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ABSTRACT The relict plains cottonwood (*Populus deltoides* subsp. *monilifera*) forest along the Missouri River between Lakes Sakakawea and Oahe includes trees as large as two meters in diameter. We cored 24 of these trees to determine their age and suitability for flow reconstruction. Because most of the trees were rotten in the center, we developed a method to estimate the date of the center ring that accounts for the increase in ring width toward the center. Estimated center ring dates were as early as 1806. Cottonwood growth at a dry site was correlated with April–August flow prior to construction of Lake Sakakawea (1929–1953; $r = 0.50$, $P = 0.011$) and to Palmer Drought Severity Index following construction (1954–2014; $r = 0.38$, $P = 0.003$). We conclude that cottonwood rings can be used to improve reconstructions of Missouri River flows before the beginning of stream-gage records.

KEY WORDS climate, flow reconstruction, Plains cottonwood, North Dakota, tree age, tree rings.

Prior to settlement the Missouri River supported a broad floodplain forest dominated by plains cottonwood (*Populus deltoides* subsp. *monilifera*). In Montana and North and South Dakota, most of the floodplain forest has been flooded and killed by construction of reservoirs (Dixon et al 2012, Volke et al. 2015), the largest being Fort Peck Reservoir in 1937, Lake Sakakawea in 1953, and Lake Oahe in 1958. Along the remaining free-flowing sections between reservoirs, flood control and channel stabilization have reduced channel migration and cottonwood reproduction, but relict forests established prior to flow regulation persist (Johnson et al. 1976, 2012). Therefore, ring widths of old trees may contain information about climate or flow prior to flow regulation. Recent studies have shown that cottonwood ring widths can be used to reconstruct precipitation and flow along tributaries to the Missouri River, including the Yellowstone, Powder and Little Missouri rivers (Edmondson et al. 2014, Meko et al. 2015, Schook et al. 2016). Cottonwoods along the main stem Missouri River, however, have not yet been used for flow reconstruction.

Improved flow and climate reconstructions for the Missouri River Basin would benefit historical studies, and would aid in planning for droughts and floods along this regionally important river. Developing flow reconstructions requires information about correlations between tree growth and environment (Meko et al. 2015, Schook et al. 2016). Reily and Johnson (1982) related growth of younger cottonwoods downstream of Lake Sakakawea to environmental factors and found that while mean growth was not greatly affected by construction of Garrison Dam in 1953, growth was more strongly correlated with flow prior to dam construction and with actual evapotranspiration after dam construction. Correlations between growth and environment are not available for older cottonwoods along the Missouri River.

Knowledge of the age of the oldest trees improves understanding of the rate of channel migration (Schook et al. 2017) and ecological succession (Johnson et al. 1976). Most old cottonwoods are rotten in the center. Age of partially rotten trees can be estimated by determining the length of core missing because of rot. The missing length can then be converted to years by dividing by mean ring width (Norton et al. 1987). This approach usually overestimates the number of missing years because ring width decreases with increasing age (Rood and Polzin 2003, Ranius et al. 2009, Meko et al. 2015). Refinement of this approach is needed to develop more accurate estimates of tree age.

Our primary objectives were to 1) measure the age of relict old cottonwoods between Garrison Dam and Lake Oahe (Fig. 1), 2) investigate whether annual growth of cottonwoods is correlated with climate or flow before and after flow regulation, and 3) refine methods for estimating the age of partially rotten trees.

STUDY AREA

The free-flowing section of the Missouri River in North Dakota, between Lake Sakakawea and Lake Oahe spans approximately 130 km and supports some of the largest plains cottonwoods in the state. Some of the trees exceed two meters in diameter and are thought to be over 250 years old (Zeleznik 2006), but dendrochronological investigations of these old trees have not been conducted.

