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DENDROARCHAEOLOGY OF THE SALT LAKE TABERNACLE, UTAH

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ABSTRACT

We examined tree rings from Douglas-fir (*Pseudotsuga menziesii* var. glauca (Beissn.) Franco) timbers in the Salt Lake Tabernacle, constructed from 1863–1867 in Salt Lake City, Utah. A seismic upgrade to the Tabernacle initiated in 2005 required the replacement of wooden timbers with steel beams. Our objectives were to 1) determine cutting dates for the timbers to identify logs that may have been salvaged from previous structures, and consequently would have greater historical significance, 2) identify the species and provenance of the timbers, and 3) develop a chronology that could extend or strengthen the existing tree-ring record for environmental and historical applications in northern Utah. We built a 162-year floating chronology from 13 cores and 15 cross-sections, crossdated visually using skeleton plots and verified statistically with COFECHA. Statistically significant ($p < 0.0001$) comparisons with established chronologies from northern Utah indicated that the Tabernacle chronology extends from 1702–1862. Cutting dates ranged from 1836–1863, with most in 1862 or 1863 and a smaller cluster around 1855. The broad range of cutting dates suggests that some of the timbers were used in previous structures, and that some trees were dead before they were cut. This study provides valuable information for the preservation of historical materials, and increases the sample depth of existing chronologies during the 18th and 19th Centuries.

Keywords: dendrochronology, tree rings, Salt Lake Tabernacle, bowery, Utah, Mormon, Douglas-fir, *Pseudotsuga menziesii* var. glauca.

INTRODUCTION

Dendrochronology has been used to date prehistoric and historic structures throughout the United States. Several historic structures east of the Rocky Mountains have been dated (*e.g.* Edwards 1982; Stahle 1979; Therrell 2000; Bortolot *et al.* 2001; Wight and Grissino-Mayer 2004), but despite the fact that dendroarchaeology has a rich history in the southwestern U.S. (Nash 1999), few published studies have applied the technique to Anglo historic structures in the Intermountain West (*e.g.* Robinson 1985; Towner and Clary 2001). This may be a consequence of the greater age and historical significance (*e.g.* Cook and Callahan 1992) of such structures in the East. Eastern U.S. trees are usually younger, so tree-ring records preserved in historic structures may be of greater value for paleoclimatic and other applications because of their potential to extend chronologies from living trees (Stahle 1979). Nevertheless, Anglo historic structures in the West represent an underutilized resource that can strengthen existing chronologies and provide useful historical and environmental information.

Tree rings are commonly used to determine dates for timbers used in a given structure. However, dendrochronology can also be used to decipher construction practices and alterations to buildings (*e.g.* Heikkenen and Edwards 1983; Therrell 2000; Wight and Grissino-Mayer 2004). For example, repair or expansion logs may be added after the initial construction of a building, which would be indicated by a large cluster of cutting dates with a smaller cluster or range of more recent dates. Conversely, some structures may be built in part with wood salvaged from previous structures, a common practice in arid, timber-scarce environments. Rusho (2003, p. 173)

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documented one such example from northern Arizona:

> A mining boat named the Nellie had been built… in 1888, then floated down to Lee's Ferry. In 1897, Jim Emett and his son dragged Nellie up to the ranch, dismantled it, and used the boards to enlarge the old Johnson cabin.

This practice would produce a cluster of cutting dates with one to several earlier cutting dates for the salvaged pieces.

