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A CUTTING-DATE ESTIMATION TECHNIQUE FOR PONDEROSA PINE AND DOUGLAS FIR WOOD SPECIMENS

Stephen E. Nash

The interpretation of noncutting tree-ring dates from archaeological sites often proves problematic, and many sites in the Southwest may be more securely dated if cutting dates can be reliably estimated. Analysis of 54 ponderosa pine and 46 Douglas fir specimens reveals that the relationship between heartwood and sapwood in these species is sufficiently structured that regression analysis can be used to estimate the number of sapwood rings, and by extension the tree's cutting date, on the basis of the number of heartwood rings present on wood specimens. The efficacy of this estimation technique is evaluated on samples from localized and well-dated proveniences at Walpi Pueblo, as well as in light of the aggregate date distribution curve for that site. Results suggest that uncritical acceptance of estimated cutting dates is ill advised, but that when cutting-date estimates (and their associated confidence intervals) are considered in light of contextualizing architectural and archaeological data, they may suggest alternative room construction and repair hypotheses. When considered as part of the aggregate date distribution for a site, estimated cutting dates may identify and augment date concentrations, thereby helping secure the chronometric placement of prehistoric sites in the Southwest.

La interpretación de fechados dendrocronológicos sin corte provenientes de sitios arqueológicos es frecuentemente problemática, y muchos sitios del Suroeste podrían ser fechados más seguramente con una estimación confiable de fechados de corte. El análisis de 54 especímenes de pino ponderosa y 46 de abeto Douglas revela que la relación entre el corazón del tronco y la madera resinosa en estas especies tiene suficiente estructura como para que una regresión se pueda utilizar confiablemente para extender el número de anillos en la madera resinosa, y por lo tanto la fecha de corte, en base al número de anillos presentes en el corazón de especímenes de madera. Se evalúa la eficacia de esta técnica en muestras de proveniencia localizada y bien fechada de Walpi Pueblo, así como en comparación con la curva de distribución de fechas agregadas para ese sitio. Los resultados sugieren que las fechas de corte estimadas no deben ser aceptadas sin una evaluación crítica, pero que cuando se interpretan en contextos arquitectónicos y arqueológicos, estas fechas pueden sugerir hipótesis alternas de construcción y reparación. Cuando fechas estimadas se añaden a la curva de distribución de fechas agregadas, ésas pueden ayudar a identificar y expandir concentraciones de fechados, y consecuentemente contribuyen a asegurar la posición cronométrica de sitios prehistóricos en el Suroeste.

A "noncutting" date is assigned to the outer dated ring of a dendrochronological specimen that, for whatever reason, is missing an unknown number of rings from its outer surface. The archaeological interpretation of noncutting dates often proves problematic because additional variables intervene between the tree-ring dates and the behavior in question (see Dean 1978). As a result, archaeologists and dendrochronologists have long sought reliable techniques for estimating cutting dates for tree-ring specimens that yield noncutting dates (Douglass 1939; Graves 1991; Plog 1980; Robinson and Ahlstrom 1980; Stallings 1940). The objective of this report is to present and test a new, empirically derived, statistically reliable, cutting-date estimation technique based on least squares linear regression analysis.

The Problem

Archaeologists who submit wood or charcoal samples for tree-ring analysis are usually interested in determining the date of a human activity, such as when a room was constructed, which is referred to as the "target event" (Dean 1978). Because wood specimens found in archaeological sites do not record the date of the target event in any absolute sense, the archaeologist must "proceed inferentially" (Graves 1991) from the "reference event" (Dean 1978), or the tree's date-of-death, to the tar-

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Table 1. Cutting-Date Estimates at Room 20, Walpi Pueblo.

No.	Species	Inner Date	Outer Date	Est. Date	# HW Rings	68% CI
WRP-822	DF	1243 p	1381 vv	1420	88	1408–1432*
WRP-400	DF	1293 p	1407 vv	1450	114	1438–1462*
WRP-826	PP	1417 p	1512 vv	1586	73	1562–1610
WRP-407	PN		1541 v			
WRP-403	DF	1511 p	1553 vv	1562	26	1550–1574
WRP-378	JN	1552 p	1665 vv			
WRP-406	DF	1579 p	1676 vv	1673	61	1676–1685
WRP-374	DF	1633 p	1690 vv	1698	37	1690–1710
WRP-824	JN		1701 rcomp			
WRP-828	JN		1706 rBcomp			

*Estimates cutting dates should be considered minima because these specimens were missing an unknown number of heartwood rings at their outside.

get event. In a perfect world, all trees used by prehistoric builders would be harvested (cut) the year they were used, and all would provide the dendrochronologist with cutting dates. Because a cutting date dates the reference event, the inferential processes leading to the target event would be gratifyingly straightforward. The archaeological interpretation of tree-ring data could then focus exclusively on room construction activity, and the known vagaries of human wood-use behavior, including differential beam acquisition, storage, use, reuse, repair, and salvage, could be largely ignored.

In point of fact, the world is not so simple—a large percentage of submitted archaeological tree-ring specimens are not datable at all, and a significant percentage of those that are datable yield only noncutting dates. Cutting dates can be applied only if there is conclusive evidence, such as bark or beetle galleries (see key to tables), that the outer ring on a sample was the last ring produced by the tree before it died. Noncutting dates must be assigned to tree-ring specimens that do not present evidence that they contain the full complement of rings. Noncutting dates do not date reference events; reference events do not necessarily date target events (see Dean and Warren 1983); therefore, noncutting dates necessarily complicate the interpretive task facing the archaeologist.