We searched for old trees along the Missouri River between Garrison Dam and Lake Oahe using published records, satellite imagery downloaded from Google Earth (https://www.google.com/earth/), personal contacts with scientists and residents familiar with the area, and visual reconnaissance. Based on this research, we selected three sites: Smith Grove, Cross Ranch Preserve, and Kimball Bottoms (Fig. 1). Smith Grove State Wildlife Management Area is managed by the North Dakota Game and Fish Department. Cross Ranch Preserve is owned and managed by

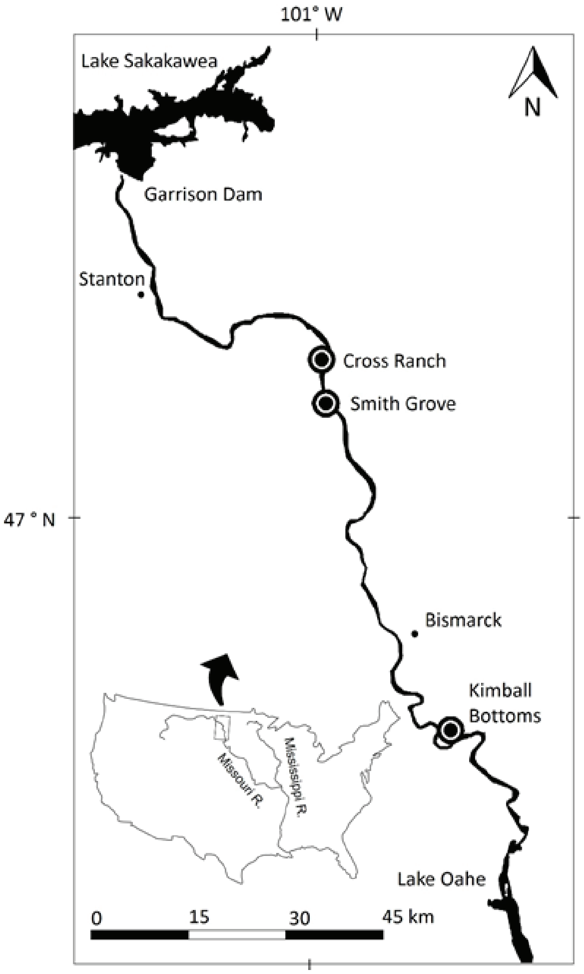

Figure 1. Location of Cross Ranch, Smith Grove and Kimball Bottoms along the Missouri River in central North Dakota.

The Nature Conservancy. Kimball Bottoms is located within the Oahe State Wildlife Management Area, and is managed by the North Dakota Game and Fish Department.

METHODS

We cored all the largest trees at Smith Grove and in an adjacent private parcel immediately to the north. At Cross Ranch and Kimball Bottoms we cored the largest trees that we observed, but since these sites are extensive, we may have missed some large trees. We measured the diameter of selected trees 1.2 m above the ground, and cored trees using Haglöf Increment Borers™ (Haglöf, Långsele, Sweden). We extracted at least two cores from each cottonwood, increasing the likelihood of collecting cores not destroyed by heart rot. We mounted all cores on wooden boards and then sanded with progressively finer sand paper from 100 to 600 grit. We cross-dated cores using the skeleton-plot method (Stokes and Smiley 1996), digitized ring widths to 0.01 mm precision using a sliding-stage micrometer, and used the program COFECHA for quality control (Grissino-Mayer 2001). Ring width data are archived in the International Tree Ring Data Bank (https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring).

Estimates of tree age were needed to provide context for management of these areas and to enhance interpretation of ring widths. Most of the sampled trees contained heart rot, which prevented precise determination of tree age. We used two methods to estimate establishment year of cores that did not pass through the pith: the ring-curvature method (Meko et al. 2015) and the missing-length method (Norton et al. 1987). If the core was sufficiently close to the center of the tree that the curvature of its rings could be quantified (less than about 7 cm), the ring-curvature method was applied. The number of additional years to pith was estimated by dividing the radius of curvature of the innermost ring boundary by the average width of the four innermost rings (Meko et al. 2015). This method is generally accurate to within 10 years.