The Salt Lake Tabernacle, a 150 × 250-foot domed structure built in Salt Lake City, Utah from 1863–1867, underwent a seismic upgrade beginning in 2005. The renovation called for many original structural timbers to be replaced by steel beams. Historians suspected that some of these timbers had been salvaged from previous structures. Before the Tabernacle was built, several temporary, open-sided "boweries" were constructed, consisting of thatched roofs made of brush and willow boughs supported by wood beams (Anderson 1992). The reuse of timber from these structures in 1857 has been documented: "The need for lumber was acute, so much so that Daniel H. Wells reported they had taken down the Bowery as well as the fences around it… on Temple Square to salvage the lumber" (Keller 2001, p. 67). Moreover, some of the seats in the Tabernacle were reported to have been "taken from the Big Bowery" (Grow 1967, p. 8). Timbers salvaged from other structures would have added historical significance, and would make a stronger case for preservation of the wood, ideally keeping the timbers in their historical context in the Tabernacle. Our objectives were to 1) determine dates for the timbers and gauge the possibility that they may have been used in previous structures, 2) identify the species and provenance of the timbers, and 3) develop a tree-ring chronology that would strengthen existing published and unpublished chronologies in northern Utah.

BUILDING DESCRIPTION AND HISTORY

The Salt Lake Tabernacle is located in downtown Salt Lake City in Temple Square, a popular tourist site (Figure 1). The structure was used primarily for religious meetings until 2000, when a larger building was constructed, and as the broadcast site for the Mormon Tabernacle Choir until 2005 when it was closed for the seismic upgrade. It has also been used as a civic and cultural center (Knowles 1967). The crowning achievement of the structure was the nine-foot thick domed roof, constructed with a lattice of timbers using bridge-building techniques to span 132 feet without the use of supporting piers (Figure 2). The building has undergone several modifications and renovations throughout its history, such as the addition of a balcony, expansion of the basement, raising of the choir seating, replacement of original wood shingles with aluminum, and installation of steel beams and reinforced concrete in some areas (Mitchell 1967; Anderson 1992). However, much of the supporting structure on the west end of the Tabernacle, underneath the speakers' stand, pipe organ and choir seating, still consisted of original, mostly unhewn timbers and brick piers before the seismic upgrade (Figure 3). Given the weight and significance of the organ, one of the largest pipe organs in the world, this was an area of particular concern during the renovation.

METHODS

In 2005, we sampled 21 timbers *in situ* on the west end of the Tabernacle. Core samples were taken from 19 of the timbers using a dry wood borer kit powered by a cordless drill. Cross-sections were taken from four timbers, two of which were also cored. Before sampling, the locations and orientation (north–south, east–west, or vertical) of the timbers were noted, and each one was inspected for the presence of bark, beetle galleries, or an unaltered exterior surface, which would indicate that the terminal ring was still intact. Most timbers were hewn on top and bottom in places, but the sides were usually unshaped. Core samples were taken through existing bark or unaltered exterior surfaces when present, and always on unhewn portions of the timbers. Sample points were marked with indelible ink to determine whether any wood was lost in the sampling process.

All of the original timbers were removed from the building between 2005 and 2006 as part

