collect debris during use, and the outer surfaces of all parts should be wiped clean with a cloth that has been sprayed with lubricant. The inside of the auger especially should be cleaned periodically after perhaps 10–15 cores have been taken and prior to long-term storage. Debris left inside the auger shaft for long periods can facilitate chemical reactions that develop microscopic pits in the metal of the auger. These can become larger over time, and may increase the chances of cores jamming inside the auger shaft. Hardened resin stuck in the threads of the auger tip can be carefully removed with a pocket knife or similar sharp instrument. Resin that remains stuck to the exterior of the auger shaft can be removed in the laboratory with a cloth saturated with a stronger kerosene-based solvent in a well-ventilated area (preferably under a fume hood). By far the best means to clean the inside of the auger is to use a 22-caliber rifle gun cleaning kit (Figure 2; Reineke 1941; Maeglin 1979; Phipps 1985), available from most sporting goods and department stores. A cotton swab sprayed with WD-40® is inserted into the end of an aluminum rod. The rod and swab are pushed into the auger as far as possible, then pulled back alternately several times.

At least twice a year (more often during heavy usage), the end cap should be removed from the handle, and the inside thoroughly cleaned with the gun cleaning kit and solvent. A table-mounted vise may be necessary to firmly grip the end cap. The cork should be replaced as well.

SHARPENING AN INCREMENT BORER

Learning how to sharpen the tip of the auger is one of the most important skills required for maintaining an increment borer, although borers made since the late 1990s supposedly never require sharpening. You should take time to learn how to manually sharpen the increment borer, both in the field and in the laboratory (Reineke 1941; Bauck and Brown 1955; Maeglin 1979; Jozsa 1988). Sharpening kits can be purchased from most forestry supply stores. The kit includes sharpening stones, cutting oil, and a cork on which the auger shaft can be rested while sharpening. Three types of sharpening stones are necessary: a flat stone (1) to "true" or flatten the surface of the tip (thus removing any microscopic nicks); the tapered sharpening stone (2) to sharpen the outer surface; and a conical stone (3) to sharpen the inside of the tip (Figure 3).

Begin by first gently rubbing the flat stone across the tip, while slightly rotating the auger. Next, while firmly grasping the auger in one hand, rub the tapered stone across the tip with the other hand at an approximate 45° angle (Reineke 1941; Cantara 1983; Jozsa 1988) while turning the auger. The auger shaft must be continually rotated to ensure the sharpening procedure is evenly distributed across the tip, or else the tip may become asymmetrical (*i.e.* indented). This step takes practice and techniques will vary. Maeglin (1979) recommends rotating the auger shaft away from you and against the stone, while Cantara (1983) recommends rolling the auger on a flat surface while

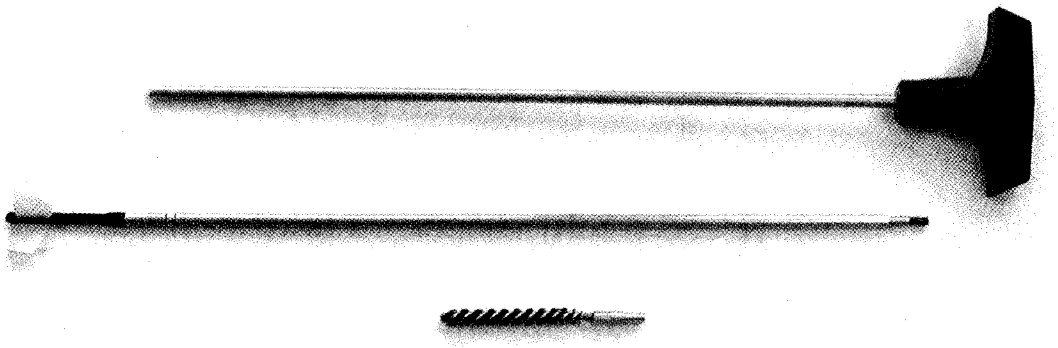


Figure 2. A 22-caliber rifle cleaning kit, which contains a handled aluminum rod (top) and an extension (middle) that contains an attachment (left) into which a cotton swab is inserted. The bristle brush (bottom) that can be used to remove debris and resin from inside the borer.

using an up-and-down motion of the sharpening stone. Lastly, the conical stone is used to place the sharp edge on the tip by lightly inserting the stone and rubbing it against the interior of the tip. Never forcefully push the conical stone into the tip until it is snug against the auger and then turn, as this will actually widen the inside diameter of the tip (Jozsa 1988). The wider diameter may cause cores to become jammed inside the borer, and make it more difficult to insert the extractor under the core and to grasp the core. Once sharpened, place the tip of the auger against a piece of paper on a flat surface and turn the auger. The tip should be sharp enough to cut a small circle from the paper.

Individuals with access to a metal or wood shop may consider creating a table-mounted sharpening device like those described by Goodchild (1962) and Heinrichs (1964). This device uses sharpening stones fixed in a wooden frame into which the borer is inserted. This arrangement ensures a constant angle is maintained while the auger shaft is turned. A small electrical motor could easily be attached to a belt-driven mount that holds the auger shaft in place for quick, efficient sharpening. Mechanical sharpening can also be achieved by mounting the auger on a lathe headstock and securing the tapered sharpening stone on the tool post (*e.g.* Reineke 1941). The lathe can be slowly turned while slowly forwarding and engaging the sharpening

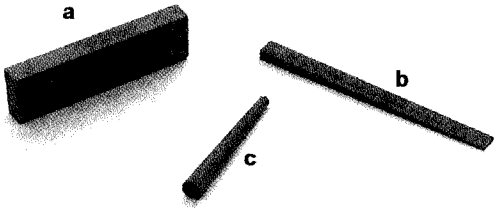


Figure 3. The three types of stones used to sharpen increment borers: (a) the larger flat stone, (b) the tapered sharpening stone, and (c) the conical stone.

