Swedish Granary/Atlantic White Cedar Project
Cumberland County Historical Society
Greenwich, NJ

Dendrochronology Report:
Creating an AWC historical master chronology and the dating of the Granary

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Note concerning the following texts: This document specifically addresses those developments that have occurred in the project to utilize dendrochronology to date the building known as the Swedish Granary since a progress report was issued in November 2014 describing the first phase efforts and results. With minor redactions for clarity, in order to provide background some introductory and methodological texts are reproduced here, in the applicable sections, from the "Dendrochronology Progress Report" submitted by the authors in November 2014 to the Cumberland County Historical Society. Within the review section outlining the results of the "Phase 1" preliminary efforts, some selected texts, tables and graphs are likewise reproduced in part. For more extensive details than are reproduced here regarding the first phase and its conduct and results, see the 2014 report available in full from the website of the Cumberland County Historical Society. - http://www.cchistsoc.org/pdf/Dendrochronology Progress Report.pdf

Introduction

In August, 2008, while engaged on an independent project studying other sites in the vicinity, dendrochronologists William Callahan and Dr. Edward Cook were asked to assist in the evaluation of a structure identified as being of historical importance. They therefore collected 10 wood core samples from a whole log building known as the "Swedish Granary", presently located on the grounds of the Gibbon House at 960 Ye Greate Street, Greenwich, NJ 08323.

In 1973 this structure was identified by G. Edwin Brumbaugh, FAIA, and Albert F. Ruthrauff, AIA, as being of early Swedish settlement origin, and they suggested a construction date of circa 1650, speculating that it might have functioned as a grain storehouse. Also proposing an early Swedish colonial origin for the building were Carl & Alice Lindborg, who referenced the work of Dr. Amandus Johnson, author of “The Swedish Settlements on the Delaware, vols. 1&2” (1911). At the time a decrepit farm outbuilding standing in Lower Hopewell Township, the Granary was strapped together, trucked, and transported in whole to and restored at its present site in 1976. A new shingle roof was laid down as part of the renovation. It is currently owned and maintained by the Cumberland County NJ Historical Society (CCHS).

The logs used in the construction are Atlantic White Cedar (*Chamaecyparis thyoides*), a species indigenous to a narrow coastal region along the Atlantic seaboard, growing in fresh water swamps and bogs. Although commonly called "Atlantic White Cedar", it is horticulturally not a cedar but a cypress. However, throughout this report the common name will be employed, often shortened for convenience to AWC. The wood is lightweight, easily worked and highly resistant to decay, and in southern New Jersey was used for shingles, barrels, siding, boats, and occasionally as primary timber for construction.

The 2008 field sampling of the Swedish Granary resulted in ten wood cores of good quality, but laboratory analysis afterward was unable to provide dates for the materials. To make precise dendrochronological datings it is necessary that the field samples be correlated with an absolutely dated "master chronology" (aka "absolute chronology" or "standard chronology"), which specifically identifies each calendar year. This master chronology must be compiled purposefully and in advance, of multiple samples of the same species sharing the same ecological region. In the case of the Swedish Granary, no such master existed at the time, and therefore no dendrochronological datings were possible.

Although the 2008 sampling did not succeed in providing dates, awareness of the potential of dendrochronology to contribute empirical evidence to the debate about the age of the Swedish Granary remained. It was realized that the absence of a regional master chronology had precluded successful analysis, and that a targeted effort could redress the limitation: if a master chronology for AWC could be compiled, then an absolute dating of the timbers used in the construction of the Swedish Granary could be possible. To that end, in 2013 the Cumberland County Historical Society NJ applied to and was granted funding from New Jersey Historical Commission to support the creation of an AWC master chronology, with the intention of dating the Swedish Granary. Moreover, it was understood that the project, if successful, would make possible absolute dating of other historical AWC structures in the region.

Dendrochronological Theory and Methodology

The word dendrochronology derives from Greek dendron/tree + kronos/a space of time. That trees develop annual growth rings in response to ecological conditions, and that these growth rings can be used to align wood specimens chronologically, is an old concept. In the 3rd century B.C. the

Greek botanist Theophrastus speculated on the correspondence between ecological factors and tree-ring development, and Leonardo da Vinci noted in the 15th century that the ring growth patterns of newly felled trees reflected weather variations that he remembered from his youth. In 1737 French naturalists Duhamel and Buffon performed a "crossdating" of tree rings based upon a severely frost damaged growth ring caused by an unusually harsh winter in 1709.

But it wasn't until the 1920's that dendrochronology began to be utilized in a formally scientific manner. An American astronomer, A.E. Douglass, was searching for correspondence between weather and sunspots, a solar activity that occurs with more or less cyclical regularity. He hoped to trace the effects of sunspots in tree rings, which he knew constituted an acceptable record of past climatological conditions. Although not successful in this experiment, Douglass noted that similar growth patterns appeared in wood samples collected throughout a very wide area in southwestern USA. In many cases the patterns of even geographically distant samples could be positioned upon each other like a jigsaw puzzle, some pieces longer and some shorter, eventually producing an overlapping collection - a "chronology"- that stretched much farther in time than any one sample.

In theory dendrochronology is simple. Trees expand around their outer diameter as they grow, and normally each year's expansion becomes visible in the wood as a single ring. Ring development is a very complicated response to local growth conditions, including factors such as temperature, precipitation, species, soil type, variations in sun, wind, etc.; in general, good ring growth reflects good conditions and bad growth bad conditions. By measuring the size of the annual rings, i.e., measuring the change in ring width from year to year, a pattern of growth over time can be established. In theory, all of the trees in an ecological region share similar growth conditions and consequently all should produce similar annual ring patterns, allowing comparison of their measured patterns with each other. In actual practice, measurement series from contemporary samples can vary greatly and even duplicate series from the same tree are never precisely alike. Comparison can prove extremely difficult or even impossible to accomplish.

Dating a sample requires not only a quality measurement but also the previously executed compilation of local growth patterns over time, the "master" or "standard" chronology. This compiled measurement represents the mean growth rates for the species and region under study, and is created by overlapping, more correctly crossdating, measurements from a large number of samples. Generally this process is begun using samples from living trees, for obviously their outermost rings are of known date. Specimens are collected from progressively older sources, from buildings or art objects or sub-fossil logs, etc., which are then measured and mathematically overlapped upon the measurements from the living trees and from each other. As this process continues, a chronology longer than any single sample is constructed, stretching back in time and absolutely dated by the samples taken from the living trees.

To illustrate simply, assume for example that a researcher in 2010 takes samples from a grove of 200-year old trees. The measurements of these annual growth rings thus represent the years 1810-2010. Samples from a nearby structure built in 1910 with 200-year old trees are collected, measured, and added to the ones from the living tree samples. With a 100-year overlap between them (1810-1910), a new mathematical mean is calculated from the two sources and the revised master chronology now covers 1710-2010. Another structure is sampled, this one built in 1810 with 200-year old trees, supplying timbers with an overlap of 100 years on the early portion of the master (1710-1810), and again the measurements are compiled and a revised mean calculated. Now the master chronology covers 1610-2010. This process is repeated until there are no samples older than those earliest in the master chronology. In this way some chronologies, for certain species in certain regions, have been produced that exceed 10,000 years in length.

Douglass was able to compile a very long master chronology for a species of pine found in America's Southwest, with each calendar year on the the chronology represented by multiple individual measurements compiled into the standardized mean measurement of growth. He hypothesized that since each ring in the master represents a single year of growth, any independent pattern that could be successfully compared to it could be assigned to a specific year by its last growth ring. Douglass used his master chronology to date to the 13th century A.D. samples from various abandoned Indian dwellings in Arizona and New Mexico. After publication of his results, dendrochronology received widespread attention in the scientific community. Standardized in practice and computerized to assist with processing the mathematics, modern dendrochronology is practiced worldwide, assisting not only archeology and architecture, but art history, climatology, geology, hydrology, vulcanology, et alia.

