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Dendrochronological dating of the Graves Mill grist mill, Madison County, Virginia, USA☆

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ABSTRACT

Historical dendroarchaeology uses annual tree-ring widths varied by climate to crossdate structures of potential historical significance. In the Southeastern U.S. Piedmont specifically, crossdating these structures can lead to a broader historical interpretation during and after the colonial era. Our study used historical dendroarchaeology to date the Graves Mill grist mill located in Madison County along the western edge of the Virginia Piedmont. The mill and mill site reflect a regional trend in eighteenth century land use as agriculture transitioned from tobacco to wheat production in response to demand from international markets, as well as the adverse impact of tobacco cultivation on piedmont soils. Mills in this region have also been subject to flooding events from storms, with events recorded in the colonial era to a recent record flood in 1995, as well as re-building with changes in mill technologies through time. In an effort to date this structure as part of its restoration, and to verify the repeatability of this dating, ring widths from six timbers from the upper stories were analyzed independently at tree-ring laboratories at the University of Tennessee, Knoxville and Rider University. Both laboratories identified an 1816 cutting date for these samples, supporting documentary evidence that the mill likely underwent modifications over time after it was initially constructed in the eighteenth century. The consistent crossdating of these samples highlights the usefulness of dendrochronology as a research tool in the Southeastern U.S. for interpreting historical structures and their surrounding historical context.

1. Introduction

Across the Southeastern United States, dendrochronology has become an important approach for interpreting the past construction of historic structures using cutting dates from wood (Grissino-Mayer, 2009). In the Piedmont province of the Southeastern U.S., the availability of soil moisture and solar radiation under a canopy strongly affects tree growth (Kozlowski, 1949; Druckenbrod et al., 2005). The variation in these two environmental factors largely controls the width of a tree ring for each year in a time series of tree growth (Cook, 1987). Subsequently, measuring the widths of tree rings from wood in historical structures enables crossdating of tree-ring width measurements against accurately dated reference chronologies, recognizing that these trees are responding to a common climate signal. Given adequate statistical confidence (usually $p < 0.0001$), crossdating these samples can determine the years associated with each ring. If bark or a waney edge (the smooth wood surface after removal of bark and phloem over time) is present on a sample, this allows determination of the year in which a tree was harvested for construction. Multiple samples from various locations within a structure more definitively establish the construction date of a historic structure. In addition to greater statistical replication, multiple samples provide more information on a structure's construction history as building materials can be re-used from older structures and parts of a structure may be built at different times. This approach has led to the dating of log structures across the southeast (e.g., Mann et al., 2009; Slayton et al., 2009; Schneider et al., 2015) as well as within the South-

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eastern Piedmont specifically (e.g., Bortolot et al., 2001; Wight and Grissino-Mayer, 2004; Henderson et al., 2009).

Towards the end of the eighteenth century, agricultural land use in piedmont Virginia transitioned from an economy based on tobacco to one based on wheat (Neiman, 2008). This transition was driven in part by the impact of tobacco production on soil fertility and erosion (Ambers et al., 2006; Nelson, 2008) and the increased demand internationally for wheat (Hunter, 2002). By 1790, wheat would supplant tobacco as the leading export of the United States (Gilbert, 1977 cited in Hunter, 2002). Grist mills ground wheat into flour typically for a toll and were an important asset for Virginia communities because they were an advancement over the previous hand-powered methods (Peterson, 1935). Grist mills became frequent across the Piedmont as well as elsewhere in eastern North America, serving as reminders of past land use and settlement patterns (Copenheaver et al., 2007), but leaving geomorphological and hydrological impacts in streams that continue to the present (Walter and Merritts, 2008).

The Graves Mill grist mill and associated buildings are cited as uncommon examples of remaining early construction in this region and also a place of historical social significance as a gathering point for the community as a voting precinct, in addition to other community functions through the twentieth century (National Register Information System No. 06000754). The mill is located along the Rapidan River (earlier known as the Stanton River) within the foothills of the Virginia piedmont adjacent to the Blue Ridge Mountains and is listed on the National Register of Historic Places. Photos of the structure ca. 1940 and prior to its recent renovation show a three-story structure (Fig. 1). Historical information on this grist mill has also been accessioned at the Library of Virginia (Collection No. 45458). The application for the National Register of Historic Places stated that the first mill on the site was constructed ca. 1745 and that Thomas Graves petitioned to build a mill on the Stanton River in 1797, likely building a five-story grist mill on the original foundation ca. 1798. A 1936 Works Progress Administration report recorded that the mill had been renovated from a five-story to a three-story structure in 1921, but that the grist mill had not been used to produce flour for 50 years at that time and that the wooden overshot was replaced about 45 years prior during its conversion to a corn mill (Tunison, 1936). A report by a millwright (Ogden, 2006) found that Graves Mill contains an English drive system on the first floor, likely installed in the mid-nineteenth century, but that the large-timber Hurst frame holding this drive system also showed evidence of an earlier Ellicott drive that could have been constructed as early as the late eighteenth century. Machine-stamped nails retrieved and inspected from the upper stories indicated a second period of construction, most likely in the early 1800s (Wells, 1998).