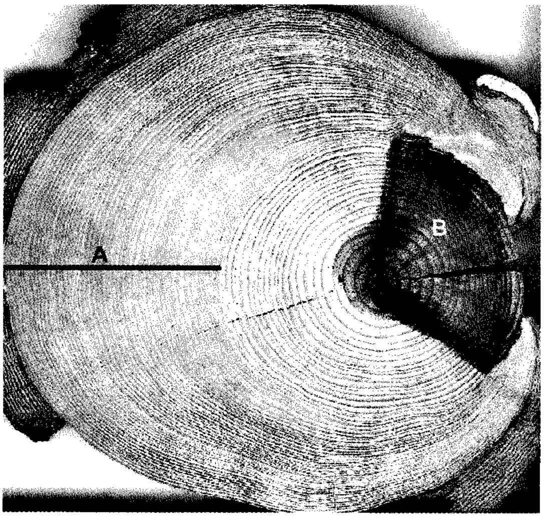


Figure 4. Extent of reaction wood (A) in a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) caused to lean by floodwaters, Chiricahua Mountains, Arizona. Impact occurred from the right (upstream). Note the compartmentalization (B) (resinosis) behind the impact scar.

Table 1. Specific gravity (*i.e.* density) of select softwoods found in North America. Larger values indicate denser wood.

Species	Specific Gravity[a]
Thuja plicata Donn ex D. Don	0.31
Abies lasiocarpa (Hook.) Nutt.	0.31
Picea engelmannii Parry ex Engelm.	0.33
Abies balsamea (L.) Mill.	0.33
Pinus strobus L.	0.34
Pinus monticola Dougl. ex D. Don in Lamb.	0.36
Picea glauca (Moench) Voss	0.37
Picea rubens Sarg.	0.37
Pinus contorta Dougl. ex Loud.	0.38
Picea mariana (Mill.) B.S.P.	0.38
Tsuga canadensis (L.) Carr.	0.38
Pinus ponderosa Dougl. ex Laws.	0.38
Sequoiadendron giganteum (Lindl.) Buchholz	0.38
Pinus banksiana Lamb.	0.40
Pinus resinosa Ait.	0.41
Taxodium distichum (L.) Rich.	0.42
Juniperus virginiana L.	0.44
Pseudotsuga menziesii (Mirb.) Franco	0.45
Pinus taeda L.	0.47
Pinus echinata Mill.	0.47
Larix occidentalis Nutt.	0.48
Larix laricina (Du Roi) K. Koch	0.49
Pinus palustris Mill.	0.54
Pinus elliottii Engelm.	0.54

[a]Specific gravity = the weight of the wood in relation to the weight of the same volume of water. For example, *Pinus elliottii* Engelm. (slash pine) with a specific gravity of 0.54 is 0.54 times as heavy as the same volume of water. Values are reported for "green wood" and are therefore comparable to the wood when cored. Adapted from Forest Products Laboratory (1974).

Table 2. Specific gravity (*i.e.* density) of select hardwoods found in North America. Larger values indicate denser wood.

Species	Specific Gravity[a]
Tilia americana L.	0.32
Populus tremuloides Michx.	0.35
Populus deltoides Bartr. ex Marsh.	0.37
Liriodendron tulipifera L.	0.40
Fraxinus nigra Marsh.	0.45
Ulmus americana L.	0.46
Nyssa sylvatica Marsh.	0.46
Prunus serotina Ehrh.	0.47
Betula papyrifera Marsh.	0.48
Acer rubrum L.	0.49
Juglans nigra L.	0.51
Betula alleghaniensis Britton	0.55
Fraxinus americana L.	0.55
Fagus grandifolia Ehrh.	0.56
Acer saccharum Marsh.	0.56
Fagus grandifolia Ehrh.	0.56
Quercus rubra L.	0.56
Quercus velutina Lam.	0.56
Quercus macrocarpa Michx.	0.58
Quercus stellata Wangenh.	0.60
Quercus alba L.	0.60
Carya tomentosa (Poir.) Nutt.	0.64

[a]See Table 1 for explanation.

stone against the auger tip. This technique is similar to that used by companies that repair/sharpen borer tips.

SELECTING THE TREE

In most situations, dendrochronologists simply core whichever species of tree is present that will provide the desired environmental (*e.g.* climatic or ecological) or cultural signal. Some studies require the coring solely of hardwoods because no softwoods are present, or perhaps all species must be cored for an accurate representation of a forest's age structure. Most hardwoods require more physical effort to core, and dendrochronologists should be aware of the difficulties associated with coring hardwoods. In general, extra care must be taken to avoid breaking the auger inside a hardwood tree (such as white oak, *Quercus alba* L.). Shorter borers are preferred, especially those with a 5.15 mm (0.20 in.) inside tip diameter. Tables 1 and 2 provide information on the specific gravity (*i.e.* density) of certain hardwood and softwood tree species found in North America.

PREPARING THE INCREMENT BORER

Begin by inserting and fastening the auger onto the handle via the clip. Place the extractor in some easily accessible location—you will use it periodically while coring. Some place the extractor upright in the bark of the tree, while others place the extractor in a pocket. Never place the extractor on the ground. To ensure the extractor is not lost should it fall onto the ground, tie bright-colored flagging (available from hardware or forestry supply companies) through the hole on the threaded cap, and leave several centimeters of flagging hanging loose off the extractor. Lubricate the *inside* of the auger shaft, the threaded tip, and the extractor with WD-40®. Avoid lubricating the outside of the auger shaft because you will need to grasp this firmly to help get it started.

The clip on the borer should be carefully inspected prior to use to ensure it is tightly fastened on the square tip of the auger. A clip that comes loose while inserting the auger into the tree is not so problematic, but if it disengages when pulling the borer from the tree, it could create a dangerous situation, especially when coring on a slope. To help secure the clip, purchase 12–18 mm (0.5–0.75 in.) rubber "O-rings" (commonly used in household water faucets) from a local hardware store and slide one onto the handle where it can remain permanently. After clipping the handle onto the auger, slide the "O-ring" over the clip.