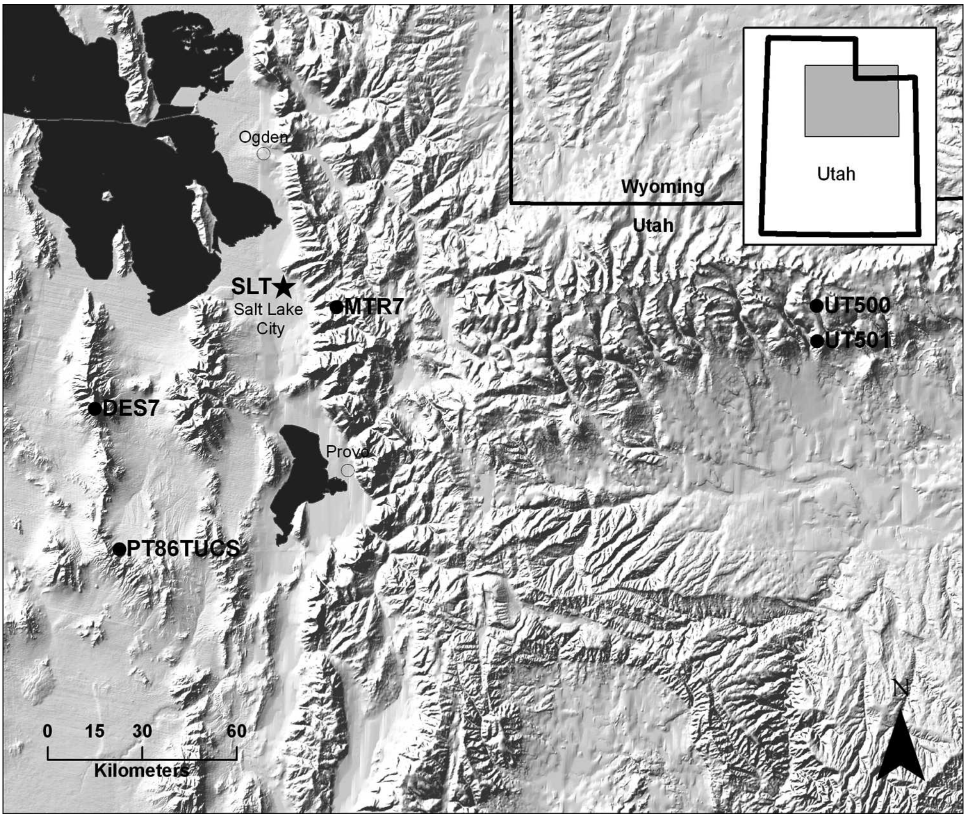

Figure 1. Locations of the Salt Lake Tabernacle (SLT) and sites from which established regional chronologies (see Table 1) used to date the Tabernacle chronology were developed.

of the renovation. In 2006, several of these timbers were reinstalled in the Tabernacle, but 25 pieces of wood were permanently removed. The timbers were not cataloged by renovation crews before removal, so to determine the cutting dates and original locations of these pieces, we sampled (cross-sections) 20 of them and transported the remaining five to the laboratory for analysis. We also removed a core from one of the timbers that had been reinstalled.

All samples were surfaced using belt, disc and hand sanders with successively finer sandpaper, beginning with ANSI 36-grit (500–595 μm) for cross-sections and ANSI 60-grit (250–297 μm) for cores, and ending with ANSI 400-grit (20.6–23.6 μm) for all samples (Orvis and Grissino-Mayer 2002). The species of all timbers was determined to be Douglas-fir (*Pseudostuga menziesii* var. glauca (Beissn.) Franco) through examination of wood color and ring and cell characteristics (Hoadley 1990). The samples were then crossdated with one another using skeleton plots (Stokes and Smiley 1968), and the rings of all samples were measured to the nearest 0.01mm using a Velmex measuring system and Measure J2X® software. The accuracy of the relatively-dated chronology was verified using COFECHA (Grissino-Mayer 2001; Holmes 1983), testing 50-year segments with a 25-year overlap. Smaller segments were also tested, but yielded spuriously low and high correlations for some segments (Grissino-Mayer 2001). To determine absolute dates for the samples we used ARSTAN (Cook and Holmes 1985) to create a chronology from the relatively-dated series, and then used COFECHA to statistically compare the standard chronology with established Douglas-fir chronologies in northern Utah (Harsha *et al.* 1972; Stockton *et al.* 1972; Woodhouse 1988), as well as data from