A historical and ongoing risk to grist mills was the threat of structural damage to the mill by floods, or freshets, as they were frequently termed in colonial Virginia. For example, in a letter to Thomas Jefferson on Oct. 4, 1795, George Washington also spoke of regional mill damage when referring to the recent weather of August and September:

> The Rains have been very general, and more abundant since the first of August than ever happened in a summer within the memory of man. Scarcely a mill dam, or bridge between this and Philada. was able to resist them; and some were carried away a second, and even a third time (Washington, 1795).

These particular events were also recorded by James Madison and his father at their Montpelier plantation further downstream along the Rapidan River. In their meteorological diaries, the August 24, 1795 entry recorded a "Great Fresh in the upper part of the Rappidann (Rapidan) & Robinson" and "thunder clouds & rain at night" (Madison, 1793–1796). Combined with the outbreak of war in Europe, the weather in the mid-Atlantic led to high prices for grain (Hunter, 2002) two years before Thomas Graves petitioned to build his mill, perhaps serving as his motivation for its construction.

As a motivation for this study, tree-ring dating of the Graves Mill grist mill would not only verify the age of this structure, but could also place it within this larger historical economic and environmental context. Additionally, this project provided an opportunity to verify cutting/construction dates obtained from dendrochronology by involving tree-ring scientists at two universities (The University of Tennessee, Knoxville and Rider University in Lawrenceville, New Jersey) who independently participated in crossdating these samples. Baillie (2014) discussed how crossdating should be repeatable between labs, but published comparisons have generally been limited to re-evaluations of previous results in this region (e.g., Henderson et al., 2009). Lastly, the acquisition of tree-ring samples from historical structures in turn strengthens the replication and past extent of reference chronologies in the Virginia piedmont.

2. Methods

Graves Mill is located in Madison County at 29 Graves Road, in the town of Graves Mill, Virginia (Fig. 2). The structure had been disassembled in preparation for restoration as some of the beams were failing structurally from insufficient maintenance. During a site visit by Dr. Druckenbrod and Mr. Doug Graves (a descendant of the family who originally built the mill), several oak beams were selected that featured bark or waney edges with a high number of rings for sampling. Mr. Graves cut cross-sections from seven of these beams. These samples (referred to as GRAVE-A through G) were shipped to the Laboratory of Tree-Ring Science (LTRS) at the University of Tennessee, Knoxville for initial processing and crossdating. Beams from the first floor, including those that supported the mill works, were not sampled because they were to be re-used in the restoration of the structure and did not have bark or waney edges.

Once at the LTRS, each section was sanded using progressively finer sandpaper beginning with ANSI 100-grit (125–149 μm) and ending with ANSI 400-grit (20.6–23.6 μm) (Orvis and Grissino-Mayer, 2002). Hand-finishing with ANSI 1200-grit (4.5–6.5 μm) was used to further polish the sections for visual acuity. We used a binocular stereozoom microscope at standard 10X magnification to initially mark all rings with standard dot notation (Stokes and Smiley 1996; Speer 2010) beginning with the first innermost complete ring labeled as ring "1." All rings were then measured to 0.001 mm accuracy using a Velmex measuring stage and digital display coupled with MEASURE J2X software.

Next, we used the computer program COFECHA to perform segmented time-series correlation analyses (Holmes, 1983; Grissino-Mayer, 2001) on the undated series to place each series in proper temporal alignment with all other series. Log transformations, spline-fitting, and autoregressive modeling were applied in the COFECHA software to remove low-frequency trends and highlight year-to-year variation (Grissino-Mayer, 2001). We analyzed 40-year segments lagged by 20 years to ensure that most if not all segments crossdated with the same calendar segment from the other series. In the Southeastern U.S., we use a minimum interseries correlation coefficient of 0.40 to indicate that a series has been crossdated correctly relative to other series.