Blocks of beeswax occasionally come shipped with increment borers to be used as a lubricant applied to the exterior of the auger shaft. These can be used, but a spray lubricant such as WD-40® is easier to apply and can be used to lubricate the inside of the auger shaft as well. The lubricant actually has little effect placed on the outside of the auger because the tight seal between the auger exterior and the wood inside the bark prevents entry of lubricant into the tree. This should allay any fear some may have of harmful chemicals being introduced into the interior of the tree via the lubricant. Lubricant will, however, reduce the bothersome "quacking" noise that commonly occurs while coring some tree species. Lubricant inside the auger will also help prevent cores from jamming.

If chemical analyses are to be conducted on the cores, no lubricant should be used. Although exact ingredients are unknown, WD-40® (the most common lubricant used) contains no graphite, silicone, or kerosene, and contains no nitrogen, calcium, magnesium, or heavy metals. Sodium exists as a by-product at less than 50 ppm, as does sulphur at less than 500 ppm (P. R. Sheppard, personal communication).

Pathological studies demand special attention because bacteria can be transported from one tree to the next via the increment borer. Not only can this provide misleading information on which trees are affected by a particular pathogen, but the borer has potential for actually spreading the pathogen being analyzed. It's recommended that dendrochronologists disinfect increment borers between trees using a proven bactericide/fungicide (such as Citracidal®). The bactericide/fungicide chosen should be a non-irritant, non-corrosive, and non-carcinogenic product that is biodegradable and easily applied via spray bottle or complete immersion.

CORING HEIGHT AND LOCATION

Because most dendrochronological studies require the maximum ages for living trees be attained, coring at breast height (*ca.* 1.3–1.4 m) is rarely justified. Obtaining cores at breast height is useful only when coring trees (such as pines growing in plantations) to help standardize calculations of the potential yield of wood for a given stand. Many dendrochronologists extract cores as close to ground level as possible while still allowing room for the handle on the borer to turn. To increase ground clearance, the auger shaft squared end can be slightly tilted upward from true horizontal (generally < 5°), and may also allow a few more inner rings to be obtained. Do not tilt the borer too much, however, because this will cut the wood cells at the same angle as the tilt and could make ring boundaries more difficult to distinguish (the cells will be become more elliptical in shape the higher the angle). On trees with heavy lower branches (*e.g. Juniperus*), a handle can be borrowed from a shorter borer to avoid the branches. Additionally, longer handles can be used on shorter borers to add leverage, especially useful when coring hardwoods. Handles from the same manufacturer are interchangeable.

For trees growing on slopes, cores should be extracted at right angles to the slope direction, *i.e.* along a contour of the slope. Trees growing on slopes often contain reaction wood (Figure 4), created when trees (especially when younger) are caused to lean by soil creep, high winds, snow accumulation, or floodwaters (Scurfield 1973; Wilson 1984; Grissino-Mayer 1995; Telewski 1998). Reaction wood is often darker in appearance and denser than wood normally produced by the tree.

For many dendrochronological studies, such rings contain environmental "noise" unrelated to the "signal" being studied and therefore should be avoided while coring. Some dendrogeomorphic studies, however, rely on the information gained from reaction wood to help evaluate the history of mass movements such as soil creep, debris flows, landslides, and snow avalanches (Shroder and Butler 1987; Fantucci 1999). For such studies, additional cores should be extracted from the downslope/upslope side of tree. Cores should still be taken along the slope contour because these likely will contain clearer ring patterns and help in the precise dating of the tree.

Trees growing on slopes will likely exhibit eccentric growth, *i.e.* the majority of growth is concentrated on the downslope side for conifers and upslope side for hardwoods. This should be considered when coring trees where determining the maximum age is an objective. For conifers, the center or pith of the tree will be displaced in the upslope cardinal direction, and a slight re-positioning of the auger bit toward this off-center pith is necessary to increase the likelihood of reaching the pith.

To further position the borer closer to the base of the tree trunk, some researchers have used handles with one side removed, or even ratchets with a modified socket to fit the square end of the auger shaft. These arrangements work most efficiently on softwood species. Keep in mind, however, that backing the borer out from the tree, which usually requires some pulling on the handle, will be much more difficult. Additionally, damage can occur on the borer by such "short-cut" methods (*e.g.* "rounding" the square end of the auger).

Another modification of the handle is useful for coring trees known to have very thick bark, such as giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchh.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). The handle on each side is first crimped with a chisel approximately 25 mm (1 in) from the central connector on the side where the clip is found. Using a table-mounted vise, the handles are then bent backward approximately 25–35°. The seams where the bend occurs are then welded for reinforcement. A metal cross-brace can also be welded onto the inside of the V-shaped handle for further reinforcement. Known as a "Quad-B" ("Brown's Bent Boomerang Borer"), this modified handle allows deeper entry of the auger into the thick-barked tree by several centimeters. It has also proven useful for obtaining cores from archaeological samples (*e.g.* log cabins; Mann 2002) where cores must be extracted from locations that are particularly difficult to access.

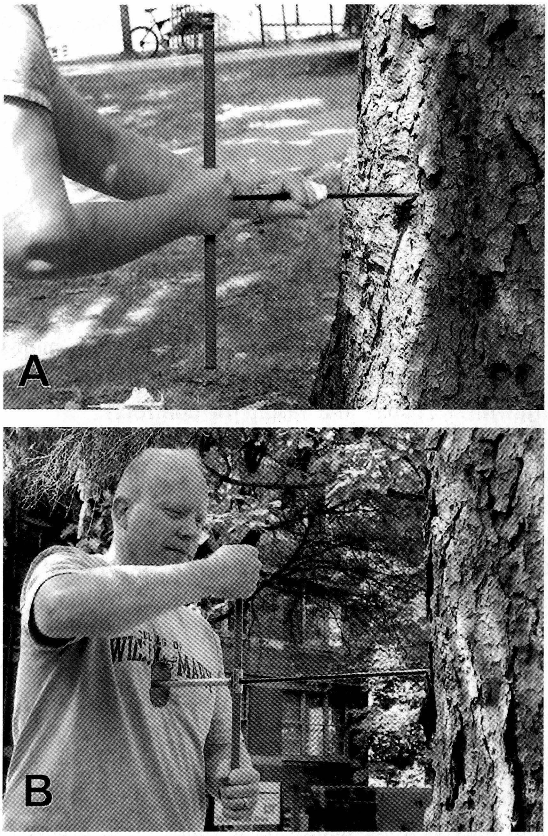


Figure 5. (A) When coring a tree, the auger shaft can be grasped with one hand while the handle is turned by the other hand while applying mild inward force. (B) Using a borer starter (the brace against the chest) can help steady the auger.