Modern dendrochronology relies heavily on statistical evaluations to aid in synchronizing crossdating positions between series, and to determine the strength of correspondence between them. Specialized computer programs evaluate the massive amounts of mathematical data, sometimes involving thousands of individual series comprising millions of data points, and establish positions of correspondence exhibiting high degrees of statistical similarity. It is the responsibility of the dendrochronologist to evaluate this information, for in practice random statistical correspondence between series may occur at multiple positions, and these "false positives" must be recognized and disregarded.

The wood samples themselves are collected using a variety of techniques, the particular manner dictated by the type of object. Most commonly samples are taken using specially designed and manufactured drill bits, which extract thin cores efficiently and with negligible harm; aesthetic considerations can be satisfied by carefully selecting locations for drilling. Occasionally an artifact can be taken whole for measurement in the laboratory, or if permissible a piece may be sawn and removed. Measurement in place can be done using a handheld loupe after some surface preparation, but this method is extraordinarily time-consuming and inevitably yields imprecise data sets, and so is used very rarely.

In the laboratory the samples are assigned identity numbers and the surfaces carefully prepared to allow accurate measurement. Each sample is examined ocularly on a geared and movable stage that passes under a microscope, the operator controlling the speed and distance of the movement. As it passes under, the researcher uses crosshairs in the reticle to measure the breadth of each growth ring on the perpendicular, to a precision of .001mm, and the width is recorded. A single sample may contain hundreds of rings, some wider than 10mm -a centimeter- and some as small as .002mm - only one or two cells wide. The measurements are entered into the computer database, easily manageable and accessible.

Phase 1 of the AWC Project: Review

One inescapable circumstance guided the initial organization of the AWC Project: without a functional master chronology for comparison, no dendrochronological dating of the Swedish Granary could be possible. Therefore, development of a suitable standard chronology for Atlantic White Cedar (*Chamaecyparis thyoides*) for dating historical structures in southern New Jersey was essential. A complex undertaking, it would be necessary to locate multiple regional sources of both living and historic AWC, sufficient in quality and quantity to provide the materials for compiling a viable and representative mean. Living AWC, preferably trees 200+ years old, had to be found and sampled, and compiled into a viable "live tree" master that would secure the outermost year of the chronology. Older sources, specifically historic structures, had to be located and sampled, and they had to provide material of such quality and age that the individual "site chronologies" could overlap the earlier portions of the "live tree dating master" with minimally a statistically significant 50+ years. Furthermore, the various historic sites had to be synchronized and overlapped with each other, in order to extend the master in an unbroken chronological chain sufficiently far back in time to traverse the potential age of the Swedish Granary. In short, a sequential series of measurements had to be created, affixed in live trees and continuing uninterrupted back to approximately 1550, a period covering the purported age of the Granary.

Following extensive planning, field work began in May, 2014. Together with associates from CCHS familiar with local geography, history and flora, over a period of several months Callahan & Cook made more than 20 exploratory and sampling visits to the SW New Jersey region, visiting dozens of historical sites and collecting samples whenever the AWC material was judged promising (see Table 1). In addition, samples were collected from multiple stands of living trees in state forests and from sub-fossil (i.e., dead and fallen) trees found at various locations. Not all the collected specimens could be utilized, as ultimately many were rejected after examination in the laboratory due to the poor physical quality of the wood, and/or because they had too few rings to ever reliably support statistical evaluation. Moreover, during a conversation with his colleague Nicole Davi, a researcher at the Lamont-Doherty Tree Ring Lab and William Patterson University, Dr. Cook discovered that in 2000 she had sampled some living old growth AWC trees in NJ together with Stockton University colleagues, and that these measurements, some extending back to 1790, could be utilized in the on-going AWC project.

Table 1

1) Moses Crossley House, Cape May Court House, NJ
2) Caesar Hoskins House, Mauricetown NJ
3) ⇮ Veale-Sewall Cabin, Upper Hopewell, NJ
4) Reeves-Iszard-Godfrey House, vicinity Seaville, NJ (originally located in Middle Township)
5) ⇮ Historical Society Museum Barn, Cape May Court House, NJ
6) ⇮ Swing Family Cabin, Mannington, NJ
7) Seaville Quaker Meeting House, Seaville, NJ
8) ⇮ Stites Barn, John Gandy Homestead, vicinity Greenfield, NJ
9) ⇮ Falkenburge Barn, South Dennis, NJ
10) Schorn Cabin, Swedesboro, NJ
11) Hope House, vicinity Nesco, NJ
12) Richard Townsend House, Middle Township, NJ
13) Penny Watson House, Greenwich, NJ
14) Fred Peech Barn, Marmora, NJ
15) Inn at Historic Cold Spring Village, Lower Township, NJ (originally in Dennisville, NJ)
16) Swedish Granary, Greenwich, NJ (originally located in Lower Hopewell Township)

Table 1. Historical sites and structures from throughout south and south-central New Jersey providing AWC wood material for laboratory analysis. Not all source materials were of sufficient quality to allow subsequent laboratory processing. The symbol ⇮ indicates sites included in the relative master chronology, see Figure 2 and Table 2.

Taken together, these efforts provided the necessary material for an absolutely dated, live tree master chronology for the period 1788-2014 (see Figure 1). It was operationally robust back to the early 1820's - i.e., there were enough individual samples calculated into each year to produce a statistically representative mean - but prior to that decade the number of sampled trees was too few to be considered rigorously representative statistically. Nevertheless, this master was the longest calendar-year-dated record of regional annual growth for the species *Chamaecyparis thyoides* ever developed. In a remarkably short time and with restricted resources, unprecedented progress was made in constructing a viable AWC master chronology, a scientifically complicated and technically demanding undertaking.

