Dating Construction with Tree Rings and Sapwood When Felling Dates Are Unavailable

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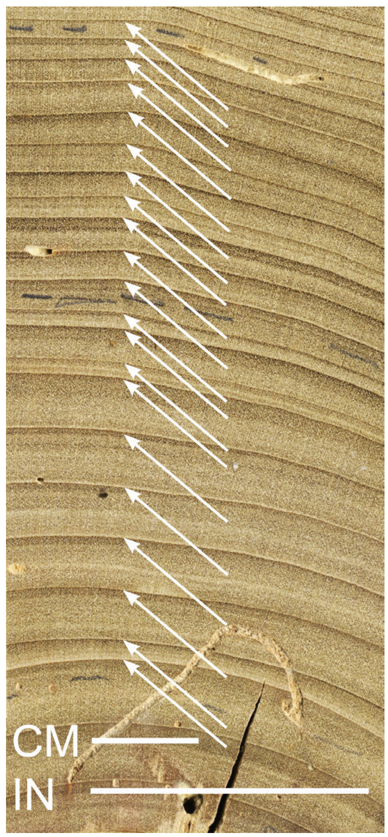
Fig. 1. Magnified cross section of a tulip poplar timber indicating ring boundaries, 2023. The varying width of each ring reflects the growth conditions experienced by a tree in a given year; this variation allows researchers to date timbers of unknown age through a process of growth pattern matching called crossdating. All images courtesy of the authors.



Construction dates for historic buildings can be estimated using a simple model based on sapwood ring counts.

Knowing the precise year that a historic structure was built informs preservation and interpretation efforts. Moreover, a clear understanding of when a building was modified can indicate how a structure has evolved. Oral traditions and archival documents, such as deeds and tax records, are commonly consulted in determining construction and modification dates for a building.[1] Often, however, such resources are scant, contradictory, incomplete, or non-existent. Although often helpful, they can make determining a precise construction date challenging and imprecise.

Tree-ring science (dendrochronology) offers the unique ability to date past natural events, such as droughts and forest fires, to the exact year (Fig. 1). Tree rings can also be used to date how and when humans interacted with their environment.[2] Dendroarchaeology, a subfield of dendrochronology, uses tree rings to date historic objects, such as buildings, by determining when trees were felled and subsequently used as timber.[3] It has long been established that tree-ring analysis offers a unique opportunity to date the construction of historic buildings with annual precision, and

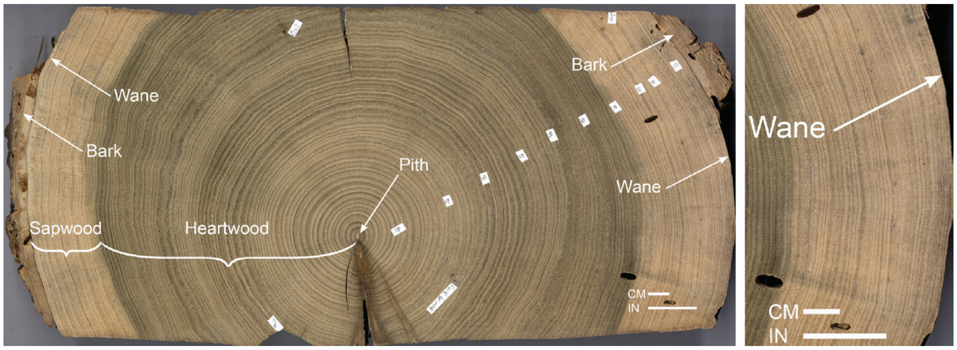


Fig. 2. Cross section of a horizontal wall timber from an 1849 log house in Vanderburgh County, Indiana, showing green heartwood and yellow sapwood, 2023. The innermost ring surrounding the pith dates to 1747. The ring adjacent to the bark represents the last year of growth, or a felling date of 1849.

