DENDROCHRONOLOGICAL DATING OF THE WORLD TRADE CENTER SHIP, LOWER MANHATTAN, NEW YORK CITY

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ABSTRACT

On July 2010, archaeologists monitoring excavation at the World Trade Center site (WTC) in Lower Manhattan found the remains of a portion of a ship's hull. Because the date of construction and origin of the timbers were unknown, samples from different parts of the ship were taken for dendrochronological dating and provenancing. After developing a 280-year long floating chronology from 19 samples of the white oak group (*Quercus* section *Leucobalanus*), we used 21 oak chronologies from the eastern United States to evaluate absolute dating and provenance. Our results showed the highest agreement between the WTC ship chronology and two chronologies from Philadelphia ($r = 0.36$; $t = 6.4$; $p < 0.001$; $n = 280$) and eastern Pennsylvania ($r = 0.35$; $t = 6.3$; $p < 0.001$; $n = 280$). The last ring dates of the seven best-preserved samples suggest trees for the ship were felled in 1773 CE or soon after. Our analyses suggest that all the oak timbers used to build the ship most likely originated from the same location within the Philadelphia region, which supports the hypothesis independently drawn from idiosyncratic aspects of the vessel's construction, that the ship was the product of a small shipyard. Few late-18th Century ships have been found and there is little historical documentation of how vessels of this period were constructed. Therefore, the ship's construction date of 1773 is important in confirming that the hull encountered at the World Trade Center represents a rare and valuable piece of American shipbuilding history.

Keywords: dendroarcheology, dendroprovenance, eastern United States, oak, *Quercus*.

INTRODUCTION

Since at least the time of early Dutch settlement, shipping was one of the most important economic activities of New York City. In 1647 the Dutch West India Company built the first docks and wharfs in New York (Buttenwieser 1987). In 1664, the English occupied and took possession of New Amsterdam, renaming it New York. In 1686, lands and water bodies within the island were

transferred from the British Crown to the City of New York. Soon after, waterfront property was sold to private owners who in many cases extended their property with landfill. Since that time the coastline around the island of Manhattan has undergone extensive physical alterations (Squires 1992). Cheap and abundant fill materials such as rocks, earth, and refuse, were placed behind wooden barriers or within wood structures to create new land. Earlier wharfs and abandoned merchant ships were often a component of the fill in newly constructed land.

On July 13, 2010, archaeologists monitoring excavation for the Vehicular Security Center at the

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Figure 1. The ship as it was found during excavation for a Vehicular Security Center at the World Trade Center Site in Lower Manhattan. The ship was 6.7 m below current ground surface. Courtesy of the Lower Manhattan Development Corporation.

World Trade Center site (hereafter WTC) encountered the intact remains of a portion of a ship's hull (Figure 1). The vessel remnant was recovered from landfill deposits approximately one city block west of Manhattan's original shoreline at Greenwich Street and approximately 300 m east of the present coastline (AKRF 2013). The World Trade Center was built between 1966 and 1971 by the Port Authority of New York and New Jersey on land that had been filled between roughly 1760 and 1818 CE. The location where the ship was found had been infilled by the 1790s (AKRF 2013). Our hypothesis is that the ship was built in the mid to late 18th Century and was sunk, either deliberately or accidentally, less than thirty years later.

THE IMPORTANCE OF DENDROPROVENANCING FOR MOBILE WOODEN ARTIFACTS

Determining the dates of construction of wooden structures was one of the first applications of dendrochronological techniques (Douglass 1921, 1929). A major limitation of dating shipwreck material is establishing the origin of the timbers used for construction and the shipyard where it was built (Farrell and Baillie 1976). A similar limitation is encountered when dating other mobile wooden artifacts such as furniture or artwork (Haneca *et al.* 2005; Bridge 2012). Thus, determining the timber's origin or provenance is performed simultaneously with the process of correctly dating the ship's

timbers. This process, called dendroprovenancing - the use of dendrochronological methods to identify the region of origin for wooden material - has been successfully used in Europe (Bridge 2012). Success in dendroprovenancing requires a dense network of site regional chronologies for different species from potential areas of origin. Such a network exists for the eastern United States where tree-ring width chronologies have been developed for many sites representing many different tree species (*e.g.* Stahle and Hehr 1984; Stahle *et al.* 1985, 1998; Stahle and Cleaveland 1988; Cook *et al.* 1999; Pederson *et al.* 2012a, 2012b). In addition, previous dendroarchaeological work to date historical buildings in the eastern United States (Grissino-Mayer *et al.* 2012; Therrell and Stahle 2012), including the Independence Hall in Philadelphia, Pennsylvania (Cook and Callahan 1992), has allowed for the extension of tree-ring records both in space and back in time. This kind of network expansion in turn facilitates further dendroarchaeological research (Stahle and Wolfman 1985).