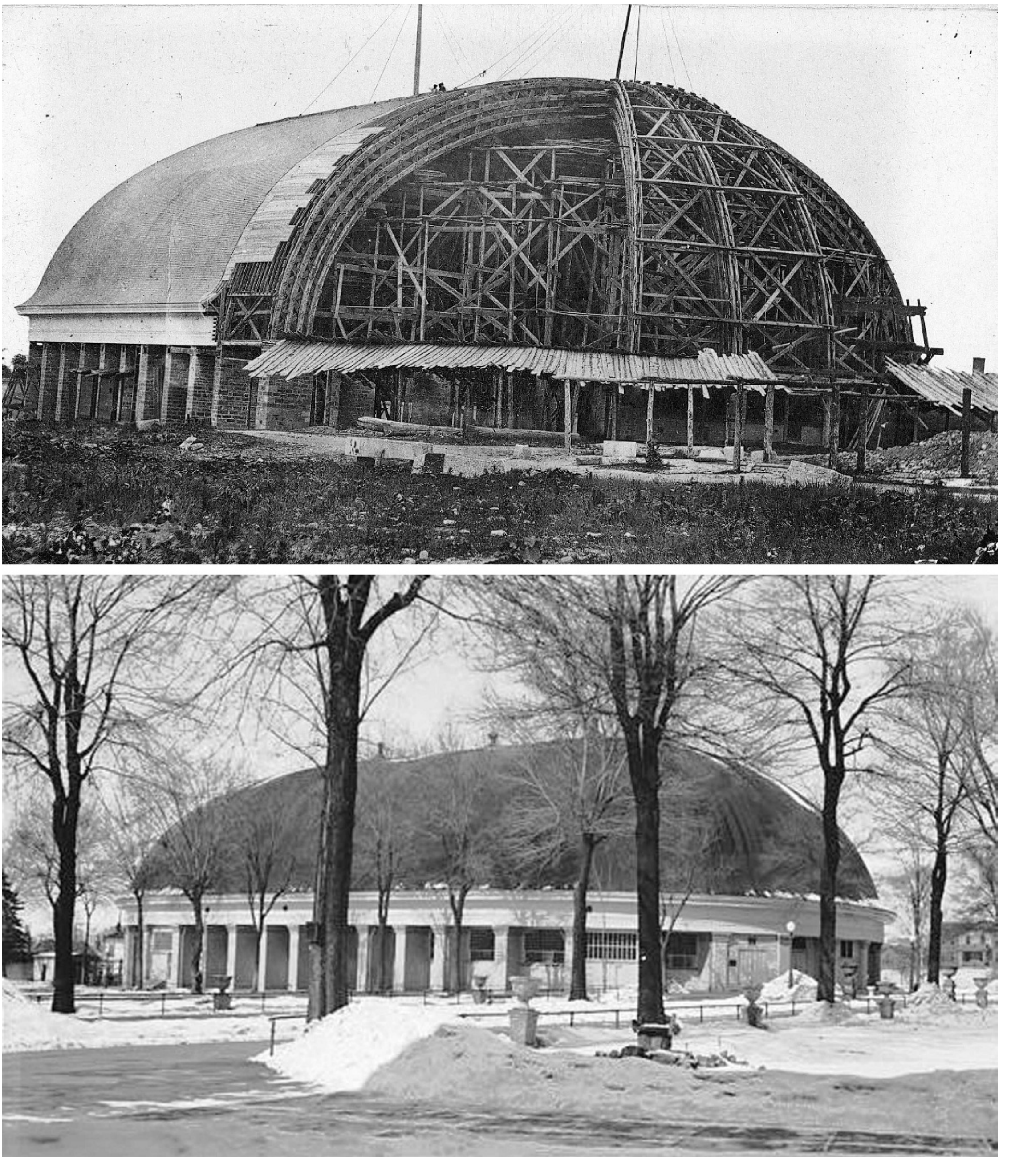

Figure 2. The Salt Lake Tabernacle under construction in the 1860s (top), and in 1937 (bottom). Both views are from the southeast.

the closest grid point from the Cook *et al.* (1999) reconstruction of the Palmer Drought Severity Index (Table 1). The date for a given timber was assigned to the last visible ring on a sample, whether complete or incomplete.

RESULTS

By comparing photographs taken during the first sample collection with external features (*e.g.* paint, hew marks, wood discoloration, etc.) on the

Figure 3. Interior of the Salt Lake Tabernacle underneath the main level, showing original timbers and brick piers (background), along with steel beams from previous renovations.

samples removed from the Tabernacle, as well as analyzing ring characteristics, we determined that 21 of the 49 total samples were duplicates (*i.e.* multiple samples from the same timber and/or tree), and we were able to identify the original locations of many of the removed pieces. The final chronology reported here includes only the remaining 28 samples that appear to be from different trees. All 50-year segments among series were significantly correlated ($p < 0.05$, most at $p < 0.0001$). Correlations (Pearson's r) between each series and the master chronology (consisting of all other samples), were also significant ($p < 0.001$, most at $p < 0.0001$, Table 2), as was the overall interseries correlation coefficient ($p < 0.0001$). No segments were flagged by COFECHA for possible dating errors.