To make inferential use of noncutting dates, archaeologists rely on the analysis of date clusters (Ahlstrom 1985; Bannister 1962; Haury 1935). Ahlstrom (1985:59) defines a date cluster as "three or more dates falling in a brief time interval," usually one to three calendar years. The interpretive utility of any date cluster is directly dependent on the number and kind of tree-ring dates: weak clusters contain a number of noncutting dates scattered over one to three years; strong clusters contain a number of cutting dates that fall in one calendar year (Ahlstrom 1985:60). Noncutting-date clusters are interpretively useful

Key to Tables: Relevant Archaeological Tree-Ring Date Symbols

Relevant Symbols Used with Outside Date

- **B** bark present
- **G** beetle galleries present on the surface of specimen
- **r** less than a full section is present, but the outermost ring is continuous around the available circumference
- **v** a professional assessment that, although there is no direct evidence of the true outside of the specimen, the specimen is a cutting date
- **vv** there is no way of estimating how far the last ring is from the true outside
- **comp** outer ring is complete
- **inc** outer ring is incomplete

Relevant Symbols Used with Inside Date

- **p** pith ring present

Species Designations

- **DF** Douglas fir
- **PP** ponderosa pine
- **PN** pinyon pine
- **JN** juniper

Other

- **HW** heartwood
- **CI** confidence interval

The symbols B, G, r, and v indicate cutting dates in order of decreasing confidence. An underlined symbol means that such evidence was documented in the field, not on the tree-ring specimen itself.

only if the archaeologist is willing to accept a critical assumption: that noncutting dates are not likely to cluster unless the beams from which they were derived were cut at about the same time. Fortunately, and for reasons having to do with tree physiology, nature has provided us with a means to obviate this assumption, for two critical portions of wood specimens are differentially preserved in the archaeological record. If it were possible to use the preserved wood portion to estimate the decayed or missing portion, it might be possible to estimate cutting dates for wood specimens that provide only noncutting dates. If such estimates were statistically reliable, such a technique might lead to secured chronometric positions for many archaeological sites currently burdened by an abundance of noncutting dates.

Background

The stems of dendrochronologically important tree species are divided into two primary components relevant to this study: heartwood and sapwood. Heartwood is the darker, inner portion of the trunk consisting of wood that is physiologically dead (Hillis 1968, 1971). Sapwood is the lighter, living, outer portion of the trunk (Fritts 1976). Sapwood does not survive well in the archaeological record for a number of reasons. First, it is naturally more susceptible to decay and insect damage than the chemically preserved heartwood (Hillis 1971). Second, sapwood is often removed from a tree as it is cut, debarked, transported, shaped, or otherwise manipulated to fill the construction needs for which it was harvested. Third, site abandonment processes are more likely to affect the exterior of beams that are burned or later salvaged and reused.

During the 1920s and 1930s, dendrochronologists assumed that all dendrochronologically useful tree species, at that time Douglas fir (*Pseudotsuga menzieseii*) and ponderosa pine (*Pinus ponderosa*), carried a complement of 50 sapwood rings. To estimate cutting dates, they modified the noncutting date with a plus-or-minus X (± X) figure that indicated their professional assessment of how many sapwood rings were missing from the outside of the specimen. If 20 sapwood rings were present on the dated specimen, the dendrochronologist would assume that 30 rings were missing, and would add a "± 30" to the outer cross-dated ring to estimate a cutting date for that specimen. The use of this variable is unfortunate for two reasons. First, it was based on the erroneous assumption that all trees of these species have 50 sapwood rings. Second, if the plus-or-minus figure is taken literally, it implies that up to X number of rings could be subtracted from the outer dated ring of the specimen to arrive at an estimated cutting date. Obviously, the modifying figure was intended to suggest that anywhere from 1 to 30 sapwood rings should be added to the outer ring's date to arrive at the estimated cutting date.

Douglass (1939) recognized the fallacy of assuming that 50 sapwood rings were present in these tree species, noting that ponderosa pines typically have between 40 and 80 sapwood rings, and that Douglas firs have between 30 and 60 sapwood rings. At the interpretive level, he noted that the assumption of 50 sapwood rings led to systematic errors in the cutting-date estimates: cutting dates for Douglas fir specimens were usually overestimated, those for ponderosa pine were usually underestimated.

The new sapwood values proposed by Douglass were never adopted in full, and the practice of adding a plus-or-minus figure to noncutting dates ended shortly thereafter. A review of the *Tree-Ring Bulletin* reveals that the last published use of plus-or minus figures by a dendrochronologist occurred in Douglass's (1941) report on the dating of Forestdale Ruin in east-central Arizona. By 1946 a symbol system foreshadowing that now used by the Laboratory of Tree-Ring Research (see key to tables) appeared in a report on the dendrochronology of Mesa Verde National Park (Schulman 1946). Archaeologists continued citing the published plus-or-minus figures when analyzing archaeological tree-ring dates (see Haury and Sayles 1947).

In an unpublished attempt to estimate cutting dates for a collection of Spanish colonial *santos*, or pine panel paintings, Stallings (1940) of the Taylor Museum in Colorado Springs conducted an empirical analysis of the relationship between the number of heartwood rings, sapwood rings, and tree age in 360 ponderosa pine cores collected in and around the Rio Grande Valley (see Wroth 1982). Stallings (1940) used "unusual" statistical techniques (Robinson and Ahlstom 1980), including a crude form of linear regression analysis, to