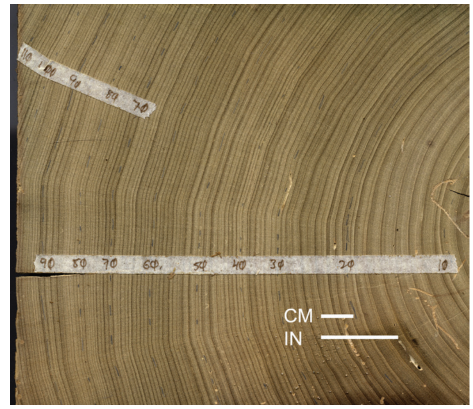


Fig. 4. Timber dating from 1606 to 1727, exhibiting no bark or wane and consisting only of heartwood, 2023. The precise year the tree was felled is indeterminable, as the number of rings removed to shape the beam is unknown.

tree rings have frequently been used to provide or verify construction dates.[4]

Determining when a building was constructed requires establishing when trees were cut to produce timber. The year in which a living tree was felled—its harvest or death date—can be determined if the outermost dated ring in a timber represents the last year that a tree was alive. If the outermost ring is adjacent to bark or comes from a waney edge, the date of that ring represents a tree's felling or death date (Fig. 2). Wane is characterized by a uniform, rounded surface lacking toolmarks. The surface of the timber represents the last ring or annual increment of wood produced; the bark either sloughed off or was removed. When numerous timbers from throughout a structure have a similar—or, ideally, the same—felling date, a construction date can be inferred.[5]

Challenges and Methods

Dating the construction of a building requires access to timbers for sampling, which is most commonly performed using a drill and a boring bit to extract cores from timbers (Fig. 3). Sample acquisition should not cause unnecessary structural damage to the building or detract from its historic significance or appearance. Sampling is often performed on floor joists in cellars and crawlspaces; rafters, ties, and ceiling joists in attics; and studs in staircases and closets. When timber access is limited, it may not be possible to sample a sufficient number of timbers with bark or wane. When available timbers lack bark or a waney edge, it is not possible to determine when a tree was cut and later processed into timber, since the number of rings removed during sawing or hewing cannot be determined (Fig. 4). Additionally, the outer portion of exposed timbers or those that are continuously exposed to moisture, such as floor joists, is often eroded or degraded by wood-deteriorating organisms and insects (Fig. 5). In such situations, a minimum or earliest possible construction date can be determined for the structure based on the date of the most recently formed, outermost ring in any of the building's timbers. For example, if the outermost date in any timber is 1853, it can be concluded that the building was built sometime after 1853, but the actual construction date cannot be determined with any more precision. In such situations, the utility of tree-ring

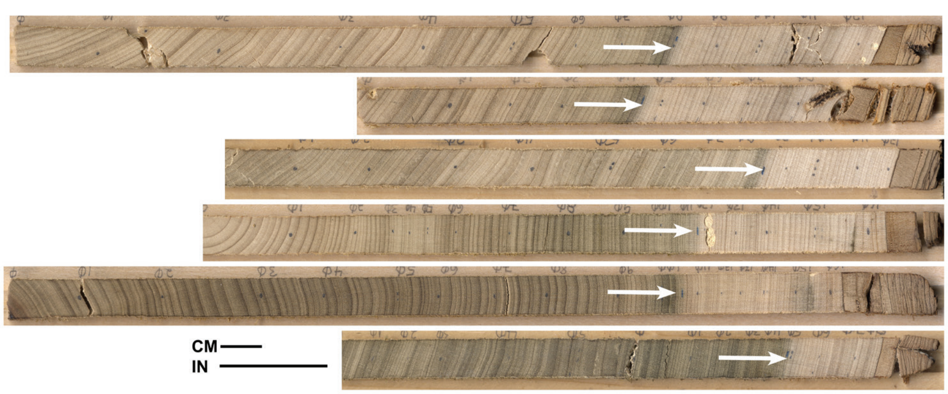


Fig. 3. Sanded cores extracted from *in situ* timbers from several regional buildings, with arrows indicating the heartwood-sapwood boundary, 2023.

Fig. 5. Cole Barn, Clark County, Indiana, 1842, showing the eroded outer portion of exposed timbers, 2021. When the outermost rings are lost, the exact year of felling cannot be determined.