CORING THE TREE

On living trees, place the tip of the borer at an appropriate coring height, grasping the shaft of the auger with one hand while holding the handle center with the other hand (Figure 5A; Phipps 1985). If the bark is furrowed, place the tip between the bark furrows to help the threads engage the bark.

Point the borer to the estimated inner center of the tree where the pith is likely to be encountered. Apply enough inward pressure on the borer to help the sharp tip slightly penetrate the outer bark surface. Under no circumstances should the auger be hammered into the tree as this will significantly stress and weaken the steel. Continue to apply inward pressure and rotate the increment borer as much as possible. Repeat this procedure until the threads engage and the auger tip enters the tree. The auger handle can be turned with both hands using either half-turns (better for hardwoods) or full-turns (better and faster for conifers).

When initially engaging the auger, the shaft should be steadied as much as possible with the hand grasping it to ensure a straight core is attained. Beginning the coring process with an auger that is wobbling from one side to the other will result in the outer portion of the core having several misaligned sections that could make it difficult to place the core in a storage straw or cause the core to break at these weakened points.

Occasionally, dendrochronologists must core a surface of the trunk where the bark is no longer present. For example, the tree may still be standing but may be long-dead (*i.e.* a "snag"), or a core is required through a surface stripped of its bark by flood or fire events (Sheppard *et al.* 1988; McCord 1996). Engaging the tip of the bit requires additional inward physical exertion applied to the auger, and usually requires additional turns. Often, this may severely damage or completely obliterate the outer rings of the core, thus making any determination of the precise death date impossible. To help ensure the outermost rings remain intact as much as possible, first mark the location of the surface where the core will be taken with a highly visible ink dot (*e.g.* bright red) using a felt-tip marker. Next, place a small strip of semi-transparent tape (*e.g.* masking tape) over the dot. Place the tip of the auger over this dot when coring. The dot will help determine whether or not the outermost ring is present should the wood become damaged, and the tape will help ensure that the wood remains intact. To help engage the auger tip on these types of surfaces, an assistant can also aid in grabbing and holding steady the auger shaft while simultaneously helping apply inward pressure.

Engaging the auger in the tree trunk, especially on tree surfaces with no bark, can be aided by using a borer starter that has a plate that is placed against the chest while the other end of the starter is inserted into the hole on the square end of the auger (Figure 5B). This allows both hands to be used while turning the auger to initially engage the threaded bit, thus reducing any inadvertent wobbling of the auger (Jozsa 1988). These borer starters can be purchased from forestry supply companies.

While coring, listen for odd sounds coming from the wood inside the auger that could indicate the wood is compressing and therefore jamming the borer. You should develop a "feel" for the borer's movements and become wary of any changes in the amount of effort required to turn the handle. If you have any doubt about the integrity of the core inside the core, you should stop immediately and perform a check (Figure 6) to see if jamming is occurring inside the auger (Jozsa 1988). Make it a habit to perform this check every 5–10 complete turns of the handle.

First, insert the extractor into the auger until its tip touches the outer core surface (Figure 6A). Mark this point on the extractor with your thumb at its junction with the handle's central connector. Pull the extractor out and place it alongside the auger, with the tip of the extractor touching the surface of the tree trunk (Figure 6B). If the core is not jamming, the distance along the extractor marked by your thumb will be the same as the distance along the auger shaft (Figure 6B). If the core is becoming compressed inside, the distance along the extractor will be longer than the distance along the auger bit and handle (Figure 6C). Stop immediately and use the extractor to pull the problem core from the auger.

EXTRACTING THE CORE

Continue inserting the auger until the desired core length is reached. On large-diameter trees, try obtaining a core that is slightly longer than a radius. On small-diameter trees, one can core straight through the entire trunk if the borer is long enough and obtain a complete diameter (*i.e.* two cores in one insertion). Most cores, especially lon-

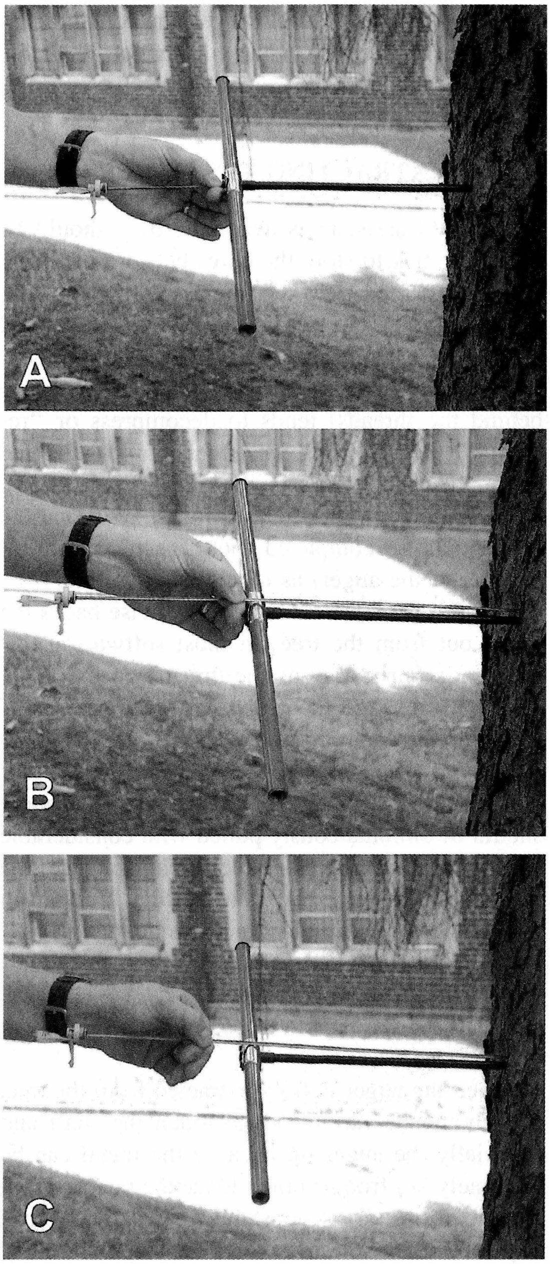


Figure 6. Determining whether your core may be jamming (compressing) inside the auger. (A) The extractor is first inserted and its location at the handle marked with the thumb, (B) then placed alongside the auger shaft. If the distance marked by the extractor is the same (B), the core is not compressing. (C) If the distance measured by the extractor is longer, then the core is jamming.