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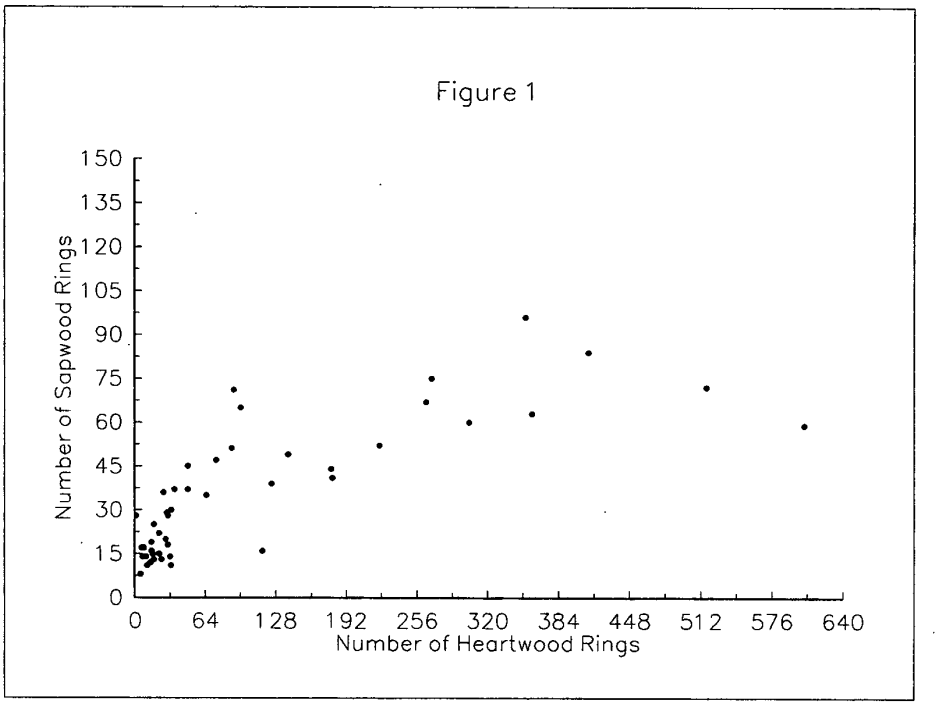

Figure 1. Scatterplot of the number of sapwood rings vs. the number of heartwood rings for the Douglas fir sample.

estimate tree age on the basis of the number of heartwood rings present on the wood specimens.

Robinson and Ahlstrom (1980) replicated Stallings's study using modern statistical techniques, noting, however, that the number of heartwood rings constitutes a significant portion of the total number of rings (e.g., tree age), and that Stallings's model was therefore inappropriate and statistically unreliable. They expanded his analysis to include 559 ponderosa pine cores from additional living tree sites around the Rio Grande Valley. Rather than estimate tree age from the number of heartwood rings directly, Robinson and Ahlstrom (1980) predicted the number of sapwood rings on the basis of the number of heartwood rings. To estimate a cutting date, they simply added the estimated number of sapwood rings to the date of the last heartwood ring.

Plog (1980) analyzed archaeological tree-ring specimens to develop a method for estimating ring loss for noncutting-date archaeological samples, including charcoal specimens. Graves (1991) analyzed 1,358 samples from 38 sites in east-central Arizona to improve on Plog's efforts by controlling for variability in ring loss by species (Plog [1980] grouped ponderosa pine, Douglas fir, and pinyon samples) and by attempting to control for perceived regional, environmental, temporal, and functional variability in sample attributes.

Previous attempts to develop statistically reliable cutting-date estimation techniques fall short of stated goals, though for different reasons. All four studies succeeded in estimating cutting dates applicable to the problem at hand, but each problem was necessarily restricted in scope. Stallings (1940) and Robinson and Ahlstrom (1980) used living-tree cores only; Plog (1980) and Graves (1991) were interested in estimating cutting dates for specific localities only—the Chevelon and Grasshopper areas, respectively.

The cutting-date estimation technique presented in this paper is similar to Robinson and Ahlstrom's (1980) in that it uses linear regression analysis to predict the number of sapwood rings from the number of heartwood rings present on a wood specimen. It improves on their analysis in three important ways. First, the analysis was expanded to include another archaeologically

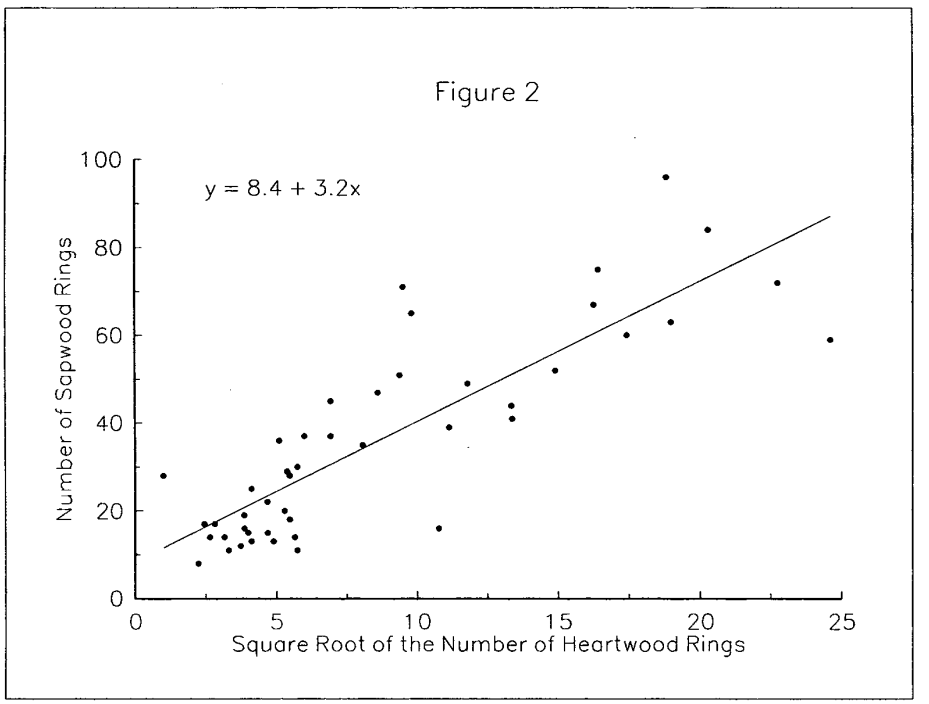

Figure 2. Scatterplot and least-squares regression line for the number of sapwood rings vs. the square root of the number of heartwood rings for the Douglas fir sample.

important tree species, Douglas fir. Second, the samples analyzed were arbitrarily selected, with no exclusive research question in mind, and therefore include specimens from archaeological and living-tree contexts from across the Southwest, not just the Rio Grande Valley. Third, due to the curvilinear relationship between heartwood and sapwood rings, the linear regression analysis is performed on transformed heartwood data, with the resultant equations providing increased, yet statistically reliable, precision in the estimation of cutting dates. Unfortunately, because the distinction between heartwood and sapwood is obliterated in charcoal, the equations presented below cannot be used to estimate cutting dates for completely burned specimens.