If the core was too far from the center to apply the ring-curvature method, we used the missing-length method, which estimates the number of missing rings by comparing core length to estimated tree radius assuming the tree is radially symmetric,

$$M = \left({}^{D}\!/_{2} - B \right) - L$$ (Equation 1)

where M is the length of missing core, D is measured tree diameter, L is the length of the core (excluding any bark), and B is bark width estimated from diameter using the regression developed by Hengst and Dawson (1994) for cottonwoods from Urbana, Illinois.

$$B = 0.0540 \times D - 0.1568$$ (Equation 2)

Error could be introduced in Equation 1 by core shrinkage in drying or inaccuracy in estimation of bark thickness. To adjust for such error we compared measured diameter, D, to diameter estimated as $2(B + L)$ by rearranging Equation 1 for the 15 nearly complete cottonwood cores in our sample that were close enough to the center to apply the curvature method (M close to 0). This comparison indicated that field measured diameter exceeded diameter estimated from dried cores, as expected, by a ratio of 1.09 ± 0.11 (mean ± standard deviation). To adjust for this discrepancy, we divided measured core lengths by 1.09 when using Equation 1 to calculate missing length M.

Converting the missing length into the number of missing years is complicated by the fact that ring width decreases strongly with tree age (Meko et al. 2015). For this reason, dividing the missing length by the mean width of rings in the incomplete core could greatly overestimate the number of missing rings. To develop a more accurate estimate, we calculated the mean ring width for every age (Meko et al. 2015) for the 15 complete or nearly complete cores described above. We assumed that the resulting relation between ring width and age described the pattern of growth for all trees. We allowed trees to differ only in their relative growth rate, k, held constant for the life of a tree. The ring width for a particular tree in any year was equal to the mean ring width from the 15 complete cores for that year multiplied by the value of *k* for that tree. Thus if $k > 1$, then tree growth rate was above average. We calculated the number of missing rings in incomplete cores using Equations 3 and 4

$$M = k\sum_{t=1}^{n} R \qquad \text{(Equation 3)}$$

$$L = k\sum_{t=n+1}^{z} R \qquad \text{(Equation 4)}$$

where *k* varies between but not within trees, *n* is the number of missing rings in an incomplete core, *z* is the age of the tree, and *R* is the sequence of mean ring widths at any age for the 15 nearly complete cores. We estimated *n* for an incomplete core by dividing the missing length by the mean width of the rings in the innermost 20 cm of that core. This allowed estimation of *z* (*n* + the number of rings in the core). We rearranged Equation 4 to estimate *k* for the tree and used Equation 3 to calculate a new estimate of *n*. We iterated this process of alternately applying Equations 3 and 4 until *n* no longer changed. No more than five iterations were required for any core.

Both methods for estimating tree age increase in accuracy for cores that are closer to the center of the tree. When curvature can be seen in the rings, then the ring-curvature method is preferable because it takes advantage of precise information about the location of the center. Furthermore the ring-curvature method requires only the limited assumptions that the unsampled rings between the end of the core and the center are radially symmetric and similar in width to the innermost 4 rings of the core. In contrast the missing-length method assumes that the entire cross-section of the tree is radially symmetric and that bark thickness and the relation between ring width and age follow the modeled distributions. Because of the decreasing accuracy of the missing-length method for shorter cores we estimated age only for cores longer than the estimated missing length ($L > M$). Because of tree asymmetry, variability in bark width and other factors, some nearly complete cores were longer than the estimated bark-free radius, resulting in negative values for *M*. In this case we set the number of missing rings to zero, and estimated age was the same as the number of rings in the core.

We related annual growth of cottonwoods to flow, precipitation, temperature and soil moisture estimated as Palmer Drought Severity Index (PDSI). To remove the effect of age from ring-width data we detrended with a 67% cubic smoothing spline in program ARSTAN (Cook 1985). We obtained flow data from the U.S. Geological Survey National Water Information System (https://waterdata.usgs.gov/nwis) for station 06342500, Missouri River at Bismarck, ND, dividing the period of record for this gage into a moderately regulated period before construction of Lake Sakakawea (1929–1953) and a heavily regulated period after construction of Lake Sakakawea (1954–2014). We characterized the 1929–1953 period as moderately regulated because Fort Peck Reservoir was operational upstream in Montana by 1937. We obtained local precipitation and temperature data from High Plains Regional Climate Center's CLIMOD (http://climod.unl/edu) for Cooperative Observer Network weather station 320819 at Bismarck Municipal Airport, ND. We estimated the influence of local weather on soil moisture using PDSI, which balances measured inputs of water from precipitation with modeled outputs of water from evapotranspiration (Heim 2002). We downloaded PDSI data for North Dakota's Climate Division Four from the National Climatic Data Center. We performed Pearson correlations in R version 3.3.1 (R Core Team 2016) to relate annual detrended cottonwood growth to monthly values of environmental variables. We present environmental data for the period April–August because it showed the strongest correlations with growth overall and is consistent with the growth season demonstrated by phenological measurements of this species (Friedman et al. 2011).