Analysis of line plots and correlation coefficients between the floating Tabernacle chronology and regional chronologies consistently suggested the strongest match with the Tabernacle chronology anchored from 1702–1862. All five chronologies showed positive and significant ($p < 0.01$, most at $p < 0.0001$, Table 1) correlations with the

Table 1. Site information for regional chronologies used to crossdate the floating Douglas-fir chronology from the Salt Lake Tabernacle and correlations (Pearson's r) of each regional chronology with the Tabernacle chronology.

Chronology	Site	Location	Elevation	Species	Range	Corr.	Prob. (p <)
DES7	Stansbury Mtns	40.4°N, 112.6°W	2896 m	Douglas-fir	1187–1986	0.63	0.0001
PT86TUCS	PDSI gridpoint	40.0°N, 112.5°W	—	Several	1650–2000	0.61	0.0001
UT500	Uinta Mtns	40.7°N, 109.9°W	2289 m	Douglas-fir	1730–1971	0.53	0.0001
MTR7	Wasatch Mtns	40.7°N, 111.7°W	2800 m	Douglas-fir	1416–1985	0.42	0.0001
UT501	Uinta Mtns	40.6°N, 109.9°W	2289 m	Douglas-fir	1635–1971	0.27	0.01

Table 2. Descriptive statistics for each series in the Salt Lake Tabernacle chronology tested by COFECHA. Dates are for the last complete or incomplete ring of each series. Sample type codes are C = core and S = cross-section. Terminal ring indicators are: B = bark; G = beetle galleries; L = patina; r = consistent outer ring on partial cross-section; vv = none (noncutting date).

Series	Sample Type	Range (yr)	Length (yr)	Terminal Ring Indicator	No. of Segments Tested	No. of Flagged Segments	Corr. with Master	Mean Sens.
EW2B	S	1765–1846	82	G, L	3	0	0.89	0.33
EW9	C	1782–1845	64	vv	2	0	0.88	0.26
R8	S	1774–1857	84	G, L	4	0	0.84	0.25
NS2	C	1725–1863	139	vv	5	0	0.83	0.31
V2	C	1806–1862	57	vv	2	0	0.81	0.22
R7	S	1733–1863	132	vv	5	0	0.80	0.31
R4	S	1777–1846	70	G	2	0	0.78	0.26
NS4	C	1757–1855	99	B	4	0	0.75	0.19
NS5	C	1762–1853	92	vv	4	0	0.75	0.25
V1	C	1770–1845	76	G	3	0	0.74	0.43
V3	C	1762–1862	101	G, L	4	0	0.73	0.19
EW6	C	1759–1853	95	B	4	0	0.72	0.19
R15	S	1752–1860	109	L	4	0	0.72	0.22
R25	S	1777–1862	86	vv	3	0	0.71	0.26
R10	S	1763–1860	98	G, L	4	0	0.71	0.21
EW3B	S	1762–1836	75	L	3	0	0.70	0.19
EW11	C	1756–1855	100	B	4	0	0.69	0.15
EW12	C	1727–1859	133	B	5	0	0.68	0.16
R6	S	1749–1855	107	B	5	0	0.66	0.18
EW8	S	1741–1858	118	G	5	0	0.64	0.27
EW5	C	1786–1863	78	vv	3	0	0.61	0.17
R1	S	1812–1863	52	vv	2	0	0.61	0.19
V0	C	1815–1863	49	vv	1	0	0.60	0.25
R5	S	1702–1859	158	G, L	6	0	0.57	0.19
NS1	C	1791–1862	72	G, L	3	0	0.53	0.24
R12	S	1822–1863	42	r	1	0	0.52	0.19
R19	S	1719–1856	138	B	6	0	0.52	0.17
R11	S	1818–1863	46	G	1	0	0.52	0.21
Sum:			2552		98	0		
Mean:			91.1		3.5	0	0.70	0.23

Tabernacle chronology from 1727–1862, the period when the Tabernacle sample depth is ≥ 4. Comparisons with the four most highly-correlated chronologies are shown in Figure 4.

