A Cutting-Date Estimation Method for Two Archaeologically Important Tree Species

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Abstract. Regression equations are developed to describe the relationship between heartwood, sapwood, and tree age in ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*), two archaeologically important Southwestern tree species. These equations are used to estimate cutting dates for dendrochronological specimens that otherwise offer only noncutting dates. Three case studies are presented that test the efficacy and interpretive utility of the method: Cutting date estimates on living-tree cores allow an analysis of the statistical behavior of the cutting date estimates; and archaeological case studies at Zuni Pueblo and Walpi Pueblo allow consideration of local provenience and site-level interpretations of the cutting-date estimates. It is concluded that archaeological contextual information and simple logic must be considered before a cutting-date estimate is accepted at face value. In addition, the disparate nature of the methods and data suggest that statistical estimation techniques and archaeological dendrochronology should be considered together only with great caution.

Introduction

This paper summarizes efforts to describe quantitatively and utilize productively the relationship between heartwood, sapwood, and tree age in ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*), two archaeologically important tree species of the American Southwest. The paper is divided into three parts: The first contains a review of necessary background definitions and literature; the second explains the data collection, analytic techniques, and results of the analysis; the third presents case studies in which the regression equations developed to estimate cutting dates are applied to living-tree cores of known cutting date and to archaeological tree-ring samples from Zuni and Walpi Pueblos. The interpretive utility of the cutting-date estimation method is then examined.

Dendrochronology Terms

A review of basic dendrochronological terminology is necessary here. If a tree-ring specimen is datable, the process by which dates are conclusively assigned to it is called "crossdating" (Dean 1978). Crossdating is *not* equivalent to simple ring-counting, as many archaeologists believe. Crossdating is "the procedure of matching ring-width variations...among trees that have grown in nearby areas, allowing the identification of the exact year in which each ring was formed" (Fritts 1976:534). When a specimen has been crossdated, the dendrochronologist gives the archaeologist two dates–an inner date and an outer date. Inner dates are then modified depending on their relationship to the center of the tree (the pith); outer dates are modified depending on whether they are "cutting" or "noncutting dates."

"Cutting dates" are given to tree-ring samples containing evidence that the outermost ring on the specimen is also the ring last grown by that tree before it died (Ahlstrom 1985:38). Because cutting dates indicate tree death dates, they are directly related to prehistoric wood-procurement and use. Cutting dates therefore have high chronometric and interpretive value for the archaeologist (Dean 1978).

"Noncutting dates" indicate only the year in which the last layer of xylem cells present on a given dendrochronological specimen was produced (Dean 1978:226). A noncutting date does not necessarily indicate tree death date, and is therefore of less interpretive utility to the archaeologist. Ahlstrom provides a useful discussion:

> A sample is given a noncutting date when definite evidence for a cutting date is lacking and, as a consequence, there is no way of knowing how many rings, if any, have been eroded from the sample's outer surface...Because of the probability of ring loss, noncutting dates are biased estimates–always in the early direction—of cutting or death dates (Ahlstrom 1985:38).

A major obstacle to the chronometric interpretation of archaeological sites has been that most tree-ring specimens provide the less useful, noncutting dates and, despite previous attempts (discussed below), no effective means have yet been devised to mitigate the chronometric effects of the "biased estimates" provided by noncutting dates.

This paper describes a recent attempt to develop a method whereby cutting dates may be estimated for specimens that otherwise yield only noncutting dates. If the method proves statistically reliable, the chronometric placement of archaeological sites in the American Southwest might be solidified. Additionally, when examined in light of their archaeological and architectural contexts, cutting-date estimates may point to necessary revisions in individual site-construction histories.[1]

Tree Physiology Terms

This paper specifically deals with empirical relationships between the number of heartwood rings and tree age in ponderosa pine and Douglas fir. As such, a discussion of the nature of heartwood is appropriate. Hillis (1971:279) defines "heartwood" as:

> The inner layers of wood which, in the growing tree, have ceased to contain living cells (whereas the sapwood contains living parenchyma) and in which the reserve materials (e.g., starch) have been removed or converted into heartwood substances.