Absolute dating was accomplished by crossdating the undated tree-ring series against a composite regional reference chronology created from five separate white oak tree-ring chronologies from Virginia and one white oak chronology from Kentucky, all extracted from the ITRDB (Grissino-Mayer and Fritts, 1997). In addition, these data sets were supplemented with a recently developed

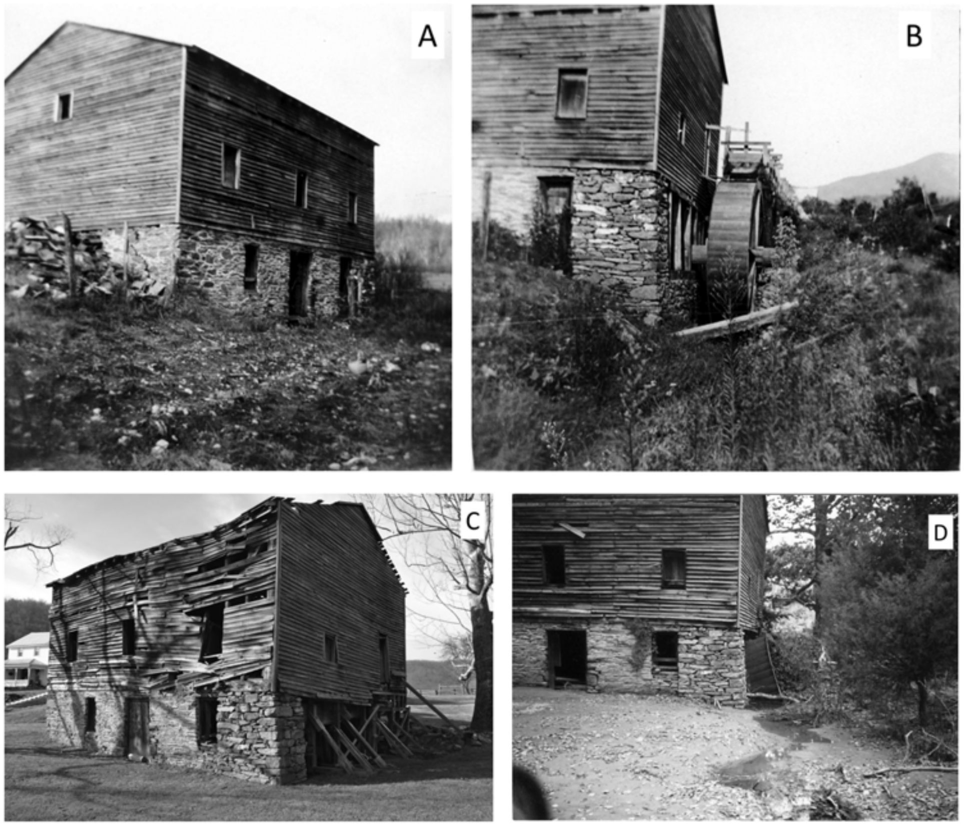

Fig. 1. Historical and recent images of the Graves Mill grist mill, located in the Piedmont of Virginia, USA: (A, B) the mill in the 1940s (courtesy Virginia Historical Society); (C) the mill in 2012 (photograph by Douglas Graves); (D) the mill in June 1995 after the June 27 storm, showing deposited sediment around the foundation (photograph by Douglas Graves).