ger ones, will be curved downward inside the auger simply because of gravity. Some advocate placing the extractor so that it slides *over* the core to prevent its tip from hitting the outer wood of the core and possibly causing damage. In most situations, however, the extractor can be carefully slid *under* the core with few problems. This method also is advantageous when gauging the amount of offset from pith using the curvature of the innermost rings, so that another attempt can be made to reach the pith (discussed below).

Slide the extractor the full length of the auger in one swift, smooth motion as far as the extractor will go (Phipps 1985). Do not exert too much force when inserting the extractor. As the extractor tip slides through the auger, it eventually reaches the upward taper (if sliding in from beneath) that characterizes the inside of the auger tip as the inside diameter narrows. This allows the serrated teeth of the extractor tip to reach upward and "clench" the core. Turn the handles counter-clockwise one or two complete turns to break the core from the rest of the wood inside the tree. Pull on the extractor cap gently until the core breaks free from the auger tip where it is still tightly held. The core should be resting in the groove of the extractor, but still held tightly by the serrated teeth.

If the study requires that the maximum age of the tree be determined (*i.e.* pith is required), first ensure that the handle stops at a near horizontal position at its maximum depth into the tree (although any handle position works, the horizontal position is most convenient). Back the borer out two complete turns, ensuring that the handle is in the exact position when at its maximum depth. This technique ensures that, when the core is extracted, the core is oriented in the position it occupied inside the tree, and allows an easier assessment of the amount of offset from the pith. Note the amount of offset because it will be required when you re-core the tree in an effort to "hit pith."

You should already have a few paper or plastic straws or plastic tubes handy, perhaps in your vest or nearby on the ground. Be sure to pinch (for paper straws) or close one end of the first straw with tape (for plastic straws) before inserting the core. Often, the core may be longer than the individual straw. If using paper straws, first fully insert the core into the straw after one end has been pinched closed. Slide a second paper straw over the core and over the first paper straw by about 2.5 cm (1 in.) after you have clenched the first straw tightly around the core. This will provide a sturdy container for transport. The excess paper straw can be torn off and used on cores taken later that require additional straw. If using plastic straws, fully insert the core, then slide a second straw over the core. Masking tape can be used to secure the second straw to the first straw. Finally, be sure to tightly seal the open end of the straw, and label the straw accordingly with a pen or black marker. Straws can easily be stored and transported in a long (>38 cm or 15 in.) mailing tube available from many office supply companies.

Some individuals prefer to store the core in straws as it comes directly out from the inside of the auger. This method is advantageous when coring certain tree species (*e.g.* eastern hemlock, *Tsuga canadensis* (L.) Carr.) whose cores are prone to breakage, or for coring trees that may have internal decay. Some researchers, however, prefer to view the entire core before placing it in a storage container. This method is advantageous in studies where the maximum age of the tree is desirable. Viewing the core in its entirety will allow one to assess the amount of offset from pith by noting the curvature of the innermost rings. Using this assessment, the tree can be re-cored to better approach or reach the pith. First, insert the extractor into the previous hole as a guide. The tip of the auger can then be placed at the proper location on the tree trunk (*e.g.* 2 cm to the left) to reach the pith. The auger should be placed *parallel* to the extractor sticking out of the hole in the tree, rather than placed at an angle.

Cores should never be permanently glued and mounted immediately after being taken from the tree. Cores should be allowed to dry before being mounted. Cores that are permanently mounted while still moist will break up into smaller sections upon drying. Instead, cores should be placed in some type of protective storage container for transport back to the laboratory. In addition, cores should never be labeled directly on the wood with a marker as the ink may obscure some of the ring boundaries. Instead, label the storage container accordingly with all the vital information (*e.g.* site code, tree number, and core ID).

EXTRACTING THE BORER

If a field assistant is available, they should be given the task to store the cores because the borer should be pulled from the tree as soon as the core is extracted. The wood that was compressed around the auger shaft during insertion (by both the highest thread on the auger bit and the lugs behind the threads) tends to decompress or "rebound," thus clasping the auger more tightly the longer the borer stays in the tree (Phipps 1985). In hardwoods especially, the process of coring the tree should be completed (both insertion and extraction of the auger) as quickly as possible.

Turning the handle counter-clockwise backs the auger out from the tree. In most softwoods, this process is fairly easy as the threads on the auger bit readily engage the wood. In some species of trees, the threads may have difficulty engaging the wood and the handle and the auger simply turn freely without backing out. In this case, the handle should be simultaneously pulled with considerable force while turning. Once the threads engage, the handle can be turned without pulling. Pulling on the handle while turning should be done with considerable caution. Sometimes the clip that holds the handle and auger together may come loose, thus causing the handle to come off, sending you tumbling backwards.

When the auger is fully extracted from the tree, you should be careful not to touch the shaft and especially the auger tip because the metal can be extremely hot from friction. Once the metal is cool enough to handle, you should carefully remove any debris from the outside of the auger shaft and from the auger bit. Debris should also be cleaned from the extractor itself. Often, a small piece of wood may remain lodged in the outer portion of the auger tip. The extractor can be inserted into the auger *through the square end* and pushed inside all the way, and most often this will cause the extra wood to come out. Never insert the end of the extractor into the tip of the auger itself, as the sharp edges of the serrated extractor can nick the tip. Rather than using a metal object, insert a small twig, wooden chopstick, or wooden golf tee to free the stuck piece of wood. You should then peer into the auger to inspect the inside of the shaft for excess debris. Sometimes simply blowing into the square end of the auger can remove loose debris, but never place the hot auger tip on your lips. The auger should also be cleaned periodically throughout the day with the gun cleaning kit.