This definition, as well as others in the literature, is relatively vague, for the true nature of heartwood and the processes leading to heartwood formation are still poorly understood (see Fritts 1976:62). However, it is known that heartwood is characterized by one or more of the following: cell death, diminished nutrient content, increased extractives content, reduced permeability and moisture, increased disease resistance, and lower pH (Hillis 1968, 1971; Shigo and Hillis 1973). For the purposes of this study, heartwood is the darker, inner portion of the tree, and "sapwood" is "the lighter colored outer water-conducting portion of the tree stem with the living ray tissue" (Fritts 1976:543).

This is not the appropriate forum to attempt a comprehensive review of theories about the physiological causes and mechanisms responsible for heartwood formation. What limited consensus is reached in the literature really indicates a surrender to the complexity of the situation. Heartwood formation is found to be due to a "complicated system of combined reactions within the parenchyma cells" (Fengel 1970:177). Recent research suggests that heartwood formation is primarily related to providing mechanical support for the physiologically active portions of the tree:

> Sapwood cross-sectional area ***at any height*** on the bole of the tree was found to be related linearly to the amount of foliage above that point. However, in large trees the sapwood area needed to supply transpiring foliage water is insufficient to provide mechanical support. The combination of sapwood and heartwood was found to provide the stem form that would be expected to ensure uniform resistance to bending by the wind (Long et al. 1981, emphasis in original).

For the purposes of this study, the debate over heartwood formation processes is of no concern, so long as there is a demonstrably regular developmental relationship between heartwood and sapwood.

Literature Review

Since the initial development of dendrochronology in the early part of this century, sporadic attempts have been made to describe the nature of the heartwood/sapwood relationship in various tree species. The earliest examination of the heartwood/sapwood relationship for archaeological purposes was by Douglass (1939). A concurrent study was published by Stallings (1939), who attempted to use the heartwood/sapwood relationship to estimate dates of construction of ponderosa pine *santos*—Spanish colonial paintings on radial cross-sections of ponderosa pine—housed at the Taylor Museum in Colorado Springs, Colorado. In 1980, William J. Robinson and Richard V.N. Ahlstrom (1980), of the Laboratory of Tree-Ring Research at the University of Arizona, reexamined Stalling's work using modern statistical techniques. The most comprehensive archaeological study of the heartwood/sapwood relationship is offered by Hughes et al. (1981). These are reviewed below in chronological order.

In the 1920s and 1930s, dendrochronologists provided archaeologists with dates for the inner and outer crossdated rings on any given dendrochronological specimen and then would add a "plus-or-minus" ("±") term as a subjective assessment of how many rings at one time might have been present on the outside of the specimen. Such assessments were predicated on the (erroneous) assumption that all tree species possess roughly 50 sapwood rings. If 20 sapwood rings were present on a given specimen, the dendrochronologist would assume that 30 sapwood rings could be missing from the outside and would add "±30" to the latest crossdated year indicated on that specimen.

The past use of the "±" term is unfortunate, for it is often confused with a standard deviation from some mean value. It cannot be stated too strongly that in this usage, the plus-or-minus term is ***not*** a statistical assessment and does ***not*** indicate a standard deviation from mean. The "±30" term really means that anywhere from one to 30 sapwood rings may have been missing from the outside of the specimen. It is a matter of historical accident that the "±" notation was used, since one cannot actually subtract extant rings from a crossdated specimen to conform to a date suggested by the plus-or-minus term.

In 1939, Douglass noted 1) the fallacy of assuming that ***all*** dendrochronologically important tree species have approximately 50 sapwood rings and 2) that the use of such a value led to consistent, species-specific, cutting-date estimation errors. Douglass then argued that ponderosa pine typically has 60±20 (i.e., between 60 and 80) sapwood rings and that, by assuming the presence of 50 sapwood rings, ponderosa pine cutting-dates were consistently underestimated. Alternatively, Douglass felt that Douglas fir typically has 30±30 (i.e., between 30 and 60) sapwood rings and that cutting dates for most of these specimens were overestimated.