Figure 1

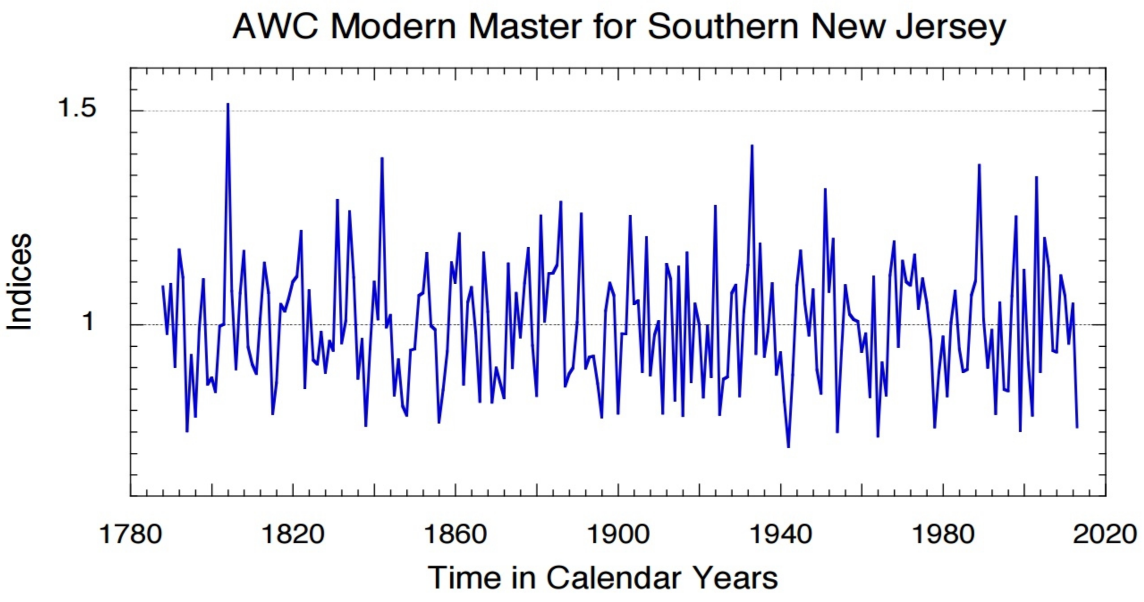
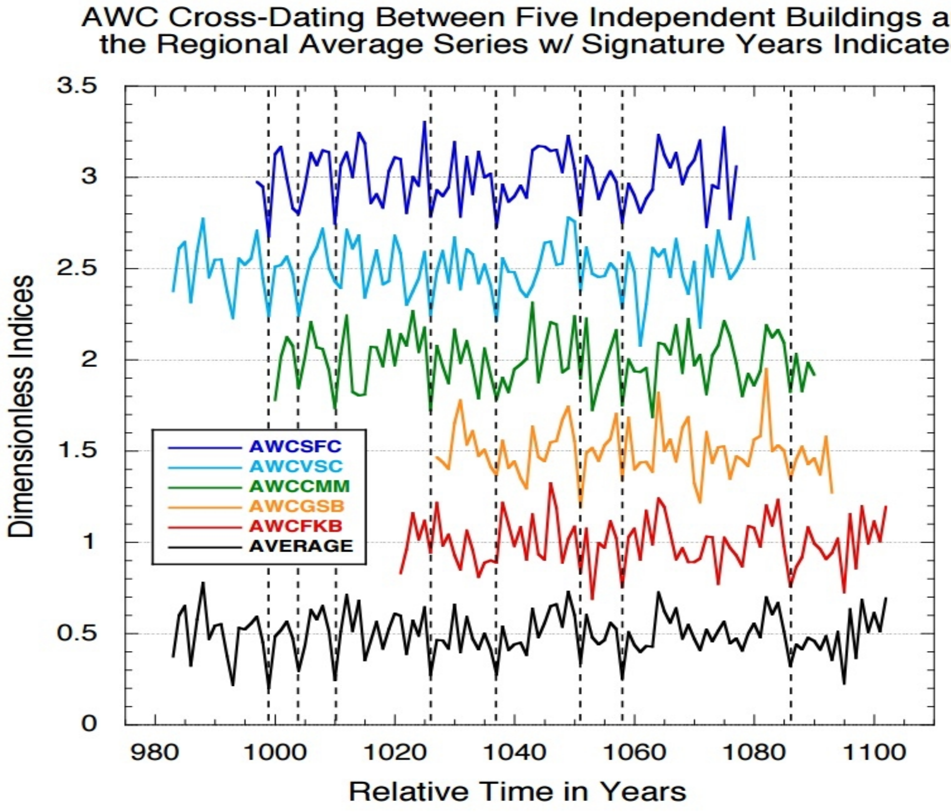


Figure 1. Regional live-tree Atlantic White Cedar (*Chamaecyparis thyoides*) dating master for Southern New Jersey, covering 1788-2014. Though statistically robust for most of its length, in the decades preceding circa 1825 the number of included series is too few to constitute adequate statistical representation for general dendrochronological functionality. To be serviceable for dating of historical structures and objects for the entire European settlement period in the region, this "Phase 1" chronology would require supplementation and extension of its length to 1550, or before.

Although a quantity of the "floating" AWC chronologies assembled from various sampled historic buildings and objects could not be assigned firm dates, the consistencies within and between the sites themselves nevertheless made possible the compilation of a "floating historical master" (see Figure 2 and Table 2). Such agreement supplied additional proof that historical dating of AWC is practicable, and more methodological evidence of a potential for extending an absolutely dated master chronology back in time.

Figure2



AWCSFC: Swing Family Cabin; AWCVSC: Veale-Sewall Cabin; AWCCMM: Cape May Museum Barn;
AWCGSB: Stites Barn, Gandy Homestead; AWCFKB: Falkenburge Barn

Figure 2. Illustration of relative positional crossdating between the five different historical site chronologies described numerically in Table 2. The building names corresponding to the series codes are given at the bottom of the table. Shared key signature years are marked with a dotted vertical line. The series at bottom -the black curve- is the composite, relatively dated AWC historical master for southern New Jersey, as configured. It serves as a basis for continued AWC chronology development in the future, with the goal of eventually connecting the absolutely-dated live tree chronology and the relatively-dated site chronologies into a continuous master chronology, functionally operable for dating AWC structures and artifacts over the entirety of the regional historical settlement period.

Table 2

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                              No.    with    995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065
Seq  Series    Time_span    Years   Master   1024 1029 1034 1039 1044 1049 1054 1059 1064 1069 1074 1079 1084 1089 1094
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  1  AWCSFC     997 1077     81     0.492    .46  .40  .42  .41  .38  .54  .56  .55  .71  .71  .57  .55
  2  AWCVSC     983 1080     98     0.497    .51  .42  .47  .52  .53  .56  .65  .67  .62  .54  .47  .38  .33
  3  AWCCMM    1000 1090     91     0.465         .26  .37  .39  .43  .51  .69  .70  .66  .66  .64  .59  .51  .45  .44
  4  AWCGSB    1027 1093     67     0.484                                  .53  .55  .76  .61  .55  .54  .49  .40  .28
  5  AWCFKB    1021 1102     82     0.362                             .24  .38  .51  .53  .52  .46  .43  .42  .39  .37
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AWCSFC: Swing Family Cabin; AWCVSC: Veale-Sewall Cabin; AWCCMM: Cape May Museum Barn;
AWCGSB: Stites Barn, John Gandy Homestead; AWCFKB: Falkenburge Barn

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Table 2. Output from COFECHA (Holmes, 1983; Grissino-Mayer, 2001) program showing the statistical strength of crossdating between five independently developed Atlantic White Cedar (AWC) site masters. The building names corresponding to the series codes are given at the bottom of the table. The Spearman rank correlations between each ‘floating’ master and the compiled mean of the site masters are shown for 30-year periods with five year, 25-year overlaps. The years assigned are arbitrary (hence ‘floating’) because no calendar year dates yet could be assigned by crossdating with a calendar year dated AWC master. However, the offsets of the years of overlap between buildings are generally consistent with purported construction dates based on historical assessments, circa 1700-1775.

Phase 2 of the AWC Project: Planning, Implementation and Results

Despite significant achievements, in a broader perspective the success of "Phase 1" of the project was limited. In addition to being too short to cover the purported date range (mid-17th century) of the Granary, the live-tree chronology proved to be insufficiently robust in its early decades to permit unequivocal dating within this segment. The separate chronology compiled from a selection of the historical sites remained "floating", i.e., was not yet absolutely dated to a specific calendar year. Finally, the ultimate goal of the AWC project to successfully date the Swedish Granary remained unfulfilled. Repeated attempts to correlate the Granary with the modern live-tree chronology and/or the historical site chronologies procured no statistically viable result. The site chronology for the Granary timbers compiled during Phase 1 contained in toto just 69 rings, a not overly large number when synchronizing with other non-robust tree ring series.

However, overall experience from the completed stages of the investigation proved that AWC could crossdate successfully and that master and site specific chronologies could be compiled thereafter. It seemed very likely that the Swedish Granary ultimately could be dated using dendrochronology, given more time and material. In order to proceed, in 2015 the Cumberland County Historical Society NJ applied for and was granted renewed funding from New Jersey Historical Commission to continue the effort to supplement and strengthen the AWC master and historical chronologies with the intent of dating the Granary.