Data Collection and Analysis

Forty-six Douglas fir and 54 ponderosa pine cores and cross sections were arbitrarily selected from the more than 300,000 archaeological and modern cores and cross sections curated at the Laboratory of Tree-Ring Research. The specimens have all been professionally cross-dated, and all have both pith and cutting dates.[1] The inner date, outer date, last heartwood date, total number of rings, number of heartwood rings, and the number of sapwood rings were tabulated for each specimen.

Figure 1 illustrates the relationship between the number of sapwood rings and the number of heartwood rings for the 46 Douglas fir specimens analyzed. The relationship is curvilinear, and a square root transformation of the number of heartwood rings is performed. Figure 2 illustrates the relationship between the number of sapwood rings and the transformed heartwood data. Least squares linear regression analysis is used to determine the best-fit line, and the number of sapwood rings can be predicted using the following equation:

$$y = 3.2(x^{.5}) + 8.4 \quad (F = 137.7; df = 1, 52; p = < .01)$$

where x is the known number of heartwood rings and y is the predicted number of sapwood rings. The adjusted r^2 value is .73, suggesting that the

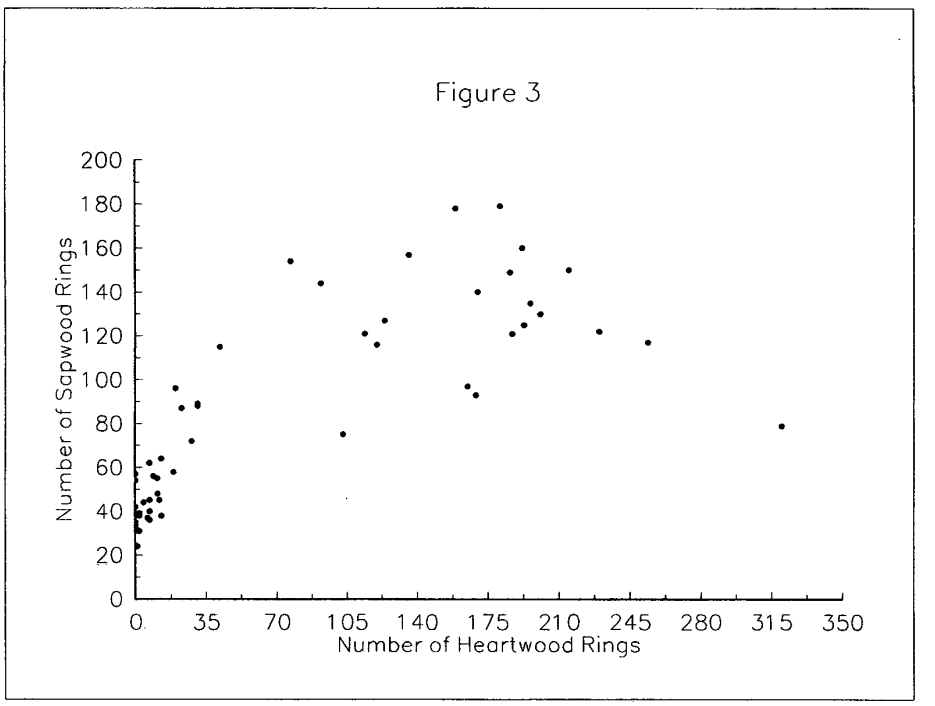

Figure 3. Scatterplot of the number of sapwood rings and the number of heartwood rings for the ponderosa pine sample.

transformed heartwood data explain 85 percent of the variability in the sapwood data. The standard error of the estimate is 12.4, rounded down to 12, because tenths of a year have no meaning dendrochronologically.

Figure 3 illustrates the relationship between the number of sapwood rings and the number of heartwood rings in the 54 ponderosa pine specimens analyzed. The relationship is curvilinear, and the heartwood data are transformed as above. Figure 4 illustrates the relationship between the number of sapwood rings and the transformed heartwood data. Again, least squares linear regression analysis is used to describe the relationship:

$$y = 7.0(x^{.5}) + 36.9 \quad (F = 109.0; df = 1, 44; p = < .01)$$

where x is the known number of heartwood rings and y is the predicted number of sapwood rings for the ponderosa pine sample in question. The r^2 value is .71, suggesting that the transformed heartwood data explain 84 percent of the variability in the sapwood data. The standard error of the estimate is 24.4, rounded down to 24, as above.

To estimate cutting dates for Douglas fir or ponderosa pine wood specimens that retain most (see below) of their heartwood complement, one simply needs to determine the number of heartwood rings on the sample, calculate the square root of that number, and solve the appropriate equation for the estimated number of sapwood rings. To estimate the cutting date, simply add the estimated number of sapwood rings to the calendar date of the last heartwood ring. Upper and lower limits of the 68 percent confidence interval for the estimated cutting date are calculated by adding and subtracting, respectively, the appropriate standard error of the estimate term. To complete the analysis, it is critical that one return to the wood specimen itself, for the statistical cutting-date estimate is not always in harmony with the known, dendrochronologically derived, outer date for the specimen. It is necessary to test the efficacy of this cutting-date estimation technique, and the well-dated site of Walpi Pueblo presents an excellent case study.