RESULTS

Cross Ranch Preserve yielded eight trees with 13 readable cores, of which two were close enough to the center to apply the ring-curvature method and six more were long enough to apply the missing-length method (Appendix A). Old cottonwoods were found in one curved line located on the highest forested terrace, about 0.67 km west of the present-day riverbank; these trees dated to between 1806 and 1894.

Kimball Bottoms Recreation Area yielded three trees with six readable cores, of which three were close enough to the center to apply the ring-curvature method and two more were long enough to apply the missing-length method (Appendix A). Targeted cottonwoods at this locality formed a curved line parallel to, but one km away from, the present riverbank, and dated to between 1855 and 1886.

Smith Grove Wildlife Management Area yielded 15 trees with 24 readable cores, of which 10 were close enough to the center to apply the ring-curvature method and nine more were long enough to apply the missing-length method (Appendix A). All the old trees found at Smith Grove were located on a high terrace and near a small tributary channel and associated swamp. The trees cored at Smith Grove separate into two distinct cohorts similar in size but different in age; an older cohort established around 1815 and a younger one established in the late 1800s to early 1900s (Appendix A). The oldest cohort consisted of large, widely spaced trees with deeply furrowed bark and advanced heart rot. Large downed logs, stumps, and old signs indicate that other trees in this cohort died in the last few decades. Although at least five of these trees were still living, most were strongly hollow, and we were able to estimate age of only two of them, GM01B and GM02A, with center rings estimated from 1813 and 1817 (Appendix A). The younger cohort was more densely spaced and formed a row along the bank of the tributary channel. All of these trees were within about 15 m of the tributary, were less hollow than the older cohort, and dated to between 1868 and 1926 (Appendix A).

Trees at Smith Grove and Kimball Bottoms were larger than trees of comparable age along the Little Missouri River in the North Unit of Theodore Roosevelt National Park near Watford City, ND (Fig. 2). In fact all of the trees at Smith Grove and Kimball Bottoms were outside of the point cloud representing ages and diameters reported from the Little Missouri River (Fig. 2). In contrast, trees at Cross Ranch were smaller for their age than trees at Smith Grove and Kimball Bottoms. All but one of the trees at Cross Ranch were within the age-diameter point cloud from the Little Missouri River (Fig. 2). Prior to construction of Lake Sakakawea, growth of cottonwoods at Cross Ranch was positively correlated with flow (r = 0.50, P = 0.011) and precipitation (r = 0.42, P = 0.037), but not with temperature (P = 0.31) or PDSI (P = 0.093, Table 1). Following reservoir construction, growth was no longer correlated with flow (P = 0.68), but was correlated with PDSI (r = 0.38, P = 0.0028). At Smith Grove growth was not correlated with flow (P = 0.22) or precipitation (P = 0.45) prior to construction of Lake Sakakawea (Table 1). After reservoir construction growth at Smith Grove, like that at Cross Ranch, was positively related to PDSI (r = 0.33, P = 0.010).