An operative review identified the determining factor restricting the success of Phase 1: that the collected materials were not yet sufficient methodologically, in either number and quality. It was realized that in order to extend the extant AWC masters and thereby establish a continuous chronology viable over the entire settlement period, and eventually to date the Granary, it would be necessary in the subsequent effort to: 1) find more buildings and artifacts constructed of AWC, in particular those containing timbers expected to have been cut during circa 1700-1850, in order to overlap and strengthen the inner portion of the live tree dating master; 2) collect more and if possible longer samples to provide enough rings to bridge the gap between the dated master and the various, still undated site masters purportedly belonging to the period ca. 1700-1850; 3) if possible, locate remnant AWC logs, so-called sub-fossil material, and sample these for eventual addition whenever demonstrated to be chronologically appropriate to the dating master.

Planning for "Phase 2" began in early 2016. An attempt would be made to rectify the identified shortcomings by seeking to augment the existing base in the most resource efficient manner by strictly targeting the location searches for serviceable materials. As was true during Phase 1, sampling was expedited greatly by the local knowledge, contact networks and reconnoitering efforts of personnel from CCHS, especially project coordinator Joseph Mathews, architectural historian Joan Berkey and historical carpenter J.P. Hand. Field work began in March 2016 and with concurrent laboratory analysis continued into the late autumn. Altogether, dendrochronologists Callahan and Cook made more than 10 operational visits to the region, and samples were collected from nearly a dozen historic structures. Additional structures were visited and surveyed without being sampled.

Importantly, in July a new sampling was conducted at the Swedish Granary itself, and 13 cores were extracted from timbers that had not been tested during the original August 2008 visit, bringing the combined total to 23 cores from the structure (see Table 4). This achieved a significant strengthening of the compiled measurement series for the site, a vital factor when attempting analyses of materials with minimal ring counts, such as those commonly confronted when working with AWC construction timbers.

During planning, circumstances forced a choice that ultimately proved critical to the success of the project. Experience from Phase 1 indicated that most structures containing sizable AWC timbers with many rings (≥ 75 rings) were constructed already by the middle to late decades of the 1700's, apparently because intensive harvesting of AWC for construction during the early colonial era quickly exhausted supplies of old-growth trees in the region. As a consequence, in order to gain sufficient overlap between the ring series from the live tree chronology and the historic structures, including the Granary, it seemed that either sub-fossil trees with 200+ rings lying precisely in correspondent time would have to be fortuitously discovered in the landscape, or an unrealistically large numbers of structures would have to be located and sampled in the hope that eventually a few of the generally short site-chronologies by chance could be synchronized.

In consideration of constrictive time and funding restraints, it was instead decided that the CCHS participants would concentrate their reconnaissance efforts specifically on locating more buildings reliably purported to be from the early to mid-1800's. It was hoped that such targeting would more quickly provide materials necessary to overlay the perceived gaps in the chronological coverage remaining after Phase 1. Analogously, what was sought was a dendrochronological "Rosetta Stone" for AWC that would allow the floating chronologies to be "translated", still reliably yet in a timely manner, into a comprehensible whole, thereby extending the live-tree chronology far enough back in history to be capable of dating the Granary.

An assortment of sites purportedly from this era were located and sampled (see Figure 5). Several of them later proved to be of high value in the historical chronology. Especially interesting in the context of the targeted search was a large collection of buildings at Batsto Village, a New Jersey State Historic Site administered by the NJ Division of Parks and Forestry in Wharton State Forest in southern Burlington County. On the grounds of this former industrial center are preserved more than 40 buildings, many of them constructed in part or in full of AWC timbers. After a preliminary survey of their condition, five were chosen for sampling due to their qualities and purported ages: the Grist Mill (ca. 1828), the Corn Crib (later construction, but with some demonstrably re-used elements marked as "1852"), the Mule Barn (ca. 1828), the Horse Barn (ca. 1830), the Post Office (established 1852).

Additionally quite important was a sub-fossil log found in the Port Norris Salt-Hay Meadow in Cumberland County, which spanned convincingly the period 1750-1916, between the Phase 1 live-tree master and the historical master chronologies (see Table 3 & Figure 3). Another object greatly useful to extending the historical master chronology was the so-called "Swedish Plank Cabin at Hancock Bridge", a single room construction of hewn AWC timbers now standing on the grounds at Hancock House State Historic Site in Alloways Creek Township, Salem County. Carefully salvaged from a local property and rebuilt as an interpretive preservation project in 1931 by the Civil Works Administration, the woodwork was reported to have come in some degree from at least three 18th century buildings. Probably because reconstruction occurred with mixed and re-used logs, most selected and sampled timbers dated variously from around the beginning of the 1740's and the early 1750's, while conversely one log from the wall abutting the fireplace and still retaining its bark dated absolutely to the dormant growth period of calendar year 1798, that is, it was cut during the autumn 1798/winter 1799.

Despite having to contend with short series in almost all the collected materials, the integration of the new measurements into the historical and live-tree master chronologies ultimately produced positive results. In particular, the samples from the five tested buildings from Batsto Village were especially important. Their purported ages proved in every case when crossdated to be precisely or nearly correct, providing the AWC project with not only viable measurement series for addition to the masters at the necessary points, but also giving reassurance of the correct positioning in time of the multiple floating chronologies. Generally, experience in dendrochronology has shown that reliance on the accuracy of purported dates of structures and objects is of irregular value and must proceed with extreme caution, since often the evidence for such datings is supposition based upon contestable sources, poor or secondary documentation, lore, and/or interpretative attestations. However, in the case of the five tested Batsto structures, the correlation with the master chronology (i.e., the indicated absolute dates) and the anticipated intervals with each other structure aligned exactly (i.e., the precise variance in years for each of the individual ring series between their purported dates of construction). Moreover, other sites likewise tested during the Phase 2 efforts yet not associated with the Batsto structures, also correlated with and within the chronologies (see Table 3).

Table 3

Table 3. Sliding correlations for the historical and modern AWC tree-ring chronologies from southern New Jersey ultimately used to date the Swedish Granary located in Greenwich, New Jersey. Refer to the bottom of the Table for the site identities of the various Series Codes. The Spearman rank correlations (r-factors) are shown for 30-year periods with 15-year overlaps. Values derived from the COFECHA program used to evaluate the strength of crossdating (Holmes, 1983; Grissino-Mayer, 2001).