Dendroarchaeology has been a less common practice in the eastern part of the United States than in the Southwest where it originated (Robinson 1976; Stahle and Wolfman 1985; Grissino-Mayer 2009). Although numerous structures have been successfully dated in the eastern United States (*e.g.* Cook and Callahan 2004, 2005; Krusic *et al.* 2004; Grissino-Mayer *et al.* 2012; Therrell and Stahle 2012), few have been published in academic journals or had their findings and data made publicly available (but see *e.g.* Huber (2006), McDonald (2006), and the Boston Dendrochronology Project (http://www.dendrochronology.net/boston_project.asp#)). Similar to the southeastern United States (Grissino-Mayer 2009), the Northeast has often been considered too mesic to develop tree-ring width chronologies that show sufficient agreement with other chronologies at the regional level to be used to accurately and precisely date wood artifacts and structures. However, because there is indeed a pervasive and well-established drought-sensitivity in trees across various ecosystems in the eastern United States (Cook and Jacoby 1977, 1983; Stahle and Hehr 1984; Stahle *et al.* 1985; Cook *et al.* 1999; Pederson *et al.* 2012a, 2012b), including across forest strata and gradients of land-use history (Pederson

et al. 2012b), the eastern United States tree-ring network can be used to date and provenance historic timbers.

Dendrochronological dating and provenancing of recovered shipwreck remains has been performed in Europe to vessels from the Baltic countries (*e.g.* Bonde and Christensen 1993; Daly 2007; Daly and Nymoen 2008) and in one documented instance in North America (Pickard *et al.* 2011). Dendroprovenancing of maritime timbers has also been successfully demonstrated, albeit in the case where the date of construction itself was not in question (Carrell 2003). Here we report on what is, to the best of our knowledge, the first successful application of dendrochronology for dating the remains of a ship on the northeastern coast of the United States. The effort of dating and determining the origin of timbers from a wreck in New York City, one of the world's busiest ports since the 1600s, presents several challenges, not the least of which is the diverse set of possible origins and construction materials for ships trading in the region over the last several centuries.

MATERIAL AND METHODS

The Ship

The WTC Ship was found approximately 6.7 m below current ground surface, oriented east-to-west. The stern section of the hull, which pointed west, was the most intact section measuring 10 m long and 4.5 m wide (Figure 2). The ship had been bisected by a slurry wall built as part of the ongoing construction along the former line of Washington Street. A small section of the bow was later found on the east side of the slurry wall. The ship remnant consisted of the lower hull of a vessel. With the exception of a small orlop deck at the stern end, none of the decks or upper portions of the ship survived. The physical characteristics of the ship remnant, including the broad beam, shallow draft, and forward-stepped mast, appeared consistent with a class of ship known as the Hudson River sloop, designed to transport goods and passengers along the Hudson River (AKRF 2013).

Wood identification analysis showed that a variety of wood types had been used to serve

Figure 2. Vertical 3D laser scanning image of the ship *in situ* World Trade Center Site in Lower Manhattan. The hull of the ship was 10 m long and 4.5 m wide. Courtesy of the Lower Manhattan Development Corporation and Corinthian Data Capture.

particular functions in the ship's construction (Robert A. Blanchette, personal communication September 9, 2010). The keel (the spine of the ship) was made of hickory (*Carya* sp., Figure 4) and the keelson (the member that runs directly above the keel) was white oak (*Quercus* section *Leucobalanus*). The sternpost and stern knee, large timbers comprising the rear of the hull, were also white oak (Figure 4). Likewise, the frames of the ship (the essential structure of the hull, including floor timbers, futtocks, and cant frames) were also white oak. The vessel remnant had two layers of planking: outer planking, which formed the exterior of the hull, and ceiling planking, which formed the interior of the hull. In several locations, sections of the vessel's plank floor appeared to be patched with replacement planks. Sample planks taken for species identification showed that several woods were used, including spruce (*Picea* sp.), pine (*Pinus* sp.), and oak (*Quercus* sp.). The orlop deck was also floored in spruce (*Picea* sp.) planks. All of the major timbers of the vessel remnant were hewn and principally fastened by iron spikes.