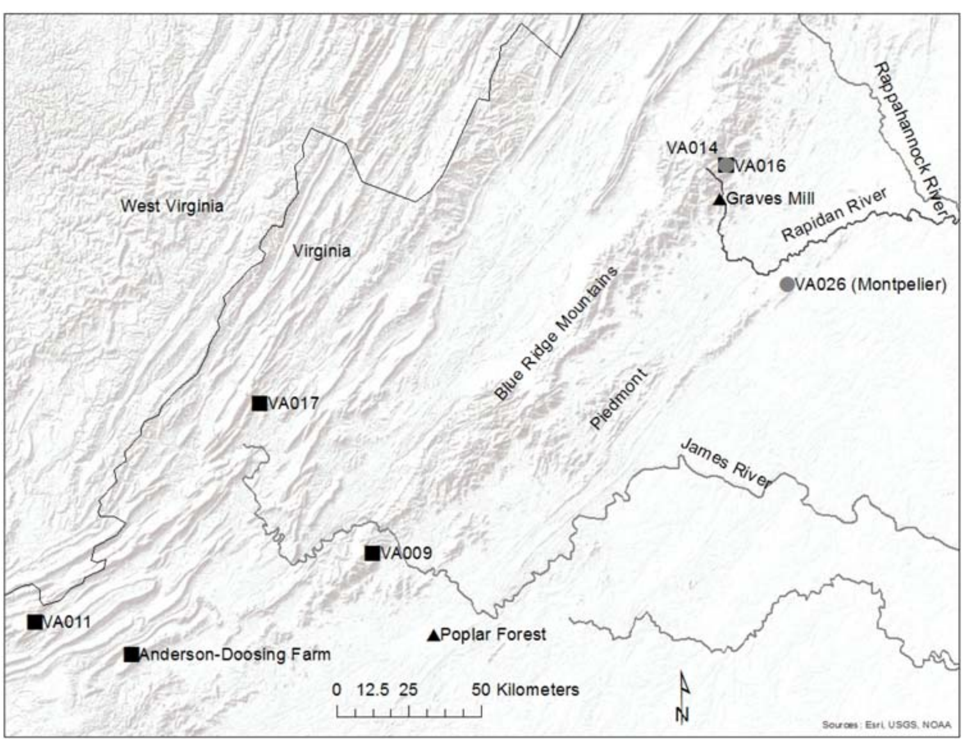

Fig. 2. Study area showing location of Graves Mill and the approximate locations of reference chronologies used in the study by the University of Tennessee, Knoxville (black squares) and Rider University (gray circles). The locations of chronologies VA014 and VA016 overlap.

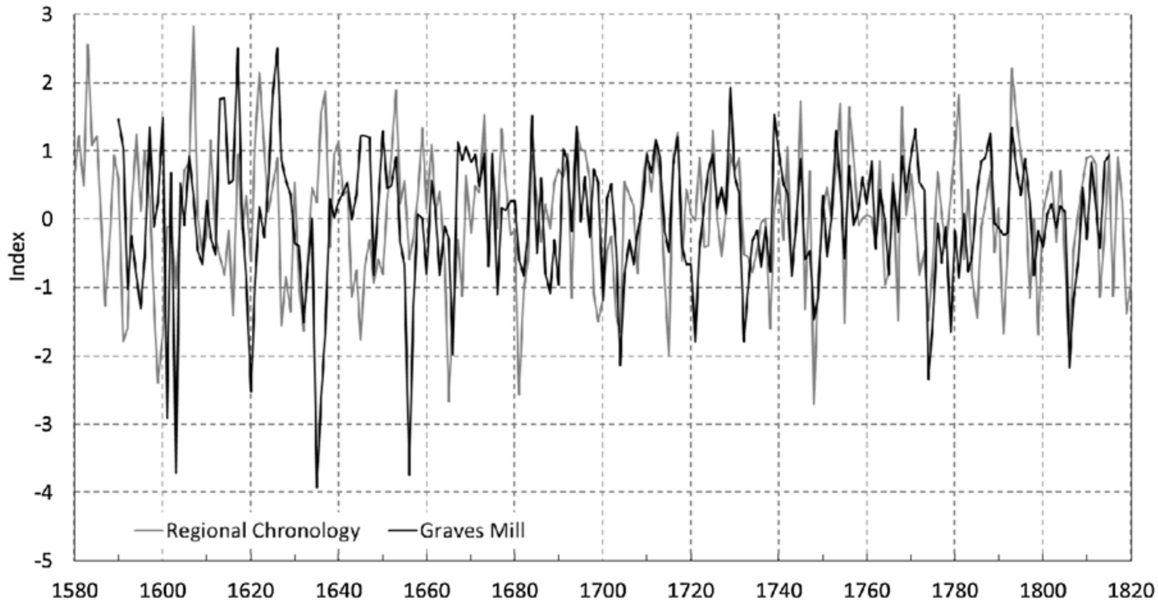

Fig. 3. Graphical comparison between the regional oak chronology used at the University of Tennessee (dark gray line) and the chronology developed for the Graves Mill samples (black line). The relationship is weak prior to 1670, perhaps due to suppressed growth in the few oak samples that extend before this period. From 1670–1815, the relationship is statistically significant (r = 0.51, n = 146 years, t = 7.19, p < 0.0001).

oak chronology from the Anderson-Doosing Farm, located north of Blacksburg, Virginia (Grissino-Mayer et al., 2013):

1. VA009, Blue Ridge Parkway, 1587–1982;
2. VA011, Mountain Lake, 1552–1983;
3. VA014, Pinnacle Point, 1612–1981;
4. VA016, Massenhutten Mountain, 1642–1981;
5. VA017, Patty's Oaks, 1569–1982;
6. KY003, Lilley Cornett Tract, 1660–1982;
7. Anderson-Doosing Farm, 1691–1849.