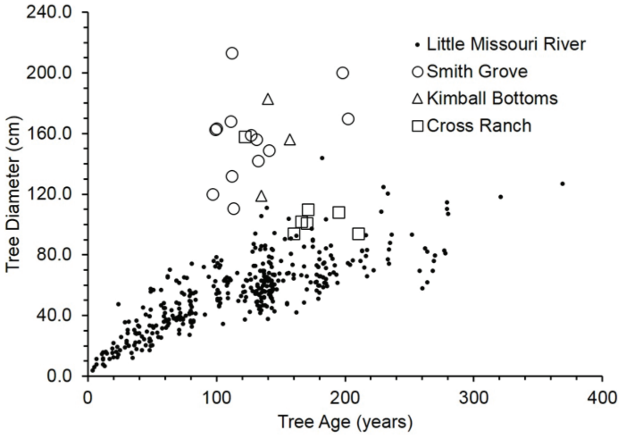

Figure 2. Diameter at a height of 1.2 m above ground as a function of age for trees along the Missouri River and along the Little Missouri River in the North Unit of Theodore Roosevelt National Park, North Dakota (Edmondson et al. 2014).

DISCUSSION

Fast growth of trees sampled at Smith Grove and Kimball Bottoms relative to those from the Little Missouri River (Fig. 2, Edmondson et al. 2014) partly reflects differences in sampling strategy. Along the Missouri River we cored the largest trees at a few small sites, while along the Little Missouri River we cored the closest trees to random points over a larger area. Because the Little Missouri River sample included almost all of the largest trees at that site, however, this comparison shows that many of the trees cored along the Missouri River were beyond the size range of trees along the Little Missouri River. Faster growth along the Missouri River is consistent with the wetter climate in central than in western North Dakota, the higher base flows on the Missouri River relative to the Little Missouri River, and the limitation of growth by water availability (Edmondson et al. 2014). The relatively mesic conditions along the Missouri River may explain the relatively fast development of heart rot in these trees. In addition, large size increases tree susceptibility to lightning strikes and wind damage (Rood and Polzin 2003, Di Filippo et al. 2015). Therefore, mesic conditions at these sites foster rapid tree growth and shorter life span, which may explain the absence of trees much more than 200 years old (Fig. 2). Water availability also appears to explain differences in growth among the three sites. Trees from Smith Grove grew rapidly, apparently because of supplemental moisture from the local tributary. In the absence of such supplemental moisture, trees from Cross Ranch grew more slowly, and all but one of them were within the age-size range of trees from the Little Missouri River (Fig. 2). Trees at Kimball Bottoms also grew rapidly (Fig. 2), possibly because of additional moisture resulting from raised water table associated with sediment deposition in the channel. Sediment deposition in this area is a result of decreased stream gradient at the upstream end of Lake Oahe (Skalak et al. 2013, Volke et al. 2015).

The oldest cottonwoods in this section of the Missouri River became established around the time of the Expedition of Lewis and Clark. Measured 1.2 m above the ground our oldest trees reached ages of just over 200 years. The age of these trees at the germination point is likely several years older. For example, along the Missouri River in Montana, the age of cottonwoods at ground surface averaged 5 years younger than the age at the buried germination point (Scott et al. 1997). Along the Yellowstone River in eastern Montana (Schook et al. 2017) and the Little Missouri River in western North Dakota (Friedman and Griffin 2017) it took a median

Table 1. Correlations between environmental factors and site-based annual growth represented by cottonwood tree-ring chronologies for two sites along the Missouri River downstream of Lake Sakakawea, North Dakota. Values are Pearson correlation coefficients and two-tailed probabilities (included in parentheses).

Interval	Precipitation[a]	Temperature[b]	PDSI[c]	Flow[d]
Cross Ranch				
1929–1953	0.42 (0.037)	–0.21 (0.31)	0.34 (0.093)	0.50 (0.011)
1954–2014	0.31 (0.015)	–0.20 (0.12)	0.38 (0.0028)	0.054 (0.68)
Smith Grove				
1929–1953	0.16 (0.45)	0.29 (0.15)	–0.047 (0.82)	0.26 (0.22)
1954–2014	0.21 (0.10)	0.11 (0.41)	0.33 (0.010)	0.079 (0.55)

[a]Cumulative precipitation from April to August; [b]Mean monthly maximum temperature from April to August; [c]Palmer Drought Severity Index for the month of July; [d]Mean monthly Missouri River flow from April to August.