The new sapwood values proposed by Douglass were never adopted by other dendrochronologists, and the practice of estimating cutting dates by including a plus-or-minus term with the outside date of a dendrochronological specimen ended shortly thereafter. A quick perusal of the *Tree-Ring Bulletin* reveals that the last published use of the "±" terms occurred in Douglass' (1944) report on the dendrochronology of Forestdale Ruin in east-central Arizona. In fact, the symbol system used by the Laboratory of Tree-Ring Research today (see Ahlstrom 1985) first appeared in 1946 in a report on the archaeological dendrochronology of Mesa Verde National Park (Schulman 1946).

At the time Douglass was working, Stallings (1939) examined the heartwood/sapwood relationship in 334 modern ponderosa pine cores to estimate manufacture dates for Spanish *santos*. Robinson and Ahlstrom (1980) expanded Stalling's analysis to include 559 more ponderosa pine cores and utilized more rigorous statistical techniques to improve upon and confirm Stalling's results. These studies constitute the impetus for the current analysis because of their narrow focus—they attempted to estimate cutting dates for a specific type of historical artifact made out of one species of wood. Their studies are "demand sided" (i.e., addressed to a specific problem), and the results obtained are therefore not broadly applicable to other problems.

The current study is "supply sided." The Laboratory of Tree-Ring Research at the University of Arizona houses an unparalleled collection of archaeological and modern tree-ring specimens and therefore constitutes the perfect setting in which to undertake research on the general nature of the relationship between heartwood, sapwood, and tree age. The results presented here constitute one application of the heartwood/sapwood data gathered on specimens of four tree species: Douglas fir, ponderosa pine, pinyon pine (*Pinus edulis*) and juniper (*Juniperus* sp.).

Data Collection and the Data Base

Data collection was designed so that replicability of measurements could be assured. While this remains to be fully tested, the following discussions assume that data collected for this study can be easily replicated within acceptable levels of precision and accuracy.

The active database for this study consists of data on 200 Douglas fir and 221 ponderosa pine cores arbitrarily selected from the extensive population of specimens curated at the Laboratory of Tree-Ring Research at the University of Arizona. "Arbitrarily selected" means that the process was not governed by any particular research design, nor was it statistically random. Despite the "unscientific" nature of sample acquisition, the results offered below argue against the need for strict sampling methods: The physiological relationships between heartwood, sapwood, and tree age in the species analyzed are found to be very structured no matter what the sampling strategy.

Slightly more than half of the current sample is represented by 4mm-diameter increment cores collected at living tree stands as part of the Southwestern Paleoclimate Project (see Dean and Robinson 1977). Slightly less than half the specimens are 10mm-diameter cores collected at various times from archaeological sites across the American Southwest. The sample thus contains specimens from many different microenvironments, from trees of vastly different ages, and from trees of unknown growth provenience (i.e., one usually cannot tell where native inhabitants of an archaeological site obtained their wood). The sample is sufficiently large that we may assume the sampling universe is represented. Indeed, the fact that strong statistical relationships are revealed within this arbitrarily selected sample, compiled without any initial and overt consideration of heartwood and sapwood parameters, suggests that general relationships between the variables are species specific and that, for our purposes, microclimatic, site-specific, environmental, or idiosyncratic variability are relatively minor factors in heartwood, sapwood, and tree age relationship.

Statistical analyses were conducted with the dBase IV, Minitab, and Axum software packages. Linear regression equations were calculated in dBase according to methods outlined by Snedecor and Cochran (1967). Curvilinear regression equations were calculated in Minitab. All other descriptive statistics come from programs within the Axum graphics package.