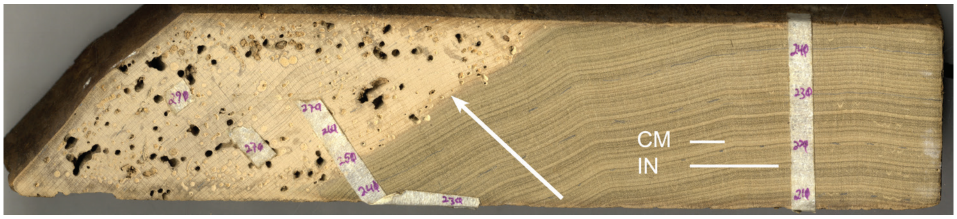


Fig. 6. Sample dating from 1759 to 1853, taken during the 2009 renovation of the Harris House, Aurora, Indiana. Photograph 2023. Tulip poplar sapwood is more susceptible to decay and insect damage than heartwood; this floor joist sample required sawing a cross section because coring would have resulted in broken, undatable sapwood fragments.

dating—and the annual precision it affords—are not fully realized.

However, accurate death or felling dates can be estimated without bark or wane if a timber contains sapwood. Sapwood consists of the rings nearest the bark toward the outside of a timber; they represent the most recently formed tree rings.[6] Toward the inside of the trunk, heartwood is found. Sapwood is converted to heartwood as a tree ages. During this conversion, living cells within the wood die, food reserves are depleted, and other chemical, anatomical, and physiological changes occur.[7] Sapwood and heartwood can, in many tree species, be differentiated by color, with the sapwood typically a lighter color than the heartwood.

When sapwood is present, it can be assumed that the outermost ring in a timber was near the bark and that a limited number of rings was removed during sawing or hewing. Also, sapwood is generally more susceptible to insect damage and decay than heartwood. If deterioration of the sapwood is extensive, rings from the outermost portion of a timber will be lost, and sampling and sample preparation may lead to the loss of tissue associated with bark or wane (Fig. 6).[8] However, if the number of sapwood rings in a timber can be counted—that is, if the ring most consistently exhibiting the heartwood–sapwood boundary can be identified—and if a reliable method of approximating the number of expected sapwood rings is available, a cutting date can be estimated (Fig. 7).

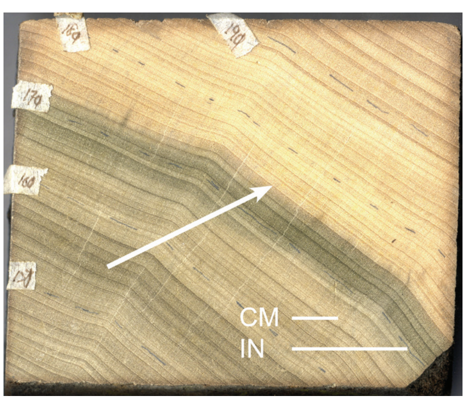


Fig. 7. Timber exhibiting no bark or wane, showing sapwood and heartwood, 2023. The felling date of the tree can be estimated using the date of the heartwood–sapwood boundary, number of visible sapwood rings in the timber, and an appropriate estimation procedure.

The number of sapwood rings is variable; it depends on the species and age of the tree, location along the length of the stem, growth rate, and the geographic region in which the tree grew.[9] Consequently, providing an exact number of expected sapwood rings is not possible. However, accurate estimates can be determined by generating a large sample of numerous trees from throughout a region and by developing an objective methodology to estimate how many sapwood rings are expected. The use of sapwood rings to successfully estimate the cutting date of timbers has been described for several different tree species throughout Europe.[10]

The expected number of sapwood rings may be determined in a variety of ways.[11] A regression model can be constructed to statistically predict the number of sapwood rings that would likely be present in a timber. For example, Stephen E. Nash created a predictive model to estimate sapwood ring numbers using linear regression for ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*), two very important building timbers in western North America.[12] Alternatively, an estimate can be made by using the normal width in millimeters of expected sapwood and the mean ring width observed in the outermost rings in a timber.[13] Finally, an estimate could be made by studying numerous timbers with bark or wane and counting how many sapwood rings are present. The mean number of sapwood rings and its associated variability can then be used to estimate the number of expected sapwood rings.[14]