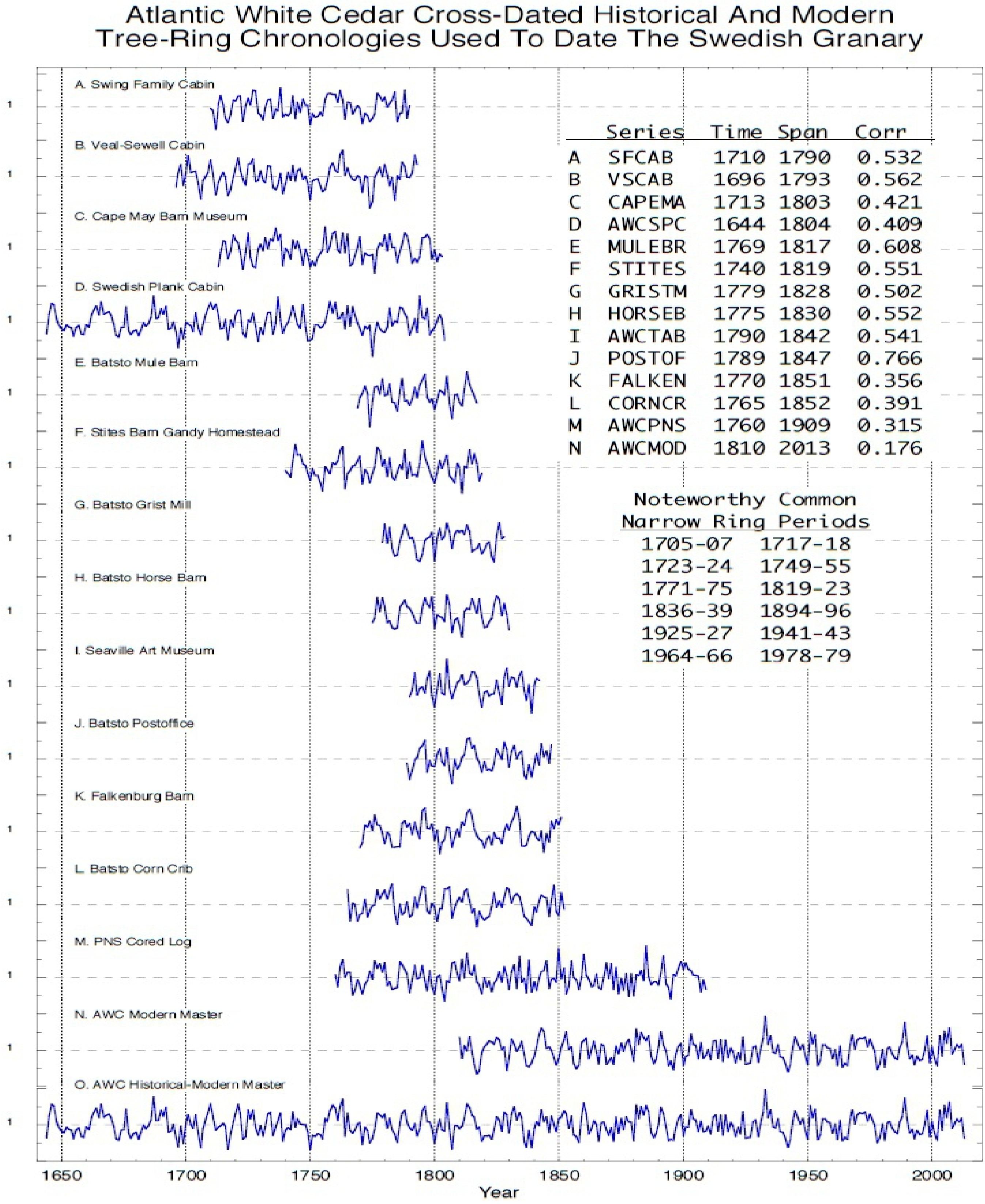
Seq	Series	Time_span		1695	1710	1725	1740	1755	1770	1785	1800	1815	1830	1845	1860	1875	1890
				1724	1739	1754	1769	1784	1799	1814	1829	1844	1859	1874	1889	1904	1919
A.	SFCAB	1710	1790		.44	.56	.64	.58	.49								
B.	VSCAB	1696	1793	.64	.65	.62	.63	.60	.48								
C.	CAPEMA	1713	1803		.28	.35	.51	.52	.54	.47							
D.	AWCSPC	1644	1804	.43	.45	.46	.35	.45	.35	.31							
E.	MULEBR	1769	1817					.47	.48	.78	.73						
F.	STITES	1740	1819				.58	.71	.63	.44	.44						
G.	GRISTM	1779	1828						.49	.36	.59						
H.	HORSEB	1775	1830						.55	.55	.58	.54					
I.	AWCTAB	1790	1842							.53	.54	.52					
J.	POSTOF	1789	1847							.78	.79	.77	.81				
K.	FALKEN	1770	1851						.21	.54	.56	.36	.30				
L.	CORNCR	1765	1852					.49	.51	.44	.31A	.40	.28				
M.	AWCPNS	1760	1909					.46	.49	.42A	.48	.63	.26	.02	.25	.38	.34
N.	AWCMOD	1810	2013								.21	.18	.27	.03	.25	.38	.34

Series codes: Swing Family Cabin (SFCAB), Veal-Sewell Cabin (VSCAB), Cape May Museum Barn (CAPEMA), Swedish Plank Cabin (AWCSPC), Batsto Mule Barn (MULEBR), Stites Barn Gandy Homestead (STITES), Batsto Grist Mill (GRISTM), Batsto Horse Barn (HORSEB), Seaville Art Studio Barn (AWCTAB), Batsto Post Office (POSTOF), Falkenburge Barn (FALKEN), Batsto Corn Crib (CORNCR), Port Norris Salt-Hay meadow Cored Logs (AWCPNS), Living-tree AWC Modern Master (AWCMOD)

COFECHA is the de facto standard program for statistical quality control testing of tree-ring data. The tree-ring data compared in Table 3 above are the mean chronologies of sampled historic buildings (Series), plus one chronology based on living trees. Correlations shown are for sliding 30-year time periods, with 15-year overlaps of each chronology compared to the mean of all the others. The method of correlation is the robust non-parametric Spearman rank correlation. For additional explanatory reference see: Holmes, R.L. 1983. "Computer-assisted quality control in tree ring data and measurement." Tree-Ring Bulletin 43:69-78., and Grissino-Mayer, H:D: 2001. "Evaluating crossdating accuracy: A manual and tutorial for the computer program COFECHA." Tree-Ring Research 57(2):205-221.

Overall, the sliding correlations indicate a high level of agreement (crossdating) between chronologies, even though each chronology was developed independently of all other chronologies. The modern master (AWCMOD) unfortunately remains somewhat weakened in its early lengths because few trees growing before 1850 could be found and included. The South Jersey pine barren regions experienced wide spread disturbance from extensive deforestation during the settlement periods, especially due to intensive exploitation of the forests to fuel the bog iron industry, as well as exhaustive harvesting consuming entire AWC stands and even swamp-mined sub-fossil AWC logs, for shingles, fencing, watercraft, etc. Remarkably, given that in anaerobic conditions, such as occasionally can exist in marshes, wood can be preserved for thousands of years, the sub-fossil logs AWCPNS found and cored in Port Norris Salt-Hay Meadow fortuitously crossdated well with both the historical dating masters and that from living trees. This chronology serves as a “bridge” that confidently locks in the well-dated historical building chronologies with the modern master, a fine example of how occasionally opportune good luck also plays a salient if unpredictable role in a successful scientific enterprise.

Figure 3



Atlantic White Cedar Cross-Dated Historical And Modern Tree-Ring Chronologies Used To Date The Swedish Granary

	Series	Time Span		Corr
A	SFCAB	1710	1790	0.532
B	VSCAB	1696	1793	0.562
C	CAPEMA	1713	1803	0.421
D	AWCSPC	1644	1804	0.409
E	MULEBR	1769	1817	0.608
F	STITES	1740	1819	0.551
G	GRISTM	1779	1828	0.502
H	HORSEB	1775	1830	0.552
I	AWCTAB	1790	1842	0.541
J	POSTOF	1789	1847	0.766
K	FALKEN	1770	1851	0.356
L	CORNCR	1765	1852	0.391
M	AWCPNS	1760	1909	0.315
N	AWCMOD	1810	2013	0.176

Noteworthy Common Narrow Ring Periods

1705-07	1717-18
1723-24	1749-55
1771-75	1819-23
1836-39	1894-96
1925-27	1941-43
1964-66	1978-79

Figure 3. Comparative positioning of the site and master chronologies used in the analysis and dating of the Granary. Series datings and COFECHA produced Spearman rank correlation coefficients ("r-factors") for agreement between individual site series and the AWC Historical Modern Master are delineated in upper right portion of graph.

As noted previously, after Phase 1 the repeated attempts made to correlate the Granary with either the newly created live-tree master chronology and/or the various site chronologies procured no scientifically defensible crossdating. This was disappointing, yet not especially surprising. Creating an operative dating chronology for a previously untested species requires resources and much patience. For instance, it took the aforementioned A.E. Douglass over seven years to finalize the master chronology for pine that enabled him to date the Anasazi dwellings in the American Southwest. The historical master chronology for oak compiled by Cook & Callahan had its beginnings in sampling expeditions to eastern deciduous forests in 1984 but was not fully functional until late 1992. The first successful tree-ring dating of Boston structures by Paul Krusic and Edward Cook was only made possible by sampling a large number of specified buildings having (purportedly) closely spaced historical construction dates of increasing age. These procedures produce multiple overlapping and cross-dated historical series as floating historical chronologies, which eventually (but not necessarily!) can overlap and successfully cross-date with modern live-tree chronologies. The same exacting procedures were applied to develop the AWC dating master in New Jersey. In comparison to the years needed to finalize the master chronologies in the given examples, since the first active field sampling phase of the AWC project began in the summer of 2014 the work has proceeded with extraordinary speed and efficacy.