Evidence of shipworm infestation was found in many of the ship's timbers. Examination of a sample of the infested wood determined that a single shipworm species was represented, *Lyrodus pedicellatus* (Kevin J. Eckelberger, personal communication; August 6, 2010). *Lyrodus pedicellatus* is a marine bivalve mollusk of the family Terebinidae typically found in warm waters with high salinity. This finding, combined with the absence of

Figure 3. Archeologists carefully labeled and disassembled all individual timbers of the ship. They were packed into storage containers, and transported to the Maryland Archaeological Conservation Laboratory in Saint Leonard, Maryland. Courtesy of the Lower Manhattan Development Corporation.

any shipworm species local to the northeastern United States led to the hypothesis that the larvae may have infested the sternpost when the ship was in the Caribbean (Kevin J. Eckelberger, personal communication; August 6, 2010).

METHODS

Sampling

The archaeologists carefully recorded the vessel remnants *in situ* (Figure 3). Each piece of timber that comprised the structure was labeled with a unique identification number. The hundreds of individual timber elements were then carefully disassembled, packed into a storage container, and transported to the Maryland Archaeological Conservation Laboratory in Saint Leonard, Maryland, where they were submerged in water until sampled. Pieces that were considered to contain a reasonable number of growth rings were selected for sampling. Samples were taken from the mid-section of each piece after wrapping them with duct tape to ensure their stability. A chainsaw was used to cut radial sections from 23 of the logs (see C-SPAN Video Library: World Trade Center Ship. URL: <http://www.cspanvideo.org/program/CenterSh>). Because all pieces were water logged, they were slowly air dried under cool temperature, to avoid cracking associated with rapid shrinking, before any further preparation. Another potential complication with dating submerged, historical samples is that the wood could have decomposed to such a

degree that the structure of the wood would be too degraded for processing. Therefore, strongly decayed pieces were first glued onto wood boards in order to protect them while handling. None of the samples presented any evidence of bark; however, nine samples had sapwood rings (Figure 4), which would suggest that the last dated ring is near the felling date of the tree. Seven samples showed evidence of being squared prior to construction of the vessel, which reduces the amount of rings present and thus the probability of finding the last ring formed before felling (Miles 1997).

Measuring and Crossdating

After drying, the samples were sanded with progressively finer sandpaper until growth rings were clearly visible (Krusic *et al.* 1987). Two radii per section were marked along the radial transects containing the maximum number of growth rings and visually crossdated to ensure within-tree relative dating for all the rings in each sample (Stokes and Smiley 1968). Tree-ring widths on all samples were later measured to the nearest 0.001 mm using a Velmex measuring stage. Internal crossdating of the two radii within each sample was verified using COFECHA (Holmes 1983). Radii from different samples were also relatively dated between themselves. We created the “ship chronology” from the relatively-dated series using ARSTAN (Cook, Krusic, Holmes and Peters, version 41d, www.ldeo.columbia.edu/trl) by detrending each series using flexible cubic smoothing spline with a 50% wavelength cutoff at 32 years to remove age-related trends and the possible effect of stand dynamics and to leave most of the high frequency variability in the time series. These detrended series were averaged using a biweight robust estimation of the mean to create a mean WTC chronology.

Fortunately, all but one of the timbers sampled were identified as oaks from the white oak group (*Quercus* section *Leucobalanus*). Having multiple samples of oak for comparison improves the likelihood of dating archaeological timbers of unknown site origin. Perhaps just as important for provenance work, the keel of the vessel was

Figure 4. Oak, *Quercus* sp., sample (A) and hickory, *Carya* sp., keel sample (B). Box in image (A) shows the general slow growth of these trees, suggesting they most likely originated from old growth forests.