We again used COFECHA to suggest temporal placements for each individual series and we considered the series as being crossdated when correlation coefficients for all segments were statistically significant (generally p < 0.0001). Once crossdated, calendar years for all tree rings on each measurement series from the samples were assigned using program EDRM (Edit Ring Measurement). Crossdating was verified graphically by inspection of line graphs that compared the crossdated (residual) chronology for the Graves Mill samples against the composite (residual) chronology created from the reference chronologies using the master dating chronologies produced in COFECHA (Grissino-Mayer, 2001).

After completion of these analyses at the LTRS, the samples were sent to the tree-ring laboratory at Rider University along with the ring-width measurement files. Dr. Druckenbrod independently verified the internal dating using the same correlation settings in COFECHA and also visually using traditional skeleton plots (Stokes and Smiley, 1996). Without knowing which reference chronologies had been used at LTRS, Dr. Druckenbrod independently selected regional reference chronologies for dating these series. The Rider University composite regional reference chronology included the two closest reference chronologies (sites 3 and 4 listed above) along with an oak chronology from James Madison's Montpelier plantation (1713–2001) (Druckenbrod et al., 2003; Druckenbrod and Shugart, 2004).

4. Results

Graphical comparisons (skeleton plots and line graphs) between the Graves Mill chronology and the regional composite chronology developed by the University of Tennessee LTRS demonstrated a convincing match but not for the first ca. 80 years or so. The correlation between the two series was statistically significant (r = 0.26, n = 226 years, t = 4.06, p < 0.0001) over the entire time span, but the correlation improved considerably when removing the initial 80 years (r = 0.51, n = 146 years, t = 7.19, p < 0.0001). Both graphical and statistical comparisons showed that the chronology for the Graves Mill samples extended from 1590 to 1815 (Fig. 3), with especially strong crossdating beginning ca. 1670. We attribute the decreased correspondence in the earlier decades to two factors. First, we had low sample depth prior to 1670, with one sample extending back to 1590 and another back to 1637. Second, both samples showed slow growth during this period (Fig. 4), likely because the trees were growing with little available light in the understory of a closed canopy and thus would be expected to have a weaker climate response (and lowered crossdating potential) during these earliest decades.

Correlations against the three regional reference chronologies at Rider University produced using ARSTAN (Cook and Krusic, 2014) also had significant correlations with the samples ending in 1815: Montpelier (r = 0.53, n = 103 yrs, t = 6.28, p < 0.0001), VA016 (r = 0.34, n = 174 yrs, t = 4.74, p < 0.0001), and VA014 (r = 0.16, n = 204 yrs, t = 2.33, p = 0.0205). Similar to the results from the LTRS, the correlation values were greater with the Montpelier and VA016 reference chronologies that did not extend into the early 1600s during the period of suppressed growth. The independent verification of the Graves Mill samples at Rider University produced the same external dating as found at the LTRS.

The individual series showed convincing crossmatching internally (Table 1) with an average interseries correlation of 0.41. Three of the dated samples (GRAVE-A, E, and G) had bark present, which enabled a determination of their last year of growth (Table 2). The last complete ring formed on these three samples was the ring for year 1815 with a final partial ring formed in 1816. We observed that some latewood was present in their outer partial rings, suggesting

Table 1
Correlation coefficient matrix produced by COFECHA demonstrating internal crossdating of six beams sampled from Graves Mill.

Sample	Ring Number[a]									
	40–79	60–99	80–119	100–139	120–159	140–179	160–199	180–219	200–239	Interseries Correlation
GRAVE-A		0.26	0.36	0.51	0.73	0.77	0.60	0.31	0.04	0.42
GRAVE-B			0.41	0.46	0.45	0.23	0.50	0.53		0.40
GRAVE-D	0.44	0.52	0.50	0.68	0.71	0.64	0.70	0.51	0.29	0.50
GRAVE-E					0.38	0.37	0.50	0.60	0.54	0.43
GRAVE-F	0.41	0.31	0.13	0.21	0.40	0.57	0.48	0.31		0.30
GRAVE-G			0.51	0.57	0.40	0.24	0.31	0.54	0.49	0.44

[a] Only one sample, GRAVE-D, extended from rings 1–40, hence no correlations were possible for the first two overlapping 40-year segments.