Taken collectively, the initial Phase 1 and the following Phase 2 efforts successfully produced a strengthened and lengthened AWC live-tree master chronology anchored in the present, without which no absolute dating of historical structures, such as the Granary, could or would be attainable. When stabilized, this chronology was referenced to prepare statistically viable crossdatings of multiple historic site chronologies (see Table 4), which then in turn allowed the synthesis of a functional historical dating chronology specifically compiled from regional historic structures. After incorporation of the new data, it became possible thereafter to proceed with the attempt to establish a precise, empirical dating of the Granary.

Dating of the Granary

It should be remembered that after the completion of Phase 1, and using a floating site chronology compiled from the mean of the original 10-core sampling of the building from August 2008, repeated attempts were made without success to crossdate the Granary with the newly created live-tree master chronology. Nor did the "floating" Granary chronology crossdate reliably with any of the floating chronologies from other sampled historic sites. It was speculated that a likely explanation for this failure was that the statistical signal of the Granary chronology simply was too weak to correlate with the existing master. At the time the compiled mean for the Granary timbers contained in toto just 69 rings from six samples, a minimal number when synchronizing non-robust tree ring series.

With the decided intention to strengthen the signal, a second sampling visit to the Granary was conducted in July 2016, collecting an additional 13 cores from previously untested timbers. In all 23 cores have been extracted, 10 from the original sampling in August 2008 and 13 from the secondary sampling in July 2016 (see Table 4 and Figure 4). This permitted a significant strengthening of the compiled measurement series for the site, a vital factor when attempting analyses of materials with minimal ring counts such as commonly found when working with AWC construction timbers. Consequently, a new, greatly strengthened and longer Granary mean was calculated, consisting of 76 rings from fifteen individual samples.

Table 4

Table 4. Dendrochronological dating results for all samples taken from the Swedish Granary, Greenwich, New Jersey. For WANEY, +BE means the bark edge was judged to be present and thought to be recovered at the time of sampling; +BE?? indicates that the BE judgement was considered likely but uncertain;-BE means that the bark edge was judged not recovered or was completely missing on the timber. If so, as the timbers are generally logs "in the round" the outermost ring date still may be close to the actual cutting date. All correlations are Spearman rank correlations of each series against the mean of all of the others of the same species in the Granary.

ID	SPECIES	DESCRIPTION	WANEY	RINGS	DATING	CORREL
PPSGNJ 01	White Cedar	1st floor, east wall, 6th log above bottom	+BE	75	1708 1782	0.34
PPSGNJ 02	White Cedar	1st floor, east wall, 4th log above bottom	-BE?	43	1740 1782	0.50
PPSGNJ 03	White Cedar	1st floor, east wall, 3rd log above bottom	+BE	63	1721 1783	0.52
PPSGNJ 04	White Cedar	1st floor, north wall, 4th log above bottom	+BE?	50	No Date	-.--
PPSGNJ 05	White Cedar	1st floor, west wall, 4th log above bottom	+BE??	47	1733 1779	0.41
PPSGNJ 06	White Cedar	1st floor, west wall, 4th log above bottom, log over northwest door	+BE?	42	No Date	-.--
PPSGNJ 07	White Cedar	1st floor, north wall, 7th log above bottom	+BE?	60	1722 1781	0.61
PPSGNJ 08	White Cedar	1st floor, center partition, 4th log above bottom	+BE??	75	No Date	-.--
PPSGNJ 09	White Cedar	2nd floor loft section, west wall, 11th log above bottom	+BE??	69	1711 1779	0.67
PPSGNJ10	White Cedar	2nd floor loft section, center partition, 11th log above bottom	+BE??	51	1714 1764	0.55
PPSGNJ11	White Cedar	2nd floor, south wall, 12th log from bottom	+BE?	52	1730 1781	0.60
PPSGNJ12	White Cedar	2nd floor, south wall, 11th log from bottom	+BE	53	1730 1782	0.54
PPSGNJ13	White Cedar	2nd floor, east wall, 9th log from bottom, same tree as #14	-BE	55	1721 1775	0.59
PPSGNJ14	White Cedar	2nd floor, east wall, 9th log from bottom, same tree as #13	-BE??	58	1721 1778	0.60
PPSGNJ15	White Cedar	2nd floor, west wall, 12th log from bottom	-BE	42	1726 1767	0.54
PPSGNJ16	White Cedar	2nd floor, north wall, 11th log from bottom	+BE??	38	No Date	-.--
PPSGNJ17	White Cedar	1st floor, north wall, 6th log from bottom	+BE	71	1712 1782	0.60
PPSGNJ18	White Cedar	1st floor, north wall, 2nd log from bottom	+BE?	61	1721 1781	0.49
PPSGNJ19	White Cedar	1st floor, east wall, 7th log from bottom	+BE	38	No Date	-.--
PPSGNJ20	White Cedar	1st floor, west wall, 7th log from bottom, same tree as #6	+BE??	53	No Date	-.--
PPSGNJ21	White Cedar	1st floor, west wall, 5th log from bottom	-BE	46	No Date	-.--
PPSGNJ22	White Cedar	1st floor, south wall, 5th log from bottom	+BE??	62	1720 1781	0.39
PPSGNJ23	White Cedar	1st floor, south wall, 6th log from bottom	+BE??	44	No Date	-.--

The "r-factor” (in "Correl" column, above) is the Spearman rank correlation coefficient, a measure of relative statistical agreement between two groups of measurements or data. It can range from +1 (perfect direct agreement) to -1 (perfect opposite agreement).