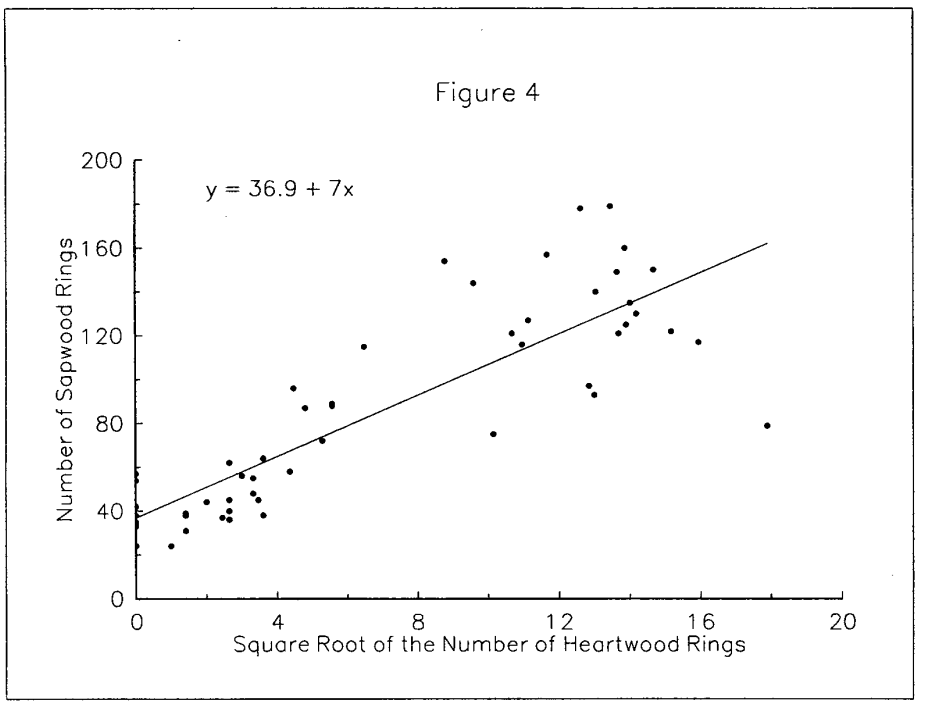

Figure 4. Scatterplot and least-squares regression line for the number of sapwood rings and the square root of the number of heartwood rings for the ponderosa pine sample.

Case Study: Walpi Pueblo

In 1977 the Laboratory of Tree-Ring Research collected 1,189 dendrochronological samples at Walpi Pueblo, on First Mesa in northeastern Arizona (Ahlstrom et al. 1991). The tree-ring data from Walpi are supported by extensive documentation, and the construction and repair sequence at Walpi is arguably better known than that of any site in the Southwest. A total of 242 dated tree-ring samples from Walpi were considered in the analysis. Removed from further consideration were 101 samples because they were juniper (60) or pinyon (11) specimens, they were Douglas fir or ponderosa pine specimens that already had cutting dates assigned (9), their inner dates were not close to pith (18), or the number of heartwood rings could not be accurately measured due to specimen decay (2). Estimated were 141 cutting dates.

Dean (1978:250–251) argues that contextual information can and should be used to detect "dating anomalies . . . on the basis of apparent inconsistencies between the dates and other archaeological data," and a similar axiom should be used when evaluating the efficacy of estimated cutting dates within their archaeological, architectural, and dendrochronological contexts. The estimated cutting dates can be evaluated in two ways. First, they should be examined by architectural unit to determine whether they suggest changes in room construction sequences or apparent beam source (e.g. reused, salvaged, or repair beam). Second, they should be examined within the aggregate date curve to determine whether they suggest changes in the overall chronometric placement of a site.

Architectural Unit-Level Analyses

This discussion of estimated cutting dates within Rooms 20, 48, and 75 at Walpi is intended only to illustrate particular issues associated with the provenience level interpretation of cutting-date estimates; analysis of estimated cutting dates from the remaining rooms at Walpi are in possession of the author. Interpretations based on the estimated cutting dates are offered as hypotheses that require

Table 2. Cutting-Date Estimates at Room 48, Walpi Pueblo.

No.	Species	Inner Date	Outer Date	Est. Date	# HW Rings	68% CI
WRP-834	DF		1892 v			
WRP-830	PP	1871 p	1915 vv	1924	4	1915–1948
WRP-846	PP		1917 GBinc			
WRP-836	PP		1918 v			
WRP-842	PP		1918 GBcomp			
WRP-844	PP	1880 p	1919 vv	1917	0	1880–1912
WRP-838	PP		1919 G inc			
WRP-840	PP		1919 Bcomp			
WRP-848	PP		1919 Bcomp			
WRP-832	PP		1919 GBinc			
WRP-850	PP		1919 GBinc			

testing, which may entail additional fieldwork. Room 20 illustrates the need for contextual data in the evaluation of estimated cutting dates, Room 48 illustrates how estimates may change the apparent source of a beam, and Room 75 illustrates the successful assimilation of cutting-date estimates in unit-level analyses.

Room 20. Ahlstrom et al. (1978:71–72) provide this discussion of Room 20 at Walpi Pueblo:

> The two primary beam dates of 1701 [WRP-824] and 1706 [WRP-828] suggest that the roof was not built until at least the first decade of the 18th century. Earlier dates of 1676 [WRP-406] and 1690 [WRP-374] are from ladder poles, which are obviously reused. Construction may well have occurred long after 1706, in which case the two beams producing the latest dates would also be reused. The presence of milled lumber primaries and secondaries shows that the roof was at least repaired after 1880, and it may actually have been totally constructed after that date.