Cutting dates ranged from 1836 to 1863, with clusters of cutting and noncutting dates in 1863 (7), 1862 (4), and cutting dates alone in 1855 (3) (Table 2, Figure 5). Nineteen of the timbers included some indicator that the terminal ring was intact, including bark (B, 6), beetle galleries (G, 10), patina (L, 2) or a consistent outer ring along an unaltered exterior surface (r, 1). Seven of the nine samples with no terminal-ring indicators had noncutting dates in 1862 or 1863. Bark dates ranged from 1853–1859, and G, L, and r dates ranged from 1836–1863.

DISCUSSION

The range of cutting dates suggests that many of the timbers had been cut prior to the start of construction of the Tabernacle. Dates for five of the samples, 1836 (EW3B), 1845 (EW9 and V1) and 1846 (EW2B and R4) precede the arrival of Mormon settlers in July, 1847. Bark was not present on any of these samples, but all except EW9 included beetle galleries or patina. It is likely that these trees were dead when cut by the settlers, a practice documented in 1847 (Keller 2001). Alternatively, the trees may have been cut by early explorers in the region, or the Donner-Reed party, which in 1846 was said to have "spent a great deal of time cutting a road through the

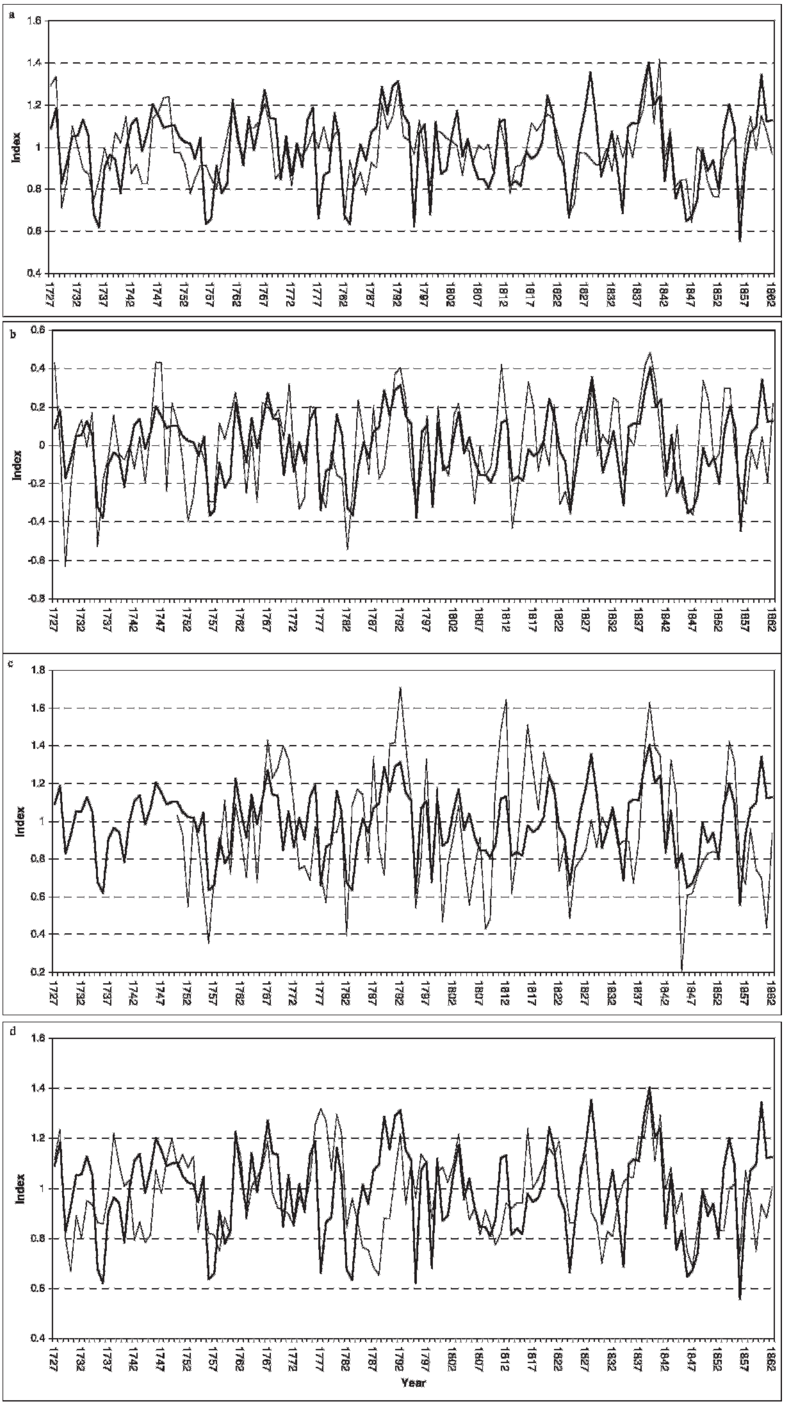

Figure 4. Comparison of the a) DES7, b) Pt86TUCS, c) UT500, and d) MTR7 chronologies (light lines) with the Salt Lake Tabernacle chronology (dark lines).

$183\text{-}\quad \underline{6}$

$184\text{-}\quad 5\underline{566}$

$185\text{-}\quad 3\underline{355567899}$

$186\text{-}\quad \underline{00}22\underline{22}33333\underline{33}$

Figure 5. Stem-and-leaf plot of outer-ring dates from the Salt Lake Tabernacle. The first three digits of each row represent the decade of an outer date, with the individual years represented by the numbers that follow. For example, "184-5566" indicates two 1845 outer dates and two 1846 dates. Underline indicates cutting dates.

thickly set timber and heavy brush wood" (Keller 2001, p. 13) in "Emigration Canyon," the same route used by Mormon pioneers the next year.