of 8.5 and 7.3 years for cottonwoods to reach a height of 1.2 m. Therefore, the oldest trees cored in this study would have been just saplings if present at all when the Lewis and Clark expedition passed through the area between 1804 and 1806. This is younger than the oldest, more slowly growing trees of the North Unit of Theodore Roosevelt National Park, ND (Fig. 2) or the lower Yellowstone and Powder rivers in Montana (Schook et al. 2016). It is also younger than the 250–300 years of age previously estimated at Smith Grove in 1988 (Zeleznik 2006). It is possible that this older age estimate at Smith Grove was based on trees that have since died. Our age estimates are conservative because they take into account the tendency of annual rings to become larger toward the center of the tree. The scarcity of old trees along the Missouri River in central North Dakota also reflects the history of tree cutting to fuel steamboats, construct buildings, and clear land for agriculture (Dixon et al. 2010, 2012).

Growth of cottonwoods at Cross Ranch was correlated to flow and precipitation before construction of Lake Sakakawea and to PDSI and precipitation after reservoir construction (Table 1). We infer that cottonwood growth at this site has always been limited by soil water availability, which was controlled primarily by flow and local weather before reservoir construction and by local weather alone afterwards. This result confirms conclusions of Reily and Johnson (1982) based on cores from younger cottonwoods in the same free-flowing reach. More generally, this result is consistent with moisture limitation of cottonwood growth on floodplains along rivers in the Great Plains of North Dakota (Edmondson et al. 2014, Meko et al. 2015, Friedman and Griffin 2017), Montana (Schook et al. 2016) and Colorado (J. M. Friedman, U. S. Geological Survey, unpublished data). The decreased influence of flow following dam construction may relate to the decrease in flow variability caused by the dam, the decrease in overbank flooding caused by flow regulation (Reily and Johnson 1982) and channel bed lowering. Bed lowering in this area has resulted from erosion by sediment-poor water released from Lake Sakakawea (Skalak et al. 2013). At Smith Grove, growth was uncorrelated with precipitation, temperature, flow or PDSI before reservoir construction, and was correlated with PDSI alone afterwards in spite of the relatively large sample size. The absence of a correlation between growth and moisture availability before flow regulation suggests that growth at Smith Grove is less strongly limited by water availability, apparently because of the moisture supplement from the local tributary. This inference is supported by the faster growth of the trees at Smith Grove compared to those at Cross Ranch (Fig. 2).

Along tributaries to the Missouri River in the Plains of western North Dakota and eastern Montana, flow reconstructions have been developed based on a strong correlation between annual growth of cottonwood and river flows (Little Missouri River near Watford City, ND, April–July flows, $r = 0.65$; Powder River at Moorhead, Montana, March–June flows, $r = 0.76$; and Yellowstone River near Sidney, Montana, March–June flows, $r = 0.69$; Schook et al.

2016). The correlation between annual growth of Cross Ranch trees and flow in the Missouri River prior to construction of Lake Sakakawea was smaller, reflecting the weaker moisture limitation in this more eastern site, but still moderately strong (April–August flows; *r* = 0.50; Table 1). We conclude that tree rings of cottonwood from dry floodplain locations along the Missouri River may be useful for reconstruction of pre-dam flows. The duration and value of such reconstructions would be improved by collection of older cores. If older trees are present in the Garrison Reach, they are most likely to be found in dry locations on high terraces, which should be more abundant in the downcut reaches relatively close to Garrison Dam (Skalak et al. 2013). Old cottonwood logs may also be present in old log buildings or on the bottoms of reservoirs.

MANAGEMENT IMPLICATIONS

The old cohort of trees at Smith Grove are dying as a result of old age and associated heart rot. These trees will most likely be gone in a few decades. The younger cohort are dense and numerous and include many trees without extensive heart rot. Therefore, without any intervention there should be large trees for visitors to see at Smith Grove for the foreseeable future. Growth of mature cottonwood trees downstream of Lake Sakakawea has not been significantly influenced by interannual variation in flow since 1953, in part because the dam has reduced this variation, and in part because dam-induced decreases in peak flows have reduced overbank flooding. Increases in flow variation between years, for example by decreasing growing-season flows during drought, could affect growth of the trees in the future. Erosion downstream of dams and sediment deposition upstream of dams affect growth and survival of riparian forest.