Figure 5. Top, bar graph of time spans for all WTC ship timbers dated. Bottom, plot of the 19 ring-width indices from the WTC ship oak samples (black) and their mean (red; 280 years; time span: 1494–1773). The strong mean interseries Spearman rank correlation (0.458; $p < 0.001$) suggests a common geographical origin for all the timbers. In both graphs, results for the keel (hickory) are shown in dashed purple.

identified as a hickory (*Carya* sp.), what we believe to be shagbark hickory (*Carya ovata* (Mill) K. Koch). The presence of hickory greatly reduces the possible provenance to the eastern United States or to East Asia (Manos and Stone 2001), the latter of which is unlikely. Therefore, the WTC resulting residual chronology from ARSTAN containing all successfully crossdated samples was used for absolute dating by comparing it with master tree-ring width chronologies for white oaks from 21 different sites across the northeastern United States (Figure 6) using COFECHA. We limited this analysis to master chronologies dating back at least to the year 1650 CE. Chronologies from several sites were used in an attempt to identify the geographical origin of the wood sample and, in all likelihood, the site of construction of the ship (Bridge 2012). In all cases, we tested 50-year successive periods with 25-year overlaps against the reference master chronologies using the nonparametric Spearman rank correlation coefficient with significance level of $p = 0.05$.

RESULTS

There were several limitations to the dating of the World Trade Center vessel timbers. First, the keel, keelson, and seven other timbers were squared off prior to construction. Because of this, there was only a small chance that the last ring formed prior to felling was present on these timbers. Second, although nine samples show signs of curvature and sapwood rings (between 6 and 41; Table 1), which are indicative of the outer surface of a tree stem, no samples were found to have intact bark. Bark is commonly removed during construction or lost after long periods of submersion under water. Third, the sapwood rings in some samples were distorted by waterlogging and were either uniformly extremely narrow or wide with little inter-annual growth variability (Figure 4). These ring patterns reduced our ability to date the outermost rings. The rotten condition of sample CN-5-1, in particular, did not allow for sanding or measuring and was therefore removed from further analysis.

Table 1. Internal dendrochronological dating results for samples taken from the excavated WTC ship. All correlations (R) are Spearman rank correlations of each individual series against the WTC chronology (built with all other series). The keel was dated against the chronology developed from the WTC oak samples. See Figure 5 for a summary plot of the dating results for all dated samples. Bark edge was not recovered or was completely missing on all the timbers.

Sample	Species	Observations	Series			Years Compared			R	T	p value
			FY	LY	N	FY	LY	N			
FN16-1	Oak	SWR (15)	1663	1773	111	1663	1770	108	0.44	5.02	<0.001
FS13-2	Oak	SWR (22)	1688	1770	200	1688	1770	83	0.49	5.09	<0.001
FS11-2	Oak	SWR (41)	1571	1770	202	1571	1770	202	0.45	7.08	<0.001
FS15-2	Oak	SWR (21)	1682	1770	89	1682	1770	89	0.36	3.55	<0.001
FN15-1	Oak	SWR (31)	1627	1769	143	1627	1769	143	0.46	6.22	<0.001
FN15-1/1	Oak	SWR (19)	1662	1764	103	1662	1764	103	0.32	3.37	<0.001
FS10-2	Oak	SWR (18)	1689	1762	74	1689	1762	74	0.55	5.54	<0.001
FS9-2	Oak	SWR (6)	1680	1743	64	1680	1743	64	0.46	4.11	<0.001
Keelson	Oak	SQ	1639	1740	102	1639	1740	102	0.43	4.78	<0.001
OUT-8	Oak	SWR (18)	1641	1732	92	1641	1732	92	0.58	6.78	<0.001
CN3-1	Oak		1662	1732	71	1662	1732	71	0.43	4.01	<0.001
FS12-2	Oak	SQ	1600	1723	124	1600	1723	124	0.54	7.10	<0.001
OUT-W	Oak		1660	1721	62	1660	1721	62	0.39	3.27	<0.001
PS1-1	Oak	SQ	1665	1716	52	1665	1716	52	0.46	3.71	<0.001
CN6-1	Oak	SQ	1644	1705	62	1644	1705	62	0.38	3.22	0.001
PS2-1	Oak	SQ	1602	1687	86	1602	1687	86	0.64	7.63	<0.001
PN2-1	Oak	SQ	1559	1685	127	1559	1685	127	0.61	8.71	<0.001
CN3-10A	Oak	SQ	1542	1681	140	1542	1681	140	0.59	8.69	<0.001
CN-1/1	Oak		1494	1650	157	1542	1650	109	0.20	2.12	0.018
CN-5-1	Oak		n.d.	n.d.	NA	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
OUT ?	Oak		n.d.	n.d.	83	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
FN-11-1/1	Oak	SQ	n.d.	n.d.	99	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Keel	Hickory	SQ	1581	1724	144	1581	1724	144	0.25	3.06	0.001