CLEARING A JAMMED BORER

Eventually, everyone manages to jam a borer in the field. A jammed borer occurs when the outer end of the core becomes lodged or stuck inside the borer. Additional turning of the handle causes more wood to enter into the auger shaft, but instead of sliding cleanly into the shaft, the wood becomes compressed. In the worst situations, the wood becomes so compressed that the extractor cannot slide under the core. Periodic checking of the core should be performed to ensure it is sliding into the auger shaft (Figure 6). If any doubt exists whether or not the core is jamming, you should stop immediately, extract the core, and begin over, perhaps in a different location on the tree trunk.

Once jammed, you can take several steps to clear the wood from inside the borer. First gauge just how much wood is jammed in the borer by inserting the extractor until it reaches the wood. The amount of jammed wood is indicated by how far the extractor protrudes from the end of the auger. If the extractor indicates that greater than 2.5 cm (1 in.) of wood is jammed, then the borer should perhaps be cleared back in the laboratory. Attempting to clear an amount of jammed wood greater than this could take considerable time in the field, and it is perhaps best to simply use a new borer.

If the amount of jammed wood is less than 2.5 cm (1 in.), you can attempt to clear the jam in the field. First, while the borer is still firmly fixed in the tree, push the extractor tip into the auger until it reaches the core and attempt to slide the extractor under the wood. Repeat this, turning the extractor slightly at each entry to see if any location exists where the extractor can slide under the jammed wood. If the extractor does slide some under the core, be sure to then pull the extractor out completely to free any wood that may adhere to the serrated teeth on the extractor tip. Moderate pressure should be applied to the extractor to gently force it under the jammed wood, but under no circumstances should the extractor be hammered into the auger shaft.

If the wood cannot be dislodged, pull the entire borer from the tree. Insert the extractor into the auger as far as possible and then point the entire borer upward. While firmly holding the cap of the extractor, spin the entire borer around the extractor by pushing one of the handles. This technique makes the extractor tip work like a drill, and has been shown effective for clearing short segments of compressed softwood.

If the wood remains jammed, a hand drill and drill bit can be used. Prior to leaving for the field, have a machine shop weld a rod of metal stock onto the end of a 4 mm (5/32 in., 0.156 in.) drill bit. Once welded, the entire length of the drill bit should be at least 12 mm (0.5 in.) longer than the entire auger. Hand drills can be found at many hardware stores. While another person holds the auger shaft, insert the drill bit into the square end of the auger. As with any metal object, under no circumstances should the drill bit be inserted through the auger tip. If the drill bit does not easily remove the jammed wood, then take the borer back to the laboratory for clearing. Applying excessive force on the drill bit could score the metal inside the auger. This could create places where chemical deterioration can occur, as well as rough spots where future cores may begin jamming.

In the laboratory, a table-mounted 20 cm (8 in.) drill press is sufficient for clearing most jammed borers. Because the drill bit mounted on a drill press can be located with precision, the drill bit can be carefully inserted into the auger tip once the auger has been securely fastened onto the tool bench of the drill press. Begin by using a narrow drill bit (3/32 in., 0.094 in., *ca.* 2.4 mm), then progress to a wider bit (1/8 in., 0.125 in., *ca.* 3.2 mm), and eventually a 4 mm (5/32 in., 0.156 in.) bit. Insert the drill bit into the jammed wood by no more than 12 mm (0.5 in) before clearing the wood swarf (the ground wood) from the drill bit. Repeat this process until the entire section of jammed wood is cleared. Afterwards, be sure to thoroughly clean the inside of the auger with WD-40® and the gun cleaning kit.

FREEING A STUCK BORER

Occasionally, an increment borer may remain stuck in the tree, no matter how hard one pulls on the handle. This situation occurs most frequently in trees with internal decay. As the auger tip enters decayed wood, the threads then have difficulty engaging onto solid wood. This situation may also occur on especially resinous softwoods, however, such as the southern pines. The resin can coat the outer threads (those that are supposed to first engage the wood when backing out), thus making extraction difficult or impossible.

The simplest means for freeing a stuck borer is to set up a simple "come-along" (Phipps 1985; Jozsa 1988). First, loop heavy-duty cord around the handle and secure it *on the shaft* where it connects to the handle. Yamaguchi (1991) recommends using a clove hitch to fasten the cord to the shaft. The cord should not be fastened onto the handle directly because the clip may loosen, causing the handle to detach with considerable force. The loose ends of the cord should be tied together around a nearby object such as another tree. The handle should then be turned counter-clockwise repeatedly, thus creating kinks in the cord. To quicken the process, a stick or similar object can be placed midway in the cord and held stationary by an assistant. As the number of kinks increases, the cord becomes tighter. Eventually, the auger threads will "grab" solid wood, and the auger will begin backing out of the tree. When the auger tip is about to exit the tree, the stick can be removed from midway in the cord, thus loosening the cord. This is important because the entire increment borer will exit with force if the cord is not slackened first.

Two other mechanical techniques can be used to free a stuck increment borer. Although both are large and unwieldy, they can be handy if coring trees close to the field vehicle. The first is a hoist-puller (commonly found in automobile repair shops), which can be purchased at all hardware stores. The second method involves use of a scissors jack, commonly found in many vehicles for repairing flat tires. Both techniques are described in detail by Yamaguchi (1991).