Results

Douglas Fir

As noted, heartwood in Douglas fir specimens is very easy to identify and measure—its dark brown color contrasts quite well with the off-white of the sapwood, and the boundary between the two is clear and does not vary much around the cross-section. Results presented in this section describe the general relationship between the number of heartwood rings and tree age for Douglas fir. Table 1 lists summary statistics for parameters; Table 2 lists correlation coefficients between several calendric and metric variables for Douglas fir specimens. Figure 1 illustrates graphically the relationship between number of heartwood rings and tree age for Douglas fir. This general relationship is described by Equation 1:

1) No. HW Rings = -22.5 + 0.8809(Age); r^2= 0.99

Figure 1 illustrates several points about heartwood formation in Douglas fir. First, heartwood formation begins between 25 and 40 years after germination, at which point the rate of heartwood formation remains

Table 1. Summary Statistics, Douglas Fir (N=221).

	Age (years)	Radius (cm)	Area (cm^2)	HwWidth (cm)	HwRings (no.)	SwWidth (cm)	SwRings (no.)
Min.	13	2.6	21.2	0.80	1	0.40	8
Max.	664	37.9	4510	36.00	605	8.00	120
Mean	229	15.74	1008	12.99	179	2.73	50
Median	229				179	48.50	
StDev	167.3	8.6	876	8.30	148	1.29	26

Table 2. Correlation Coefficients, Douglas Fir Cores (N=221).

Independent Variable	Dependent Variable	r^2
Age	# Heartwood Rings	.99
Radius	Heartwood Width	.98
Age	Radius	.50
Age	Heartwood Width	.57
Age	# Sapwood Rings	.58
Age	Sapwood Width	.03
Radius	Heartwood Rings	.48
Radius	Sapwood Width	.08
Radius	# Sapwood Rings	.33