Sapwood Estimation in Tulip Poplar

Tulip poplar (*Liriodendron tulipifera*) has long been a commonly used timber species throughout the Midwestern United States. Tulip poplar is straight-grained and noted for producing long timbers free of knots. The wood is considered fairly insect-resistant. It also accepts glues, stains, and paints well.[15] A check of the authors' database of dated timbers from nineteenth-century buildings in the Mid-Ohio River Valley reveals that tulip poplar was used for tongue-and-groove flooring, clapboard siding, studs, hewn log and sawn timber joists, stretchers in staircases, horizontal log timbers in barns and houses, lath, window jambs, knee braces, beams, top plates, rafters, roof sheathing, headers, and baseboards. Tulip poplar timber has been found in regional buildings built as early as 1809 and as late as 1883.[16] Given tulip poplar's wide geographic distribution in eastern and central North America and its extensive—even preferred—use over an extended time, a better understanding of its sapwood characteristics would prove quite useful for tree-ring studies when it is necessary to estimate felling dates. This information would be especially useful when determining the cutting date of trees used to produce sawn lumber, such as two-by-fours and two-by-sixes, which often do not have a waney edge or bark but do contain sapwood.

To provide a reliable method to estimate the number of sapwood rings present in tulip poplar, 341 accurately dated timbers obtained from 30 nineteenth-century buildings throughout the Mid-Ohio River Valley were analyzed. Only timbers with wane or bark present were selected for analysis, since they have a full complement of sapwood rings. The number of sapwood rings was counted in each timber, and the width of the sapwood was measured to determine if ring count and sapwood width were related. The age and size of the tree were also determined for 35 of the 341 timbers to determine if there was a relationship between these variables and the number of sapwood rings present.[17]

The best way to objectively estimate sapwood ring count varies among species, so different methods were investigated for tulip poplar. First, sapwood width was examined to determine whether it would be useful for predicting felling dates. If a consistent width could be found, the number of missing sapwood rings could be estimated by noting the mean growth rate in the outer rings of a timber in millimeters per year and determining the width of the sapwood, as well as the number of sapwood rings remaining on a timber. However, the width of sapwood proved to be highly variable, ranging from 10 to 96 millimeters (Table 1). Furthermore, annual growth rates in the outermost rings exhibited great variability. Consequently, given the inherent variation in width and growth rate, estimation using sapwood width and mean growth rate was deemed impractical.

Secondly, correlation analysis was performed to determine if sapwood ring count covaried with other variables so that a relationship between them and sapwood ring count could be further explored, such as by creating a predictive model using regression analysis. As Table 1 shows, no significant correlation ($P > 0.05$) was found between sapwood ring count and age, or between sapwood ring count and sapwood width, number of heartwood rings, heartwood width, and radius (pith to bark) length, which are affected by growth conditions. Since none of the variables correlated with sapwood ring count, it was concluded that creating a statistically derived predictive model would not enable reliable estimation.

Thirdly, a count of the sapwood rings in a large sample can be used to estimate the number of expected sapwood rings in a timber. Using the mean and the distribution of the data, a range of reliable felling date estimates can be made if the number of remaining sapwood rings in a timber can be counted.[18] When this estimation method is employed, providing a range of felling dates is preferable to reporting a single date.[19] The range is found by using the sample's mean and calculating an interval with an upper and lower value that would bracket 95 percent (the mean plus or minus approximately two standard deviations) of all timbers, called the prediction interval.[20]

Table 1. Descriptive Statistics and Correlation Analysis of Historic Tulip Poplar Timber Properties

Value	Sapwood Rings	Sapwood Width (mm)	Heartwood Rings	Heartwood Width (mm)	Age (yr)	Radial Length (mm)
n	341	341	35	35	35	35
Mean	40.1	39.2	79.0	108.1	118.4	144.5
Median	40	36.5	80	114	119	158
SE	0.5	0.9	4.8	7.3	5.0	8.8
SD	9.7	16.6	28.6	43.2	29.3	52.3
Minimum	8	10	39	40	62	61
Maximum	75	96	162	183	192	226
Range	67	86	123	143	130	165
CV*	24.3	42.3	36.3	40.0	24.8	36.2
CI** (95%)	1.0	1.8	9.8	14.8	10.1	18.0
r***	—	0.042	–0.053	–0.145	0.206	–0.220
P***	—	0.437	0.761	0.407	0.235	0.205

Complete radii were available for 35 of the 341 timbers that were analyzed.