The estimated cutting date (see Table 1) for WRP-406 does not suggest changes in its interpretation as a reused beam, but the estimate for WRP-374 shifts its outer date forward from 1690 to an estimate centered at 1698, with a 68 percent confidence limit at 1690–1710 (not 1686, for the lower limit of a confidence interval cannot fall before the date of the last cross-dated ring on the specimen). The upper limit of the confidence interval coincides with Ahlstrom et al.'s (1978) suggestion for construction in the first decade of the eighteenth century or later, though it does not rule out the original interpretation of beam reuse. Given that contextual information gathered in the field suggests reuse, the original interpretation cannot be rejected.

Specimens WRP-400 and WRP-822 from Room 20 illustrate a potential problem in the interpretation of certain estimated cutting dates. An untold number of heartwood rings were missing from the outer surface of the specimen. Each estimate is therefore based on an incomplete heartwood complement. The estimated cutting dates listed in Table 1 for these specimens should therefore be considered minimal.[2]

Room 48. Room 48 at Walpi presents a situation in which the apparent source of a beam changes because of an estimated cutting date. The dendrochronologists note that "four cutting dates terminate a strong date cluster extending from 1917 to 1919" (Ahlstrom et al. 1978:86). Two noncutting dates are assigned to beams in Room 48 (Table 2). WRP-844 has an outer date of 1919, which is coterminous with the cluster of cutting dates. There is no heartwood present on this ponderosa pine specimen, and the estimated cutting date is 1888, with a confidence interval of 1864–1912. Obviously the known outer date of 1919 takes precedence.

Specimen WRP-830 in Room 48 has an outer date of 1915 and, therefore, might be interpreted as a reused or stockpiled beam, although the dendrochronologists offer no supporting comment (Ahlstrom et al. 1978:86–87). The estimated cutting date for WRP-830 is 1924, with a 68 percent confidence interval of 1900 to 1948. The lower limit of the confidence interval is truncated by the known outer date of 1915, so the effective confidence interval is 1915–1948. This interval is sufficiently broad that it can be used to support a number of alternative hypotheses. First, WRP-830 is a reused or stockpiled beam if harvested between 1915 and 1918. Second, it was harvested with the others in 1919. Third, it dates between

Table 3. Cutting-Date Estimates at Room 75, Walpi Pueblo.

No.	Species	Inner Date	Outer Date	Est. Date	# HW Rings	68% CI
WRP-457	DF	1315 p	1445 vv	1463	103	1451–1472
WRP-1189	DF	1497 p	1531 vv	1536	17	1531–1543
WRP-489	DF	1508 p	1610 vv	1616	72	1610–1628
WRP-256	DF	1633 p	1672 vv	1673	18	1672–1684
WRP-1187	DF		1692 v			
WRP-255	DF	1650 p	1692 vv	1690	18	1692–1702
WRP-259	DF	1629 p	1692 vv	1695	38	1692–1704
WRP-261	DF	1591 p	1692 vv	1700	73	1692–1712
WRP-260	DF	1636 p	1696 vv	1688	27	1688–1708
WRP-257	DF	1652 p	1696 vv	1697	22	1696–1709
WRP-262	DF		1696 rcomp			
WRP-996	JN		1699 rcomp			

1920 and 1948 and therefore represents repair activity. Additional field research is necessary to test these hypotheses.

Room 75. Room 75 at Walpi presents a situation in which estimated cutting dates augment an existing date cluster. There is a strong cluster of cutting and noncutting dates in the 1690s, which suggests that the room was built by the early eighteenth century (Ahlstrom et al. 1978:94). Estimated cutting dates for specimens WRP-255, WRP-259, WRP-261, WRP-260, and WRP-257 (Table 3) provide supporting evidence that room construction was completed by the early 1700s, and associated confidence intervals suggest that tree cutting and, by extension, room construction was completed no later than 1712.

These examples of provenience-level analyses illustrate some of the problems associated with the interpretation of cutting-date estimates at the architectural unit level. The statistical uncertainty associated with estimated cutting dates necessitates caution. If an estimate runs contrary to the known outer date of a wood specimen, it must be removed from further consideration. In addition, if an estimate is at odds with architectural, archaeological, or dendrochronological data gathered in the field, it should not be used to alter the original interpretation of that architectural unit. Caution is similarly required when interpreting estimated cutting dates that must be considered minima because an unknown number of heartwood rings are missing from the specimen.

Aggregate Date Distribution Analyses at Walpi Pueblo

The statistical uncertainty associated with estimated cutting dates suggests that, especially at sites that are less well documented than Walpi, it may be advantageous to consider estimates in light of the aggregate date distribution curve. Again, Walpi provides a good case study precisely because it is so well documented. The following discussion focuses first on the Establishment phase (Ahlstrom et al. 1978), then considers estimates within the entire date distribution curve for the site.

Figure 5 illustrates the date distribution curve for the period bracketing the Establishment phase at Walpi, dated A.D. 1680–1709 (Ahlstrom et al. 1978). The distribution is composed primarily of cutting dates that cluster between A.D. 1687 and 1700. Cutting dates were estimated for 24 specimens, and the resulting date distribution is presented in Figure 6. While confidence intervals are not indicated, it is clear that three estimated cutting dates have been added to the 1660s, eight to the 1670s, five to the 1680s, four to the 1690s, two to the 1700s, and two to the 1710s. The peak in the date distribution in the 1690s remains; the two tails of the distribution are amplified by the estimates, especially during the 1680s. The estimates suggest increased tree cutting and possibly stockpiling in the 1680s and repair activity in the 1700s. These hypotheses cannot be accepted uncritically, and each estimate should be examined against architectural unit-level data, before conclusions are drawn. Nevertheless, the congruence between the estimates and known activities at Walpi is intriguing.