FY = first year; LY = last year, N = number of years compared; R = Spearman rank correlation coefficient; T = student's t-test; SWR = sapwood rings present (number of sapwood rings in parenthesis); SQ = squared timber. n.d. = no date; NA = not applicable because the conditions of sample CN-5-1 did not allow for sanding and ring counting.

Slightly more than 50% of the samples (12 of 23) had fewer than 100 rings (Table 1), which is *ad hoc* considered the minimum desirable number of rings for crossdating historical or archaeological timbers in the eastern United States. Nevertheless, tree-ring patterns in 19 sampled timbers had statistically significant internal crossdating with correlations to the WTC master chronology ranging from 0.20 to 0.62 (all significant at $p \leq 0.05$; Table 1). There were two oak samples (OUT? and FN-11-1/1) that did not yield any conclusive dating against this local chronology despite having 83 and 99 rings, respectively.

Because of the unknown provenance of the timbers, we first attempted to identify the area where they may have originated. In order to do this, we correlated the portion of our WTC

chronology consisting of 5 or more series (*i.e.* 170 years from 1599 to 1769), against 21 chronologies from the eastern United States. The highest correlation coefficient was with a chronology developed with historical timbers from the Philadelphia area ($r = 0.36$, $t = 6.40$; $p < 0.001$; $n = 280$) followed by a chronology from eastern Pennsylvania ($r = 0.35$; $t = 6.30$; $p < 0.001$; $n = 280$). (Table 2; Figure 2). In general, correlations were similar and significant with all but one of the chronologies from the Pennsylvania-New Jersey-Southern New York (PANJNY) area (Table 2; Figures 6 and 7). In contrast, correlations with chronologies from the northern Hudson Valley yielded non-significant coefficients, as was also the case for other sites to the south and west of the PANJNY area.

Table 2. Correlations of the WTC ship oak chronology versus long white oak (*Quercus alba*) chronologies from the eastern United States. See Figure 7 for a map of correlations. Correlation values are Spearman rank correlation coefficients. Chronology sites are in decreasing order of student's t statistic.

Master chronology	Years Compared			R	T	p value	Lat	Lon	Source ¹
	FY	LY	N						
Philadelphia	1494	1773	280	0.36	6.40	<0.001	40.04	75.16	3
Eastern Pennsylvania	1494	1773	280	0.35	6.30	<0.001	40.00	75.30	2
Hutcheson Forest Historic	1494	1773	280	0.32	5.60	<0.001	40.3	74.34	2
Utertown	1494	1773	280	0.29	5.10	<0.001	41.19	74.42	1
Hudson Valley	1563	1773	211	0.29	5.00	<0.001	41.46	74.08	2
Mohonk Preserve	1494	1773	280	0.27	4.70	<0.001	41.74	74.19	1
Eastern New Jersey	1620	1773	154	0.33	4.20	<0.001	40.30	74.34	2
Eastern Massachusetts	1494	1773	280	0.24	4.10	<0.001	42.30	71.3	2
Schunemunk Mountain	1648	1773	126	0.21	3.58	<0.001	41.39	74.11	1
Alan Seeger Nat. Area	1516	1773	258	0.19	3.20	<0.001	40.72	77.75	ITRDB
VA011	1554	1773	220	0.18	3.07	0.001	37.23	80.30	ITRDB
VA017	1572	1773	202	0.20	2.90	<0.001	37.55	79.48	ITRDB
Albany	1710	1773	64	0.13	2.24	0.013	42.40	74.00	2
VA014	1615	1773	159	0.11	1.89	0.030	38.30	78.21	ITRDB
Albany historic	1507	1773	267	0.11	1.77	0.039	42.40	74.00	1
OH003	1666	1773	108	-0.09	1.57	0.941	39.54	84.24	ITRDB
OH006	1628	1773	146	0.08	1.26	0.104	39.59	81.00	ITRDB
OH001	1629	1773	145	0.06	0.98	0.164	40.53	81.45	ITRDB
PA006	1662	1773	112	0.06	0.97	0.166	41.19	79.13	ITRDB
NC007	1620	1773	154	0.05	0.76	0.225	35.53	81.56	ITRDB
Prospect Mountain	1659	1773	115	0.04	0.67	0.250	43.50	73.62	1