Fig. 4. Graves Mill D showing severely suppressed growth during the first ca. 80 years.

Table 2
Outer ring dates for the six beams sampled from Graves Mill.

Sample	Outer date	Comments
GRAVE-A	1816	Bark present, latewood present, tree cut during or after summer 1816.
GRAVE-B	1802	Non-cutting date only.
GRAVE-D	1815	Possible waney edge, tree possibly cut in 1815 or after.
GRAVE-E	1816	Bark present, latewood present, tree cut during or after summer 1816.
GRAVE-F	1807	Non-cutting date only.
GRAVE-G	1816	Bark present, latewood present, tree cut during or after summer 1816.

that these trees may have been felled during or after summer of 1816. Sample GRAVE-D may have a waney edge, and the outer partial ring dated to 1815. It is possible that it also may have originally dated to 1816 as well, but that the outer ring had been worn away. Samples B and F dated to 1801 and 1806, respectively. Because these samples did not extend to bark or a waney edge, they cannot be used to determine a cutting date for the beams, but they do not contradict the dates determined by the other samples since B and F are missing their outer rings. One sample, GRAVE-C, did show crossdating both internally and against our regional reference chronologies, but did so at two competing temporal positions, graphically and statistically, and neither lab could determine which position was the correct one. This sample therefore was excluded from all our analyses, including being used to calculate the final chronology when compared against the regional oak chronologies.

5. Discussion

The consistent crossdating found during the independent verification of the dating between two laboratories supports the use of dendrochronology as a tool for dating historical structures in the Southeastern U.S. Particularly considering that this study had access to fewer samples than other studies in the Southeastern U.S., these results highlight the repeatability of crossdating in this region, especially where well-replicated reference chronologies are available. While the 1816 cutting date for the bark and waney-edge samples is more recent than the ca. 1798 construction date suggested by the documentary record, this date is also consistent with machine-stamped nails found with these samples. These nails were not common until the early 1800s (Adams, 2002). However, the 1816 outer rings on these samples does not necessarily determine the maximum age of this structure. Although the structure was disassembled when samples were extracted, it is likely that all of these samples were from one of the upper stories. As this structure has undergone multiple construction episodes, it is possible that the selected beams did not capture the oldest portion of the structure, which likely includes the first floor. From his analysis of the Graves Mill millworks, Ogden (2006) surmised that the mill was renovated at least three times as was typical for grist mills in order to remain economically competitive with new technology.

In addition to renovations from technological innovations, storms remain a threat to historical mill structures in the Virginia Piedmont today. On 27 June 1995, 770 mm of rainfall was recorded over the village of Graves Mill from a pair of convective storm systems (Pontrelli et al., 1999; Eaton et al., 2003; Wieczorek et al., 2004). These storms produced record stream flow and several hundred debris-flow channels within the upper drainage basin of the Rapidan River that snapped or removed large trees, among other instances of damage (Morgan et al., 1997; Pontrelli et al., 1999). Fortunately, while Graves Mill did not sustain substantial damage from these two storms (possibly because of its construction methods), this event highlights the difficulty of maintaining mills along the eastern slopes of the Blue Ridge Mountains.

Although no known record exists of storm damage in Madison County in 1816, Jefferson noted a very severe storm (likely a hurricane) with high winds at Poplar Forest, Virginia on 4 September 1815 (Jefferson, 1815). While it is not known whether this storm damaged Graves Mill, high winds have also been noted as a possible explanation for the reduction of the mill height from five to three stories and these beams could have been added to reinforce the structure at that time. Similarly, while documents such as an

1803 survey show the presence of a mill prior to this hurricane, the earliest known business documents for mill products occur in 1817. While earlier business documents may have been lost, it is also possible that the mill was only used for wheat from the Graves family's plantation prior to 1817 instead of business arrangements with other plantations.

Regardless of the possible causes for the addition of these upper-story beams in Graves Mill, the Antebellum Period dating of this structure confirms its historical relevance in the early nineteenth century of Madison County, Virginia, both in its preservation of early milling technology and as a focal point for the local community. At a regional scale, the current restoration of this mill will also serve as a record of both historical land use and past climate variability within the Virginia piedmont.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.dendro.2016.12.002.

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