*CV is coefficient of variation.

**CI is the confidence interval.

***r and P are the correlation coefficients and their associated probability, obtained by correlating the number of sapwood rings with the various measurements.

Other methods of estimating the number of sapwood rings expected in timbers have been developed, such as using the mean growth rate of the heartwood.[21] Many of these estimation techniques, however, require knowing the age of the tree from which the timber was made, which requires the complete radius from pith to bark. Sampling timbers from buildings usually does not allow for tree age determination, as entire trunks are not often used in nineteenth-century construction, and coring does not always provide complete radii.

Given the large variability in sapwood width and annual growth rate, the failure to find any variables that could be used for constructing a satisfactory predictive model, and the inability to determine tree age, the method of determining sapwood ring-count estimates using the expected mean and its associated variability in a large sample was explored—a method used in several European studies. In the 341 tulip poplar timbers that were analyzed, the mean number of sapwood rings was 40. The distribution of the samples suggests that 95 percent of all timbers have between 21 and 59 sapwood rings, the prediction interval.[22] Similarly sized ranges have been reported for oak in northwest England, France, Germany, Sweden, and Finland.[23]

Application

The George Ash House, located in southeastern Indiana, was built in 1809 and is one of the oldest brick structures in the state (Fig. 8).[24] The 1809 construction date was determined using dendroarchaeological analysis of tulip poplar and other hardwood timbers. Over the past two centuries, the interior and exterior of the house have been extensively modified—for example, with the installation of an interior staircase, the construction of partition walls to subdivide the first story into rooms, and the repair of failing floor joists. These changes were made almost exclusively with tulip poplar timbers. Although tree-ring analysis enabled the accurate dating of most of these timbers, none of those used in the repairs or modifications had bark or wane, making a precise felling date indeterminable.

Fig 8. The George Ash House, Lamb, Indiana, 1809. Photograph 2020.

Sapwood estimates, calculated using the 95 percent prediction interval of 21 to 59 rings, provided a date range for when the modifications were made. For example, at some point, the first story of the house was divided by the construction of an interior wall. To determine when the wall was built, 11 studs were accurately dated. Three of the studs had a clear heartwood–sapwood boundary, and the number of sapwood rings present in the timber was counted to estimate felling dates (Table 2).

Various methods have been utilized to present and interpret felling date ranges

Table 2. Estimated Cutting Dates of Studs of an Interior Wall of the George Ash House

Sample	Outermost Dated Ring	Heartwood–Sapwood Boundary Date	Number of Sapwood Rings Present	Estimated Cutting Date (assuming 40* sapwood rings)	Estimated Cutting Date Range
GAH28A	1862	1834	28	1874	1863–1893
GAH29A	1847	1833	14	1873	1854–1892
GAH31A	1848	1836	12	1876	1857–1895

Ranges are calculated using the date of the heartwood–sapwood boundary, sapwood ring counts, and the range of sapwood ring counts expected in 95 percent of all timbers.

*Mean number of expected sapwood rings is 40.

once sapwood estimates are calculated.[25] One method—interpretation using the period of common overlap among the ranges for each timber—yielded an 1863 to 1892 cutting range for the studs of the George Ash House. Ranges can also be presented by calculating the mean heartwood–sapwood boundary date and applying the range used to describe the number of sapwood rings in the 95 percent prediction interval. The mean heartwood–sapwood boundary was 1834 for the studs; applying the sapwood estimate (21–59 years) to this date yielded a period spanning 1863 to 1893. This estimate required an adjustment, since the latest dated sapwood ring was 1862 (sample GAH28); without an adjustment for dated sapwood rings, the earliest date in the range would be 1855 (1834 + 21).