Figure 4

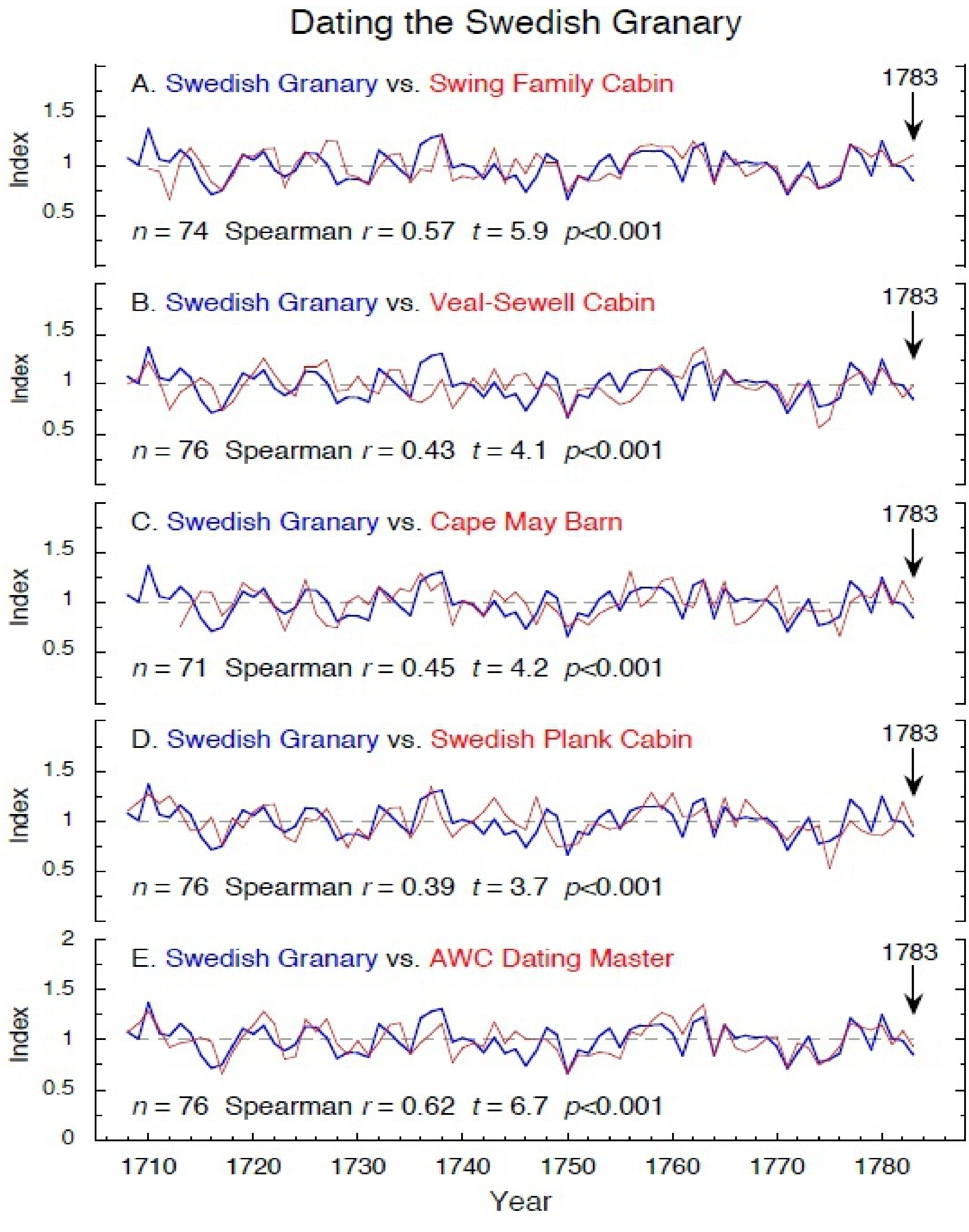


Figure 4. Swedish Granary mean chronology displayed as correlated with curves representing the AWC historical dating master chronology and four individual AWC site chronologies from contemporary, near-lying structures. The first three examples in Figure 4 are against independently developed house masters from Phase 1. In all cases, the robust non-parametric Spearman rank correlation coefficient was used for determining cross-dating. Given numerical values signify: n= the number of correlated rings, r= the Spearman rank correlation coefficient, t= Student's probability distribution value, p< is likelihood of random statistical invalidity.

The "r-factor" is the Spearman rank correlation coefficient, a measure of relative statistical agreement between two groups of measurements or data. It can range from +1 (perfect direct agreement) to -1 (perfect opposite agreement). The "t-value" is Student's distribution test for determining the unique probability distribution for "r", i.e., the likelihood of its value occurring by chance alone. As a rule, a t=3.5 has a probability of about 1 in 1000, or 0.001, of being invalid. Higher “t” values indicate exponentially increasing, exponentially stronger statistical certitude. Experience has shown that for trees growing in the northeastern United States this method of crossdating is greatly superior to the traditional skeleton plot techniques once commonly employed by dendrochronologists in the past.

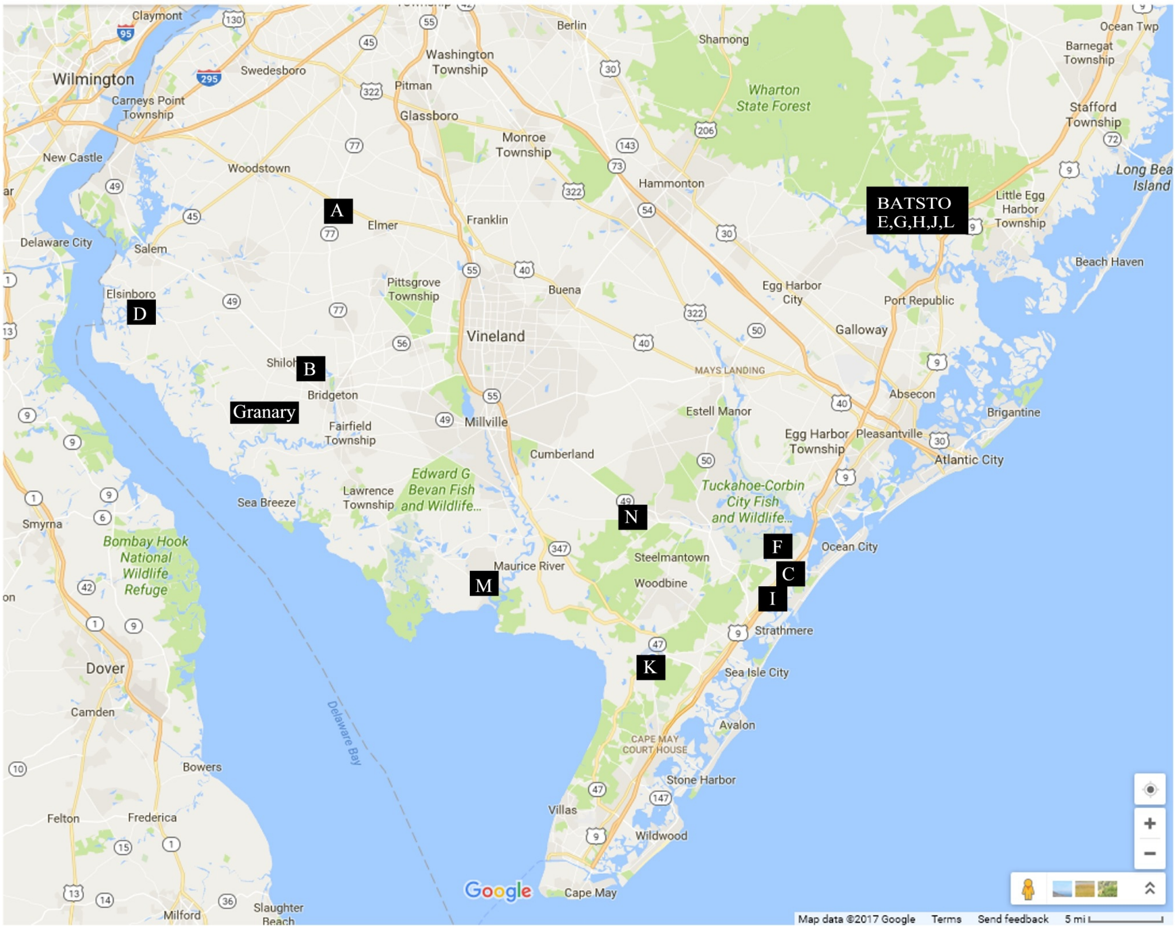
The individual correlations in Figure 4 vary slightly in statistical strength, but all are in the range that is expected for correctly crossdated timbers from buildings in the eastern United States. The t-statistics (t=5.9, t=4.1, t=4.2, t=3.7) associated with the correlation between the Granary series and the associated AWC site chronologies (r=0.57, r=0.43, r=0.45, r=.39, respectively) are statistically very significant (p<<0.001) for the general 76-year overlap. Of more consequence for the success of the dating project, the t-values (t=6.7) associated with the correlation between the Granary series and the regional historical AWC Dating Master (r=0.62) are statistically very significant (p<<0.001) for the 76-year overlap. For that reason, there can be no doubt that the dates presented here for these sampled elements of the structure are robustly valid, and that the statistical chance of the crossdates being incorrect is exponentially far less than 1 in 1000.