The high number of timbers cut before the beginning of construction of the Tabernacle, particularly the cluster in the mid-1850s, suggests that these pieces may have been used in previous structures, most likely one or more of the boweries that were constructed. All but five of the timbers postdate the establishment of the first bowery, completed July 31, 1847. The rapid construction of the first bowery (within one week of the arrival of Mormon settlers) strengthens the possibility that the trees were dead when they were cut, as they would have required less clearing of foliage and less time for curing. The first bowery was replaced by a series of successively larger ones, but the specific dates for the construction of each one is unknown. Nevertheless, given that there is documentation of a bowery on Temple Square being dismantled to reuse the lumber (Keller 2001), and that seats from one of the boweries were used in the Tabernacle, it is likely that as each new bowery was constructed, timbers were incorporated from the previous one as well as adding wood from newly-cut trees, culminating in the inclusion of both recent and successively older wood in the Tabernacle.

The cluster of four cutting and six noncutting dates in 1862 and 1863 is consistent with documented construction dates for the Tabernacle. Most 1863 cutting date samples had incomplete 1863 rings, strengthening the likelihood that this is the actual cutting date, and indicating that were cut during the growing season. The cornerstone laying for the building took place on July 26, 1864 (Anderson 1992), but the foundation was surveyed and completed in 1863, and work began that year on the sandstone piers that would support the roof (Grow 1967). Because the timbers sampled in this study were located in the basement, it would be reasonable to conclude that they were installed early in the construction process. However, much of the interior, including the location of the stand, choir seating, and organ, was not even planned until 1866, when the roof was well under construction (Grow 1967). Thus, the timbers may have not been installed in their final positions until 1866 or later. This suggests that even the timbers with 1862 and 1863 dates had been stockpiled or used for a few years, perhaps as scaffolding during the construction of the roof (see Figure 2).