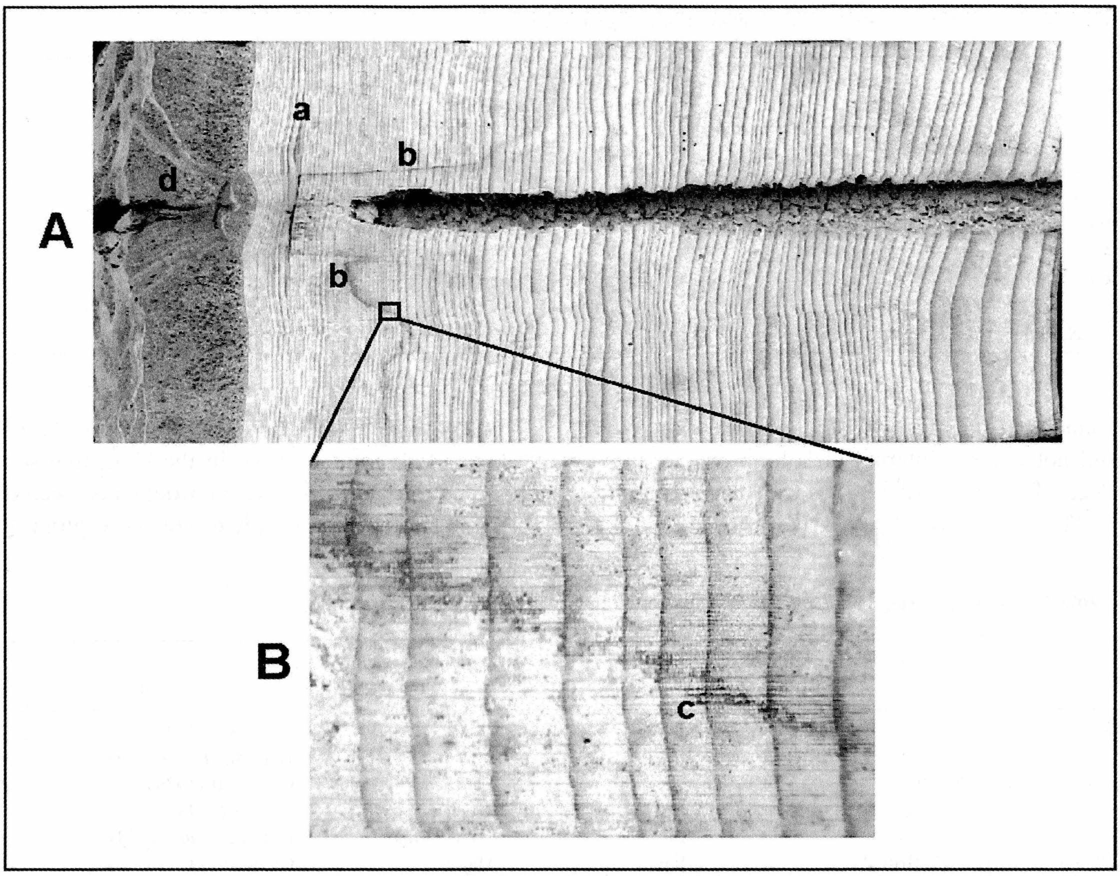
→

Figure 7. (A) Internal effects of increment borer penetration on a Douglas-fir tree. The tree was cored in 1971 (a), then cut down in early 1986. Notice the compartmentalization (b) that occurred around the hole created. (B) This microphotograph shows how the compounds deposited for the compartmentalization process are translocated via the ray cells (c). Also note the overgrowth of the bark tissue (d).

INJURY CAUSED BY INCREMENT BORERS

Increment boring causes injury that is compartmentalized by the living tree. Compartmentalization is a boundary-setting process that resists the spread of cell death and infection by microorganisms (Shigo 1985; Smith and Sutherland 2001). In healthy, vigorous trees, these boundaries form on either side of the borer injury and tend to form a roughly conical column above and below the injury. Near the borer injury along the horizontal plane, the amount of wood affected inside the tree is equal to the planar (*i.e.* "flat") area of the auger itself, extending out to the edges of the auger threads. Although the core itself is quite narrow in diameter, the increment borer is considerably wider, approximately three times the width of the core measured at the maximum diameter at the threads on the auger tip. As the tip enters the wood, the sharp edge on the tip cuts through the wood and the core enters the hollow shaft of the borer. At the same time, however, the auger significantly compresses wood on either side of the hole (Figure 7; Jozsa 1988).

Several studies offer insights on the probable effects of coring trees (Tables 3 and 4; see also Smith and Sutherland 2001) and the resistance potential of tree species to decay and disease. In general, conifers sustain little injury from increment borers (Meyer and Hayward 1936; Campbell 1939; Hepting *et al.* 1944; Lenz and Oswald 1971; Vuokila 1976), mainly because of their ability to rapidly (1) fill the hole with resin and (2) compartmentalize the damage around the hole (Shigo 1985) (Figure 7). In contrast, hardwoods can be



considerably affected primarily by discoloration (*i.e.* "staining") of the wood (Figure 8) and by fungal infection (Schöpfer 1962; Hart and Wargo 1965; Vuokila 1976; Dujesiefken *et al.* 1999), although some hardwood species are more affected than others. For example, most oaks (*Quercus* spp.) appear to be resistant to both internal discoloration and fungal attack, whereas yellow birch (*Betula alleghaniensis* Britton) is particularly susceptible to both. Although both red maple (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.) are both prone to internal discoloration, red maple appears less prone to fungal decay. Furthermore, Lorenz (1944) and Hepting *et al.* (1949) →

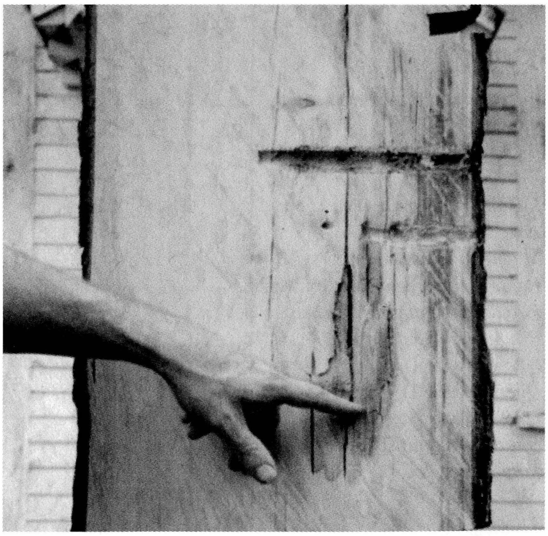


Figure 8. A maple (*Acer*) log cut vertically to reveal the hole made by the increment borer (at right) and the discoloration and staining that occurred afterward.

Table 3. Effects of coring on selected conifer species found in North America.