After comparative analysis it was possible to secure absolute dates for 15 of the individual 23 samples from the Granary (see Table 4). These dates are not uniform but rather are clustered thickly in the early 1780's, with 9 of the 15 dated samples of the outermost rings assigned to the period 1781-1783. Two more dated to 1779, and a singleton to 1778. Compiled from the individual dated Granary samples, the resulting mean site chronology correlated well with the AWC historical master synthesized from the modern AWC live-tree master chronology, in addition to strong correlation with an broad assortment of contemporary site chronologies from near-lying structures (see Figure 3 & Figure 4).

It is possible that the trees were harvested intermittently over the several years and stockpiled for future use, resulting in the mixed cutting dates. Equally reasonable explanations of the dating spread may be that the trees were in fact harvested simultaneously in just a single cutting but subsequent surface erosion and/or bark sloughing over time caused the loss of one or two outer rings, or that a misjudgment before extraction of the condition of the outer surface of the rounded log caused it to be incorrectly labelled as exhibiting BE wane, i.e., that the outermost extant ring on the log once was immediately under the (now absent) bark and thus represents the cutting year.

Regardless, though not defined with singularity the dates do cluster with temporal coherence and thus express substantive evidence of general construction activities lying close in time to the latest dated samples, i.e., the multiple 1782/1783. The compiled, 76-ring Granary mean series correlates strongly for the period 1708-1783 against the AWC historical dating master, as well as with multiple historical sites. Therefore, interpretation of the dated timbers of the Granary strongly indicates that construction of the building in its present configuration took place in or shortly after the calendar year 1783, apparently in 1784 or perhaps as late as 1785.

Figure 5.



Location of Buildings, Trees, and Logs Sampled to Create the Master AWC Chronology

	Series Code	Name	Location or Original Location*	Date Span of Timber(s) Sampled
A	SFCAB	Swing Family Cabin	Upper Pittsgrove Twp., Salem County	1710-1790
B	VSCAB	Veal-Sewall Log Cabin*	Hopewell Twp., Cumberland County	1696-1793
C	CAPEMA	Cape May Museum Barn*	Upper Twp., Cape May County	1713-1803
D	AWSPC	Swedish Plank Cabin	Lower Alloways Creek Twp., Salem Co.	1644-1804
E	MULEBR	Mule Barn, Batsto Village	Washington Twp., Burlington County	1769-1817
F	STITES	Stites Barn*	Upper Township, Cape May County	1740-1819
G	GRISTM	Gristmill, Batsto Village	Washington Twp., Burlington County	1779-1828
H	HORSEB	Horse Barn, Batsto Village	Washington Twp., Burlington County	1775-1830
I	AWCTAB	Art Studio Barn	Upper Township, Cape May County	1790-1842
J	POSTOF	Post Office, Batsto Village	Washington Twp., Burlington County	1789-1847
K	FALKEN	Falkenburge House Barn	Dennis Township, Cape May County	1770-1851
L	CORNCR	Corn Crib, Batsto Village	Washington Twp., Burlington County	1765-1852
M	AWCPNS	Port Norris salt hay meadow log	Commercial Twp., Cumberland County	1760-1909
N	AWCMOD	Living-tree modern master	Maurice River Twp., Cumberland Co.	1810-2013

*moved buildings are marked with an asterisk; their original location is noted, not their present location

Joan Berkey, January 2017

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Edward Cook was born in Trenton, New Jersey, in 1948. He received his PhD. from the Tucson Tree-Ring Laboratory of the University of Arizona in 1985, and has worked as a dendrochronologist since 1973. Currently director and Senior Scholar of the Tree-Ring Laboratory at the Lamont-Doherty Earth Observatory of Columbia University, he has comprehensive expertise in designing and programming statistical systems for tree-ring studies, and is the author of many works dealing with the various scientific applications of the dendrochronological method.

William Callahan was born in West Chester, Pennsylvania, in 1952. After completing his military service he moved to Europe, receiving his MA from the University of Stockholm in 1979. He began working as a dendrochronologist in Sweden in 1980 at the Wood Anatomy Laboratory at the University of Lund, and returned to the United States in 1999. A former research associate of Dr. Edward Cook at the Tree-Ring Laboratory of Lamont-Doherty, he has extensive experience in using dendrochronology in dating archaeological artifacts and historic sites and structures.

Some regional historical dendrochronological projects completed by the authors:

Abraham Hasbrouck House, New Paltz, NY
Allen House, Shrewsbury, NJ
Belle Isle, Lancaster County, VA
Bowne House, Queens, NY
Carpenter’s Hall, Philadelphia, PA
Charpentier House, Philadelphia PA
Christ’s Church, Philadelphia, PA
Clifton, Northumberland County, VA
Conklin House, Huntington, NY
Customs House, Boston, MA
Daniel Boone Homestead, Birdsboro, PA
Daniel Pieter Winne House, Bethlehem, NY
Ditchley, Northumberland County, VA
Ephrata Cloisters, Lancaster County, PA
Fallsington Log House, Bucks County, PA
Ferris House, Old Greenwich, Fairfield County, CT
Fawcett House, Alexandria, VA
Gadsby's Tavern, Alexandria, VA
Garrett House, Sugartown PA
Gilmore Cabin, Montpelier, Montpelier Station, VA
Gracie Mansion (Mayor’s Residence), New York, NY
Grove Mount, Richmond County, VA
Hanover Tavern, Hanover Courthouse, VA
Harriton House, Bryn Mawr, PA
Hills Farm, Accomack County, VA
Hollingsworth House, Elk Landing, MD
Indian Banks, Richmond County, VA
Indian King Tavern, Haddonfield NJ
Independence Hall, Philadelphia, PA
John Bowne House, Forest Hills, NY
Kirnan, Westmoreland County, VA
Linden Farm, Richmond County, VA
Log Cabin, Fort Loudon, PA
Lower Swedish Log Cabin, Delaware County, PA
Lummis House, Ipswich MA
Marmion, King George County, VA
Martin Cabin, New Holland PA
Menokin, Richmond County, VA
Merchant’s Hope Church, Prince George County, VA
Millbach House, Lebanon County, PA
Monaskon, Lancaster County, VA
Morris Jumel House, Jamaica, NY
Frederick Muhlenberg House, Trappe, PA
Nottingham DeWitt House, NY
Old Barn, Madison VA
Old Caln Meeting House, Thorndale, PA
Old Parsonage, Kinderhook NY
Old Swede’s Church, Philadelphia, PA
OTB House, West Nyack, NY
Panel Paintings, National Gallery, Washington, DC
Pennock House & Barn, London Grove, PA
Penny Watson House, Greenwich, NJ
Podrum Farm, Limekiln, PA
Powell House, Philadelphia, PA
Pyne House, Cape May, NJ
Radcliff van Ostrade, Albany, NY
Reese's Corner House, Rock Hall, MD
Rippon Lodge, Prince William County, VA
Rochester House, Westmoreland County, VA
Rockett¨s, Doswell VA
Rural Plains, Hanover County, VA
Sabine Hall, Richmond County, VA
Shirley, Charles City County, VA
Sisk Cabin, Culpeper VA
Stiles Cabin, Sewickely PA
Spangler Hall, Bentonville, VA
Springwater Farm, Stockton, NJ
St. Peter’s Church, Philadelphia, PA
Strawbridge Shrine, Westminster, MD
Sweeney-Miller House, Kingston, NY
Thomas & John Marshall House, Markham, VA
Thomas Grist Mill, Exton, PA
Thomas Thomas House, Newtown Square, PA
Ticonderoga Pavilion, Ticonderoga, NY
Tuckahoe, Goochland County, VA
Tullar House, Egremont MA
Updike Barn, Princeton, NJ
Varnum’s HQ, Valley Forge, PA
Verville, Lancaster County, VA
West Camp House, Saugerties, NY
Westover, Charles City County, VA
White Plains House, King George, VA
Wilton, Westmoreland County, VA
Yew Hill, Fauquier County, VA