The estimated cutting dates for the studs suggest that the wall was built in the mid- to late-nineteenth century. Further, none of the other studs from the wall had an outermost heartwood ring that dated later than 1834. The estimated date range is for the wall that was sampled in this analysis. The wall may be a replacement for an original 1809 wall, a replacement for a modification made sometime after the initial construction, or a new element added during the period estimated using sapwood analysis.

Conclusions

When precise felling dates are not available because bark or wane are absent from timbers, combining sapwood ring counts with a simple predictive model and standard tree-ring analysis establishes a range of potential felling dates. Tulip poplar timbers harvested in the nineteenth century in the Mid-Ohio River Valley have, on average, 40 sapwood rings, and 95 percent of all timbers contain between 21 and 59 sapwood rings.

Although sapwood estimates provide an objective way to estimate cutting dates, certain caveats must be kept in mind:

- Estimates may only be accurate in the same region from which the estimation technique was developed.[26]
- The sapwood estimate produced in this analysis was determined from timbers used in the construction of nineteenth-century structures. Core samples obtained from currently living trees exhibit a markedly different number of sapwood rings.[27]
- Estimates provided here are only appropriate for tulip poplar timbers. There is great variation in sapwood characteristics among different tree species.

Estimated dates are useful only when they are coupled with a thorough evaluation of the building's material type, style, and construction method.[28] Care must be taken when interpreting potential cutting date ranges and when obtaining samples from structures. Erroneous conclusions may be reached if context clues are not interpreted simultaneously with the estimated felling dates. For example: are the nail or screw types consistent with the estimated dates? Were the timbers prepared in a similar manner (sawn vs. hewn)? Were timbers joined in a similar manner (mortise and tenon vs. nailed)? And was the timber recycled, as evidenced by unnecessary mortises?

To the best of the authors' knowledge, the sapwood estimation methodology described for tulip poplar is the only sapwood estimate available for a hardwood timber species in the Midwestern US. Future studies investigating the sapwood properties of white oak and beech should be explored, since these timber types were commonly used throughout the study area in nineteenth-century construction.

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Christopher Baas *is a professor of landscape architecture at Ball State University in Muncie, Indiana. He teaches design and planning studios, as well as courses in landscape history and preservation. Christopher can be reached at rcbaas@bsu.edu.*

Notes

1. Darrin L. Rubino and Christopher Baas, *Dating Buildings and Landscapes with Tree-Ring Analysis: An Introduction with Case Studies* (Oxford: Routledge, 2019), 76–87.

2. Bryant Bannister, "Dendrochronology," in *Science in Archaeology*, ed. Don Brothwell and Eric Higgs (New York: Basic Books Inc., 1963), 172–74.

3. James H. Speer, *Fundamentals of Tree-Ring Research* (Tucson: University of Arizona Press, 2010), 1–7.

4. Accurate tree-ring dating of structures is possible through the process of crossdating, which involves matching the tree-ring growth patterns in the timbers of a building of unknown age with the patterns observed in reference chronologies—series of accurately dated tree rings from timbers and trees from the same geographic region. See Andrew E. Douglass, "Crossdating in Dendrochronology," *Journal of Forestry* 39, no. 10 (Oct. 1941): 825–31.

5. More precisely, the felling date of the tree from which the timber was made can be determined. However, the time between the felling of a tree and incorporating its wood into a structure is not usually known. In the region where this study was performed, hewn timbers were most likely felled immediately prior to their use in construction. See Donald A. Hutslar, *The Architecture of Migration: Log Construction in the Ohio Country, 1750-1850* (Athens: Ohio University Press, 1986), 362–76.

6. The oldest part of a tree is found in the center of a stem. The innermost ring, adjacent to the pith, is the first—or oldest—tree ring formed, while the outermost ring, adjacent to the bark, represents the most recent ring.

7. Andreas Kampe and Elisabeth Magel, "New Insights into Heartwood and Heartwood Formation," in *Cellular Aspects of Wood Formation*, ed. Jörg Fromm (Berlin: Springer Verlag, 2013), 74–80.