Figure 7 presents the date distribution curve for all 242 dated tree-ring samples included in the analysis. The peak in tree-cutting activity during the Establishment phase is readily apparent, as are lesser peaks in the early and mid-fifteenth century,

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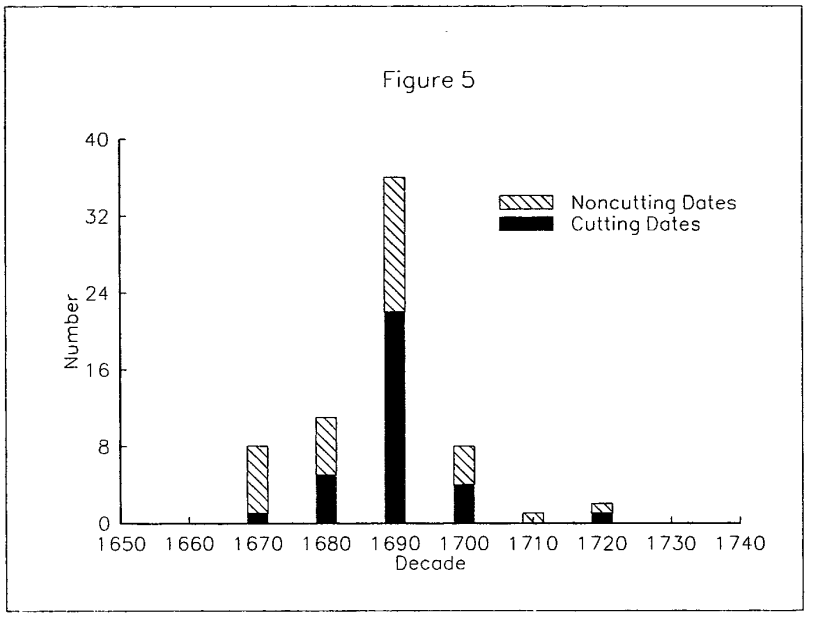

Figure 5. Tree-ring date distribution for the period bracketing the Establishment phase (A.D. 1680–1709) at Walpi Pueblo, grouped by decade.

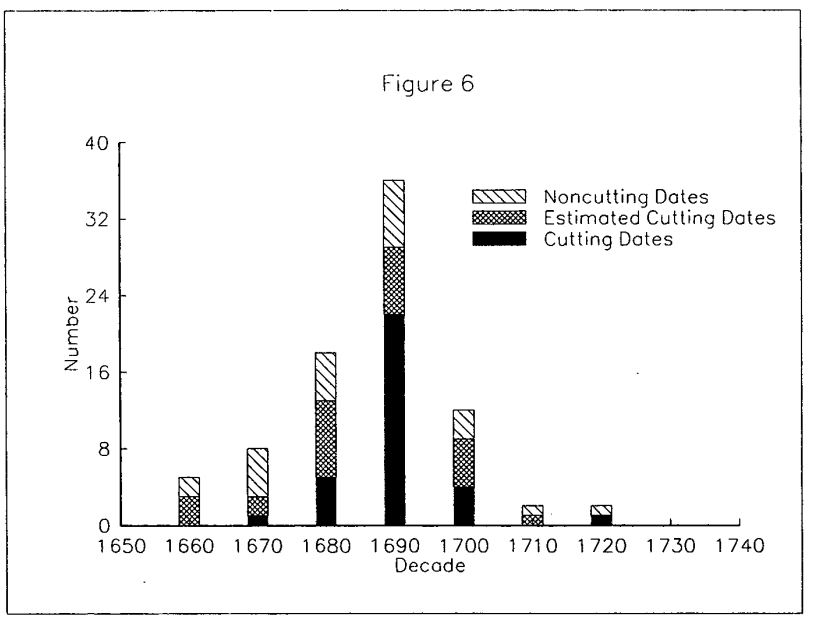

Figure 6. Tree-ring date distribution for the period bracketing the Establishment phase (A.D. 1680–1709) at Walpi Pueblo with estimated cutting dates, grouped by decade. Confidence intervals for the estimates are not indicated.

early seventeenth century, late nineteenth century, and early twentieth century.

Figure 8 presents the same distribution after 121 cutting dates have been estimated. While confidence intervals are not indicated in the figure, it is clear that estimated cutting dates augment peaks in the aggregate date distribution curve, amplifying the previously noted date concentrations in the 1410s and 1420s, the 1610s, 1620s, and 1630s, the late seventeenth century, and the decades surrounding the turn of the twentieth century.

The estimates were particularly effective in reducing the number of noncutting dates at the early end of the date distribution, particularly in the early 1400s. The number of noncutting dates during the Establishment phase might have been further reduced save for the fact that many specimens from this period are juniper and therefore lie beyond the scope of this analysis. The concentration of noncutting dates in the late 1800s and early 1900s (Figure 7) is interesting because estimates were less effective in reducing the number of noncutting dates from this interval (Figure 8). This is simply a function of age. Specimens occupying the later end of the date distribution have been exposed to the elements for less than a century, and their outer surfaces have not suffered the serious decay characteristic of centuries-old specimens. They therefore retain most, if not nearly all, of their original sapwood complement. Because estimated cutting dates are calculated on the basis of a statistical relationship between the number of sapwood rings and the number of heartwood rings, there remains a 50 percent chance that a predicted cutting date will underestimate the known outer date. In such situations, the estimated cutting date is dropped from consideration, and the noncutting date is retained.

Analysis of the aggregate date distribution curve at Walpi Pueblo clearly demonstrates that known tree-ring date concentrations can be augmented and amplified by estimated cutting dates and therefore may be used to identify date concentrations at less-well-dated sites characterized by ponderosa pine and Douglas fir noncutting-date wood specimens.

Discussion

Walpi Pueblo is better understood chronometrically and chronologically than any other site, archaeological or historic, in the Southwest. It therefore serves as an ideal test case on which to evaluate the efficacy of this cutting-date estimation technique.