FY = first year; LY = last year, N = number of years compared; R = Spearman rank correlation coefficient; T = student's t-test; Lat = latitude (°N); Lon = longitude (°W).

¹ Sources: 1 = Pederson *et al.* (2012a), 2 = E. Cook, 3 = Cook and Callahan (1992); ITRDB = International Tree-Ring Data Bank.

The strongest evidence for the felling date of the trees prior to construction was found in sample FN-16-1 whose last ring was dated to 1773 (Tables 1 and 2). In addition, there were three other samples dating to 1770 and one dating to 1769. The presence of sapwood in these four samples suggested a close proximity to the missing bark and thus to the cutting year. In contrast, the

Figure 6. Comparison of the ring-width index of the WTC ship oak chronology (19 samples crossdated) against the Philadelphia area oak master chronology based on living trees and independent archaeological samples. The Spearman rank correlation between the series ($r = 0.36$) is highly significant ($t = 6.3$; $p < 0.001$) with an overlap of 280 years. This strong match suggests that the origin of the oak logs used in the WTC ship was from the Philadelphia area.

Figure 7. Map of the northeastern United States showing the strength of the WTC ship chronology (green triangle) against site white oak master chronologies. Dot size is proportional to the strength of the t-test value for significant correlations ($p < 0.01$). Chronology sites with non-significant correlations (n.s.; $p > 0.01$) are marked by black squares. Higher correlations with master chronologies in eastern Pennsylvania suggest the trees used for building the WTC ship grew in that area.

earliest outer ring date found was 1650 in sample CN-1/1. This sample did not have sapwood rings and could be missing an unknown number of heartwood rings. In general, samples from timbers that had been squared for construction and had no sapwood rings yielded earlier dates than those with sapwood rings.

Finally, although the keel was a different species (*Carya* sp.) than the rest of the samples, we did attempt to crossdate it against the WTC chronology. Although there is some confidence in an outer date of 1724 for the keel, the statistics are weak ($r = 0.25$) and the date should be considered provisional until more hickory chronologies covering the mid-17th Century become available for the eastern United States.

DISCUSSION

Dendroprovenance

A ship mainly built with timbers from the white oak group and found in New York City could have many possible origins. Oak species of *Quercus* section *Leucobalanus* thrive in different parts of the world and include some of the most widely used timber oak species such as *Quercus alba* L. (East North America), *Q. petraea* (Matt.) Liebl and *Q. robur* L. (Europe and West Asia) or *Q. aliena* Blume (East Asia) (Nixon 2006). From the 17th Century onwards there was constant traffic across the Atlantic Ocean, so the WTC ship could have been built at a shipyard in either Europe or North America. At least one study has documented a 17th

Century ship wrecked off the North American coast and built with oaks from western France (Carrell 2003). The presence of an essential piece of the ship like the keel made of hickory, however, indicates that the place of construction for this ship is likely to be the eastern United States. It is estimated that by the 1770s at least 40% of all British ships were built with American timbers (Williams 1992; p. 93), but the possibility remains that the original keel had been replaced with American timbers. Therefore, we focused dating the WTC timbers against site master chronologies from the eastern United States.

Our results showed the strongest agreement between the WTC chronology and two master white oak (*Q. alba*) chronologies from Philadelphia and eastern Pennsylvania (Table 2; Figure 7). Lower but significant correlations were found with master chronologies in New Jersey and Southern New York. The lack of correlation with the northern Hudson Valley and eastern New York chronologies is intriguing in that those chronologies are only 300–400 km from Philadelphia. The lack of correlation here, compared to stronger correlations in central Pennsylvania and central Virginia, could arise from a fairly sharp climatological boundary in the northern Hudson Valley. This finding would corroborate a changing climatic response in *Q. alba* moving up the Hudson valley (Pederson *et al.* 2004). The individual series correlations of the WTC samples with the WTC chronology suggest that most if not all of the timbers used to build the ship came from the same forest in the Philadelphia area.