Species	Discoloration, Staining	Fungal Decay	Reference
Abies balsamea (L.) Mill.	Minor	None	Campbell (1939)
Picea rubens Sarg.	Minor	None	Campbell (1939)
Pinus spp.	Minor	None	Campbell (1939)
Pinus echinata Mill.	Minor	None	Hepting *et al.* (1949)
Pinus rigida Mill.	Minor	None	Hepting *et al.* (1949)
Pinus strobus L.	Minor	None	Hepting *et al.* (1949)
Pseudotsuga menziesii (Mirb.) Franco	Minor	None	Meyer and Hayward (1936)
Tsuga canadensis (L.) Carr.	Minor	None	Campbell (1939)

found that disinfection of the borer with alcohol did not prevent internal discolorations and fungal decay from occurring.

The sensitivity of tree species to decay is also a function of temperature and moisture (Forest Products Laboratory 1974). In the U.S., tree species found in warm, humid environments, such as the Southeastern coastal plain, are more prone to

Table 4. Effects of coring on selected hardwood species found in North America.

Species	Discoloration, Staining	Fungal Decay	Reference
Acer rubrum L.	Major	None	Campbell (1939)
	Major	Minor	Hepting *et al.* (1949)
Acer saccharum Marsh.	Major	Major	Campbell (1939)
	Minor	Major	Lorenz (1944)
	Minor–Major	Minor–Major	Hepting *et al.* (1949)
Betula alleghaniensis Britt.	Major	Major	Campbell (1939)
	Major	Major	Lorenz (1944)
	Major	Major	Hepting *et al.* (1949)
Betula papyrifera Marsh.	Major	Major	Campbell (1939)
	Major	None	Lorenz (1944)
	Major	None–Major	Hepting *et al.* (1949)
Betula lenta L.	Major	Major	Hepting *et al.* (1949)
Carya spp.	Minor	None	Campbell (1939)
Celtis laevigata Willd.	Major	Major	Toole and Gammage (1959)
Fagus grandifolia Ehrh.	Major	Major	Campbell (1939)
	Major	None–Major	Hepting *et al.* (1949)
Fraxinus americana L.	Minor	None	Campbell (1939)
Fraxinus pennsylvanica Marsh.	Minor	Minor	Toole and Gammage (1959)
Liquidambar styraciflua L.	Major	Major	Toole and Gammage (1959)
Liriodendron tulipifera L.	Major	Minor	Hepting *et al.* (1949)
Magnolia acuminata L.	Major	None	Hepting *et al.* (1949)
Populus deltoides Bartr. ex Marsh.	Minor	Minor	Toole and Gammage (1959)
Populus tremuloides Michx.	Major	Major	Laflamme (1979)
Prunus serotina Ehrh.	Minor	None	Campbell (1939)
Quercus spp.	Minor	None	Campbell (1939)
Quercus alba L.	Minor	Minor	Hepting *et al.* (1949)
Quercus coccinea Muenchh.	Minor	Minor	Hepting *et al.* (1949)
Quercus nuttallii Palmer	Major	Major	Toole and Gammage (1959)
Tilia americana L.	Major	None	Campbell (1939)
	Minor	Major	Lorenz (1944)
	Minor	None	Hepting *et al.* (1949)

fungal decay than are species found in drier and/or cooler environments, such as the American Southwest or Rocky Mountain corridor (Scheffer 1972). Coring during the growing season is preferred (especially for hardwoods) as the wounds are more rapidly compartmentalized (Campbell 1939; Lenz and Oswald 1971; Dujesiefken *et al.* 1999; Eckstein and Dujesiefken 1999).

In summary, the evidence is strong that coring minimally affects conifer species. The evidence is also strong that coring affects the internal physiology and health of hardwood species to varying degrees. Cleaveland (1998) succinctly points out, however, that coring hardwoods provides valuable information on current and past environments. The scientific importance of this information must be weighed against the possible injury inflicted.

PLUGGING THE HOLES

A related question concerns whether or not the holes left after coring a tree should be plugged. Meyer and Hayward (1936) studied the effects of various methods for plugging holes left in Douglas-fir trees, and recommended that the holes remain unplugged as they were soon filled with resin. They also noted that plugs could act as infiltration mechanisms for fungi. Campbell (1939) concluded that improper or careless use of plugs could result in more injury, especially on thin-barked hardwoods such as maple or birch. Lorenz (1944) found that plugging trees helped only slightly to reduce the incidence of heart-rotting fungi. Hepting *et al.* (1949) found that "plugging had little good effect," and noted that some dowel plugs had swollen, causing splits in the trunk near the entry hole. Thiercelin *et al.* (1972) statistically analyzed the effects of different disinfectants on plugged and unplugged holes and found no significant influence of either the disinfectant or the plug. Lenz and Oswald (1971), however, found that injury to spruce could be "reduced drastically" using an artificial seal of wax stoppers. Dujesiefken *et al.* (1999) strongly discouraged plugging holes with creosote-impregnated wooden dowels. In fact, creosote, a common fungicide and protectant used by tree surgeons, was found to enlarge the original wounds. Eckstein and Dujesiefken (1999) found that fungi were always present no matter how the holes were chemically treated and plugged.

The overwhelming majority of studies clearly indicate that plugging holes in conifers and hardwoods has little benefit, and may actually cause more harm than good. Although certain types of plugs (*e.g.* wax stoppers) may minimize external injury, internal injury caused by coring trees simply cannot be prevented by plugging the hole.

SUMMARY

Increment borers are precision instruments and all tree-ring researchers should be properly trained in their use. Basic knowledge of an increment borer includes knowing:

- the proper length and core diameter required when purchasing an increment borer;
- where on the tree to core and how to properly start a borer;
- how to determine whether a borer is jamming or not;
- how to properly clean and sharpen a borer;
- how to extract cores and how to remove stuck pieces of wood in the tip;
- how to clear a jammed borer; and,
- the potential injury to living trees caused by increment borers.

With proper care, increment borers should last many years and can extract hundreds or thousands of high-quality cores. The techniques outlined in this paper should supplement the hands-on experience that only field work can provide.

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