8. M. G. L. Baillie, *Tree-Ring Dating and Archaeology* (Chicago: The University of Chicago Press, 1982), 54–55.

9. Baillie, *Tree-Ring Dating and Archaeology*, 53–61.

10. Malcolm K. Hughes, Stephen J. Milsom, and Patricia A. Leggett, “Sapwood Estimates in the Interpretation of Tree-ring Dates,” *Journal of Archaeological Science* 8 (1981): 381–89.

11. Hughes, Milsom, and Leggett, “Sapwood Estimates,” 386–89.

12. Stephen E. Nash, “A Cutting-Date Estimation Technique for Ponderosa Pine and Douglas Fir Wood Specimens,” *American Antiquity* 62, no. 2 (Apr. 1997): 264–65.

13. Baillie, *Tree-Ring Dating and Archaeology*, 58–60.

14. Hughes, Milsom, and Leggett, “Sapwood Estimates,” 386–89.

15. Simon Elliott, *The Important Timber Trees of the United States* (New York: Houghton Mifflin Company, 1912), 283–85; Henry H. Gibson, *American Forest Trees* (Chicago: The Regan Printing House, 1913), 487–90.

16. Darrin L. Rubino and Christopher Baas have performed tree-ring analyses of over 200 structures in the Mid-Ohio River Valley.

17. The decrease in the number of timbers analyzed (from 341 to 35) resulted from the inability to determine the exact age (lifespan) and size of the tree from which the timber was obtained; 35 samples allowed for dating and radius measurement from bark or wane to pith. Timbers from historic structures often do not allow for sampling of radii extending from pith to bark. Sawing, hewing, and decay lead to the loss of heartwood, making it difficult to determine the tree’s exact age and size.

18. Hughes, Milsom, and Leggett, “Sapwood Estimates,” 386–89.

19. A. J. Arnold, R. E. Howard, and C. D. Litton, *Tree-ring Analysis of Timbers from the Bell Frame and Tower Roof of St. Margaret’s Church, Wetton, Staffordshire* (University of Nottingham Centre for Archaeology Report 22/2003), 32–34.

20. Hughes, Milsom, and Leggett, “Sapwood Estimates,” 388–89.

21. For example, this technique has been used for European oaks. See Hughes, Milsom, and Leggett, “Sapwood Estimates,” 386–87; and Dan Miles, “Refinement in the Interpretation of Tree-ring Dates for Oak Building Timbers in England and Wales,” *Vernacular Architecture* 37 (2006): 92–93.

22. The sample data were normally distributed (Shapiro-Wilk test; $W = 0.995$, $P = 0.323$) and showed little skewness ($g_1 = -0.07$) and kurtosis ($g_2 = 0.36$). The 95 percent prediction interval was accordingly calculated: mean $\pm\, t_{a(2),v} \cdot (\text{variance} + \text{variance}/n)^{1/2}$. See Jerrold H. Zar, *Biostatistical Analysis* 5th ed. (Upper Saddle River, New Jersey: Prentice Hall, 2010), 107–08 and Hughes, Milsom, and Leggett, “Sapwood Estimates,” 388–89.

23. Hughes, Milsom, and Leggett, “Sapwood Estimates,” 386–89; J. Hillam, R.A. Morgan, and I. Tyres, “Sapwood Estimates and the Dating of Short Ring Sequences,” in *Applications of Tree-Ring Studies: Current Research in Dendrochronology and Related Subjects*, ed. R. G. W. Ward (Oxford: BAR International Series 333, 1987), 166.

24. Rubino and Baas, *Dating Buildings*, 150–53.

25. Miles, “Interpretation of Tree-ring Dates,” 92–93.

26. Miles, “Interpretation of Tree-ring Dates,” 91–92.

27. The mean number of sapwood rings present in 62 living trees from the sample area was 25.2 (SD = 5.4 rings). The 95 percent prediction interval ranged from 12 to 34 sapwood rings.

28. Steven E. Nash, “A Cutting Date Estimation Method for Two Archaeologically Important Tree Species,” *Arizona Anthropologist* 10 (1993): 85–95.

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