The very narrow tree-ring widths found in the analyzed samples (with an overall mean and standard deviation of 1.05 ± 0.06 mm year⁻¹; Figure 4) suggest the trees originated from dense old growth forests. These primeval forests were substantially affected by European settlers as early as the 17th Century (Williams 1992). In this period logging was typically carried out first along the major waterways and the coast before continuing further inland.

Dating

According to the outer rings of seven dated samples (Table 1), the construction date of the

ship was most likely 1773 or soon after. Although we did not observe bark in any samples, the seven samples dating to 1762 or later had between 15 and 41 sapwood rings, suggesting that relatively few rings, if any, were missing from the outer part of the timbers (Hughes *et al.* 1981). These results would support the hypothesis of an early 1770s construction date for the ship. Assuming that few rings are missing from the edges of two samples dating to 1732 and 1743, it would suggest that the timbers might have been obtained from already dead trees or older timbers may have been reused (Farrell and Baillie 1976). Further, sample OUT-8 (dated to 1732) was dislocated from the ship remnant when it was found and although it appeared to represent a displaced ship frame, it is possible that the sample was not in fact part of the ship. The rest of the timbers, with outer dates back as early as 1650, had been squared prior to construction; no waney edge or sapwood rings were present in these samples. Therefore, the outermost tree rings from these samples can be interpreted only in support of a *terminus post quem* (earliest possible) construction date of 1773. The latest possible period of construction would be the 1790s, when the site where the ship was uncovered had been filled in (AKRF 2013). Assuming the older date of 1773 as the date for the felling of the trees, we can conclude a construction date of the mid to late 1770s, allowing for a few years for the seasoning of the wood (Farrell and Baillie 1976). These results would indicate that the vessel was in operation for at most 20 to 30 years before being abandoned or sinking in what was then a harbor on the west side of Lower Manhattan.

A close examination of the WTC ship chronology and the Philadelphia master chronologies shows two simultaneous reductions of growth in the late 1660s and 1690s supporting the hypothesis that the trees used to develop both chronologies originated from the same locality. Most likely the shipyard where the ship was constructed was close to where the trees were felled. This evidence appears to support a hypothesis put forth by Norman Brouwer (AKRF 2013), who stated that based on certain idiosyncratic aspects of the vessel's construction, it may have

been built at a small rural shipyard rather than a large, established, and well-financed shipyard (AKRF 2013). A small shipyard may have been more likely to take limited timber stock from a single geographic location for the construction of a vessel. According to Scharf and Westcott (1884), shipbuilding was an important industry in eastern Pennsylvania and Philadelphia from as early as 1693 through the 1770s. In 1698, the shipyards in the city were observed to “have very stately oaks to build ships with” and that “logs of pine, hemlock, and oak are cut for ship frames, and wharf timbers” (Scharf and Westcott 1884; p. 2336, 2244), suggesting that at the time adequate timber for ship-building was almost certainly available in the Philadelphia area.

Our dendrochronological analysis provides a number of crucial insights into the history and origin of the World Trade Center ship. First, it provides an approximate construction date for the ship. In North America, few 18th Century ships have been found and little historical documentation survives of how vessels of this period were constructed. Therefore, confirmation of the ship’s date was important in establishing that the hull uncovered at the World Trade Center represented a rare and valuable piece of shipbuilding history in the United States. The construction date of 1773 or soon after and the history of Manhattan indicate that the ship had a short life span before becoming part of the landfill. Hard use, repairs, and shipworm infestation may have contributed to the ship’s demise. Evidence that the vessel may have made at least one trip to the Caribbean suggests that, although the ship was constructed for use in a river environment, it may have actually been used to transport cargo much farther afield, possibly undermining the condition of the vessel. The dendrochronological analysis also confirmed the American origin of the timbers, and yielded evidence that it was most likely built in the Philadelphia area. Lastly, the analysis suggests that the oak timbers used to build the vessel frame likely originated in the same specific location, lending credence to the notion that the ship was the product of a small shipyard.

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