The timbers used in the Tabernacle may have come from any of several canyons in the Wasatch Mountains that open into the Salt Lake Valley, especially given the range of dates. The canyons closest to the Tabernacle are relatively low in elevation and contained little timber when settlers arrived, but the first documented lumber cut in the area was from City Creek Canyon, only a few kilometers northeast of the Tabernacle (Keller 2001). Within one to a few years, mills were successively established in the larger, more heavily-timbered, and more distant Mill Creek, Big Cottonwood, and Little Cottonwood canyons (Keller 2001). Much of the lumber used in the Tabernacle is known to have come from Big Cottonwood Canyon (Grow 1967; Keller 2001), where logging began in earnest in 1854, but most of it probably consisted of milled timbers, such as those used for the roof, and shingles. The unshaped or partially-hewn logs analyzed in this study likely came from more than one canyon, but some, particularly those with earlier dates, probably were cut from canyons closer to the Tabernacle.

Although established Douglas-fir chronologies in northern Utah extend back to the 12th Century, the Tabernacle chronology does increase the sample depth for these records in the 1700s and 1800s. Moreover, tree rings from historic buildings in mountain environments such as this one may be particularly moisture-sensitive, because early settlers would have cut the most accessible, lowest-elevation trees first. The strong correlation of the Tabernacle chronology with the Cook *et al.* (1999) PDSI reconstruction suggests that these trees were indeed sensitive to moisture. As with many other areas in the United States during this period, logging was carried out indiscriminately, so that there were "precious few trees left" by 1881 (Keller 2001, p. 115). Some moisture-sensitive species may have even been extirpated from the area. "Yellow pine," a common name usually referring to ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), is reported to have been cut from Mill Creek Canyon in 1869 (Keller 2001). This species is no longer found in the Wasatch Mountains near the Salt Lake Valley, although a few individuals exist in the southern portion of the range (Bekker, unpublished data). Douglas-fir is still relatively abundant in the Wasatch, but trees greater than 150 years old are restricted primarily to high-elevation sites (Bekker, unpublished data; Woodhouse 1988), and thus may have a different climatic signal than trees at low elevations. This is illustrated by the relatively low correlation between the Tabernacle and the MTR7 chronology in comparison with the other reference chronologies (Table 1, Figure 1). The MTR7 site is the closest reference chronology to the Tabernacle, but the low correlation suggests strong elevational differences in the response of Douglas-fir to moisture in the Wasatch Mountains. The climatic information contained in the Tabernacle timbers may therefore be particularly valuable, providing a context for understanding environmental conditions during important historical events. For example, ring widths for the years 1846, 1847, and 1848 were the 6th, 10th, and 16th smallest, respectively, in the Tabernacle chronology, and the average width during the 1840s was smaller than in any other decade. Thus, the drought that faced Mormon settlers as they attempted to establish irrigation agriculture in the late 1840s appears to have been particularly strong.

CONCLUSIONS

The Salt Lake Tabernacle is one of the first historic structures dated by dendrochronology in the state of Utah. This study produced valuable historical and environmental information, highlighting the potential for the dating of other historic structures in northern Utah, which would further increase the spatial resolution and extent of tree-ring records, and potentially provide a better understanding of precipitation variability in this region.

Major renovations to historic structures often produce a conflict between structural and historical integrity. The knowledge that some of the timbers in the Tabernacle may have been salvaged from previous structures helped historians to successfully argue for the reinstallation of some of the pieces, thus keeping them in their historical context, although the process was unfortunately carried out with little regard for the historical significance of the timbers or their original positions in the Tabernacle. The knowledge of dates for the pieces that were permanently removed will also aid in decisions of which pieces to preserve, and will facilitate the establishment of museum exhibits. It is hoped that this example will encourage more careful renovations to historic structures.

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