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APPENDIX A All cores analyzed from the Missouri River below Lake Sakakawea, North Dakota. Length units are cm. When applying the missing length method, if the core was longer than the estimated radius (missing length < 0) the number of missing rings was set to 0. The missing length method was not applied to cores shorter than half of the estimated radius because of large uncertainty.

			Age Estimation						
			Missing Length Method				Curvature Method		
Study area[a]	Core ID[b]	Tree diameter	Core length	Missing length	Missing rings	Center year[c]	Center distance[d]	Missing rings	Center year[c]
SG	GM01A	200	33.44	47.66					
SG	GM01B	200	45.12	35.98	58	1817			
SG	GM02A	170	41.86	27.10	49	1813			
SG	GM02B	170	20.43	48.53					
SG	GM03A	127	15.35	36.21					
SG	GM07B	168	61.81	6.34	6	1912	6.3	10	1904
SG	GM07D	168	59.54	8.61	7	1923			
SG	GM08A	149	39.80	20.66	28	1874			
SG	GM08B	149	damage						
SG	GM09A	156	32.22	31.07	47	1868			
SG	GM09B	156	53.46	9.83	11	1884			
SG	GM10A	159	52.53	11.98	13	1888			
SG	GM11A	213	62.92	23.44	18	1903			

			Age Estimation						
			Missing Length Method				Curvature Method		
Study area[a]	Core ID[b]	Tree diameter	Core length	Missing Length	Missing rings	Center year[c]	Center distance[d]	Missing rings	Center year[c]
KB	GM12A	119	52.56	–4.24	0	1885	1.5	5	1880
KB	GM12B	119	47.39	0.93	2	1886			
KB	**GM13A**	**156**	**51.20**	**12.09**	**15**	1858			
KB	**GM13B**	**156**	**60.45**	**2.84**	**4**	1855	1.2	1	1858
KB	GM16A	183	damage						
KB	GM16B	183	55.24	18.98	19	1876	2.4	4	1875
SG	GM20A	163.5	46.67	19.66	20	1900	3.9	7	1913
SG	GM20B	163.5	64.13	2.20	2	1916	1.2	2	1916
SG	GM21A	162.5	72.13	–6.21	0	1920	1.8	3	1917
SG	GM21B	162.5	71.74	–5.82	0	1919	3	5	1914
SG	GM22B	110.5	39.58	5.30	7	1906	6	10	1903
SG	GM23A	142	68.92	–11.29	0	1892	1.2	9	1883
SG	GM23B	142	60.90	–3.27	0	1891	0.9	7	1884
SG	GM24B	132	56.32	–2.74	0	1906	2.6	2	1904
SG	GM26A	120	35.41	13.31	15	1926			
SG	GM26B	120	55.01	–6.29	0	1922	2.7	3	1919
SG	GM27B	129	14.82	37.35					

			Age Estimation						
			Missing Length Method				Curvature Method		
Study area[a]	Core ID[b]	Tree diameter	Core length	Missing Length	Missing rings	Center year[c]	Center distance[d]	Missing rings	Center year[c]
CR	GM28B	110	21.61	23.07					
CR	GM28C	110	29.83	14.85	31	1846			
CR	GM29A	117	18.74	28.77					
CR	GM30A	94	19.81	18.39	71	1806			
CR	GM30B	94	4.71	33.49					
CR	GM31B	158	33.50	10.37	16	1894			
CR	GM32A	108	damage						
CR	GM32B	108	44.65	–0.78	0	1826	1.5	5	1821
CR	GM33A	94	9.44	28.76					
CR	GM33B	94	25.87	12.33	28	1857			
CR	GM34A	101	30.75	10.28	22	1846			
CR	GM35A	102	39.97	1.47	3	1852	3.3	5	1850
CR	GM35B	102	41.73	–0.29	0	1853			

[a]SG = Smith Grove, KB = Kimball Bottoms, CR = Cross Ranch; [b]First two letters identify this study, number identifies tree, final letter identifies core within tree; [c]Estimated year of the center ring; [d]Perpendicular distance from the last measured ring to the center of the pith estimated by ring curvature in the core.