The interpretation of estimated cutting dates within localized proveniences must be undertaken with caution for two reasons. First, estimates are based on a calculated prediction of the mean number of sapwood rings for a specimen with a given number of heartwood rings, and the actual mean value has a 68 percent chance of falling within an interval of 24 years for Douglas fir and 48 years for ponderosa pine. Second, cutting dates estimated on the basis of an incomplete heartwood complement (i.e., specimens without pith dates or those missing heartwood from their outer portions) will by definition underestimate the actual cutting date. Individual cutting-date estimates should therefore be considered in light of the architectural, archaeological, and dendrochronological contexts from which they derive, and suggested changes in the interpretation of the construction sequence at any locality should be treated as hypotheses that require further testing.

The analysis of estimated cutting dates within aggregate date distribution curves seems less prone to difficulty. The Walpi example suggests that estimated cutting dates can amplify date concentrations and may identify previously unrecognized tree-cutting and construction periods. Again, contextualizing data must be analyzed to test hypotheses suggested by the estimates.

Conclusion

Previous attempts to develop cutting-date estimation techniques have not proven widely applicable or successful. Unpublished studies focus on the dating of one particular type of artifact (Robinson and Ahlstrom 1980; Stallings 1940); published studies estimate cutting dates for archaeological samples in particular regions (Graves 1991; Plog 1980). The statistically reliable cutting-date estimation technique presented here is applicable to any archaeological site with ponderosa pine or Douglas fir wood specimens on which most of the original heartwood complement is preserved. Critical evaluation of estimated cutting dates may help solidify the chronometric placement of poorly dated archaeological sites in the American Southwest.

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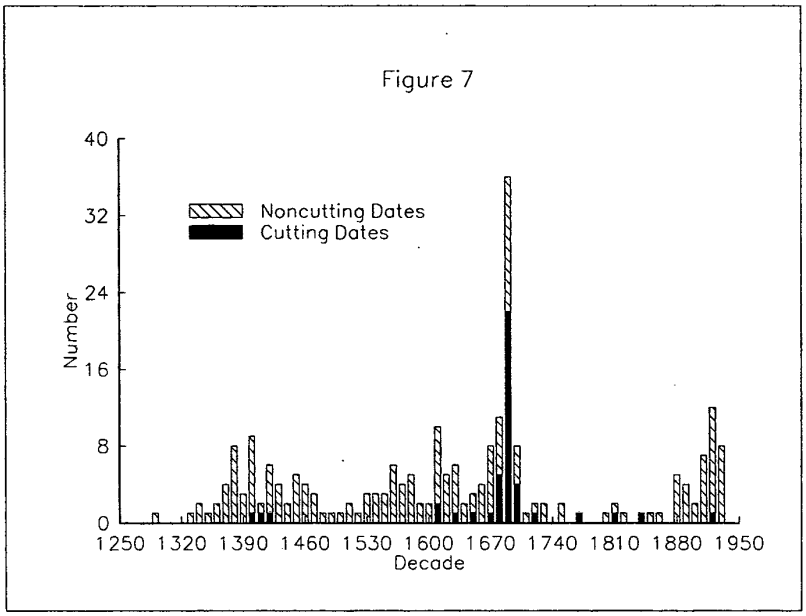

Figure 7. Tree-ring date distribution curve for Walpi Pueblo (A.D. 1250–1950), grouped by decade.

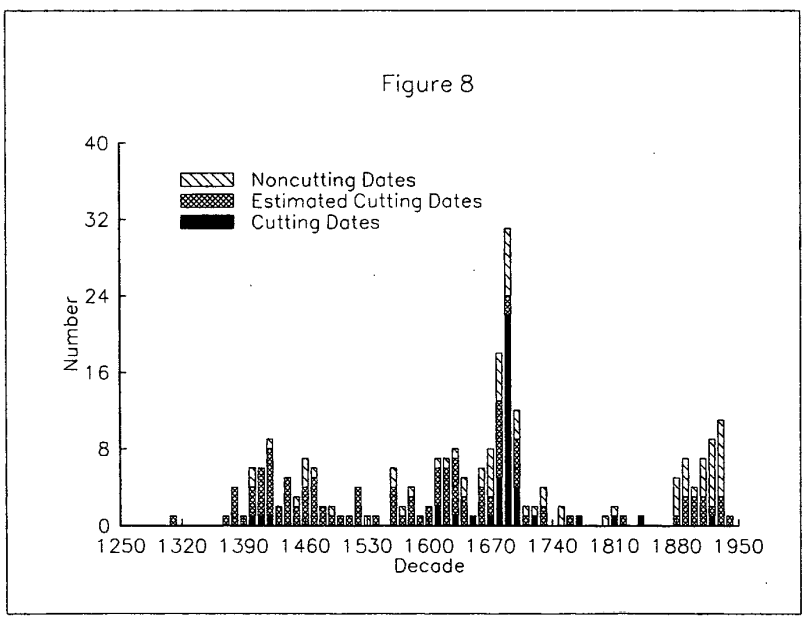

Figure 8. Aggregate tree-ring date distribution curve for Walpi Pueblo (A.D. 1250–1950) with estimated cutting dates, grouped by decade. Confidence intervals for the estimates are not indicated.

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Notes

1. Nash (1993) analyzed 221 Douglas fir and 200 ponderosa pine specimens, arbitrarily selected from archaeological and modern contexts and without regard to pith or cutting dates, to estimate tree age on the basis of the number of heartwood rings. The equations presented herein supersede.

2. As noted above, 18 specimens were removed from the analysis because their inner dates were clearly far (more than about 10 rings) from pith, although 34 specimens whose inner dates were less than about five rings from pith, based on professional assessments of ring curvature, were retained in the analysis. The estimated cutting dates for these specimens, like those from Room 20, which were missing heartwood from the outer surface, should be considered minima and should be evaluated on a case-by-case basis in light of accompanying contextual data.

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