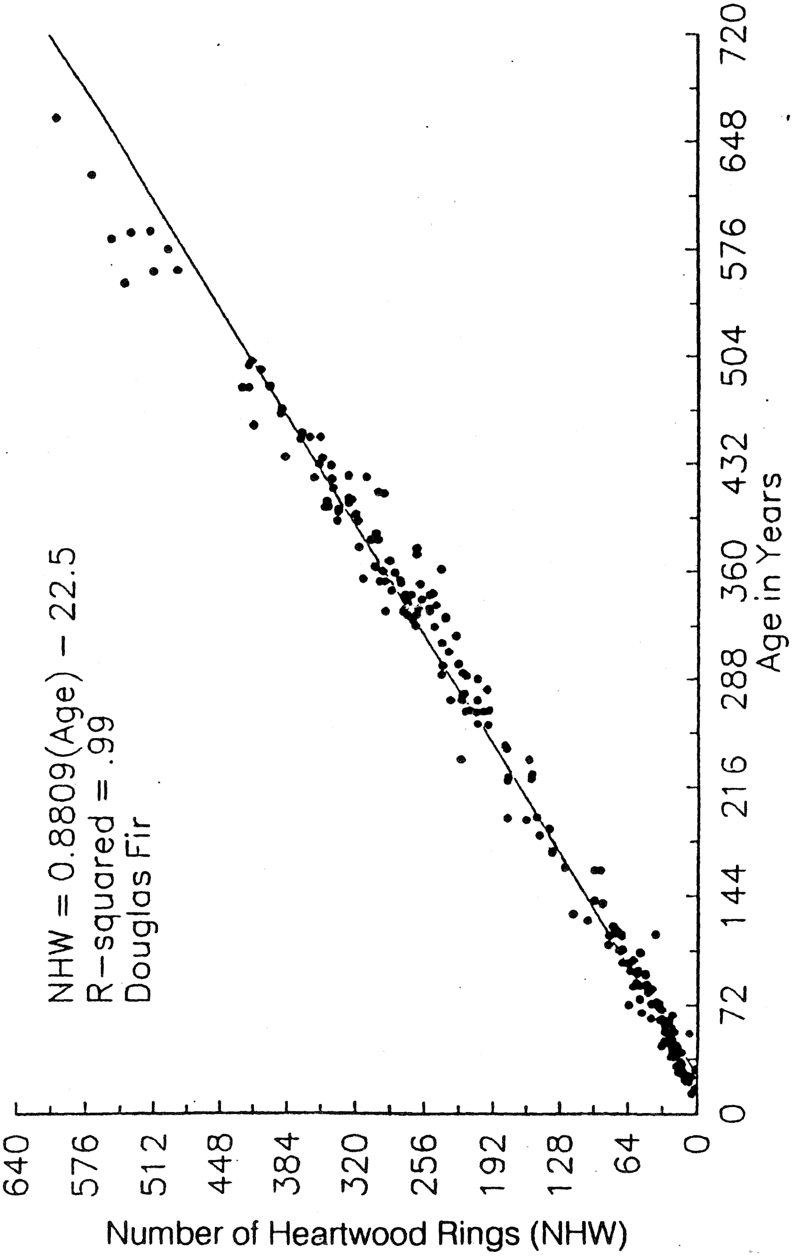

Figure 1. Number of Heartwood Rings vs. Tree Age, Douglas Fir.

remarkably constant throughout the life of the tree. The correlation coefficient between number of heartwood rings and tree age is very high (0.99), suggesting that tree age explains 99% of the variation in the number of heartwood rings for Douglas fir. It should be noted that this high r-squared value (and the one offered for ponderosa pine below) may be artificially inflated due to the fact that two cores from each modern tree sampled are included in this database, and that the number of heartwood rings is in fact a component of tree age (Robinson and Ahlstrom 1980). Preliminary analysis of Douglas fir cross-sections suggests that heartwood/sapwood boundary variability in Douglas firs is such that data from two cores from the same tree may be redundant. However, given the fact that the database contains additional variability from 1) archaeological cores, which may or may not be given pith dates and cutting dates, and 2) modern cores, whose cutting dates are known but which may or may not be given pith dates, the high r-squared value is very reassuring.

Ponderosa Pine

Heartwood in ponderosa pine specimens is also very easy to identify and measure—its brown color contrasts with the yellow color of the sapwood, and the boundary between the two is clear and does not vary much around the cross-section. Results presented in this section describe the general relationship between the number of heartwood rings and tree age for ponderosa pine. Table 3 lists summary statistics for important ponderosa-pine parameters; Table 4 lists the correlation coefficients between several calendric and metric variables for ponderosa-pine specimens.

Table 3. Summary Statistics, Pondersosa Pine (N=200).

	Age (years)	Radius (cm)	Area (cm^2)	HwWidth (cm)	HwRings (no.)	SwWidth (cm)	SwRings (no.)
Min.	24	2.6	21.2	0.0	0	1.2	5
Max.	399	34.0	3630.0	29.0	320	25.2	189
Mean	169	16.7	1242.3	9.0	82	7.5	87
Median	209				77		
StDev	122	10.8	1169.0	8.5	84	4.3	46

Table 4. Correlation Coefficients, Ponderosa Pine Cores (N=200).

Independent Variable	Dependent Variable	r^2
Age	# Heartwood Rings	.90
Radius	Heartwood Width	.94
Age	Radius	.59
Age	Heartwood Width	.77
Age	# Sapwood Rings	.21
Age	Sapwood Width	.04
Radius	Heartwood Width	.53
Radius	Sapwood Width	.37
Radius	# Sapwood Rings	.52

Figure 2 graphically illustrates the relationship between number of heartwood rings and tree age. The relationship is described by Equation 2:

2) No. HW Rings = -37.1 + 0.6614(Age); r^2= 0.901

The correlation coefficient between these two variables is 0.90, suggesting that tree age explains 90% of the variation in heartwood width. Heartwood ring formation begins 25 to 50 years after germination. Heartwood formation slows until about age 170, after which the process accelerates and becomes more variable.

The relationship illustrated in Figure 2 suggests that a curvilinear (polynomial) regression equation might better describe the observed distribution. Such an equation was calculated in Minitab, but the statistical attributes did not improve significantly; hence, the simple linear regression was retained.

Case Study: Estimates on Living-Tree Cores

Tests of the regression equations on modern cores with known cutting dates produced results that leave something to be desired and yet are somewhat reassuring. One hundred twenty-four cutting dates were estimated using the following equations:

3) Age = 0.9419(No. HW Rings) - 45.9

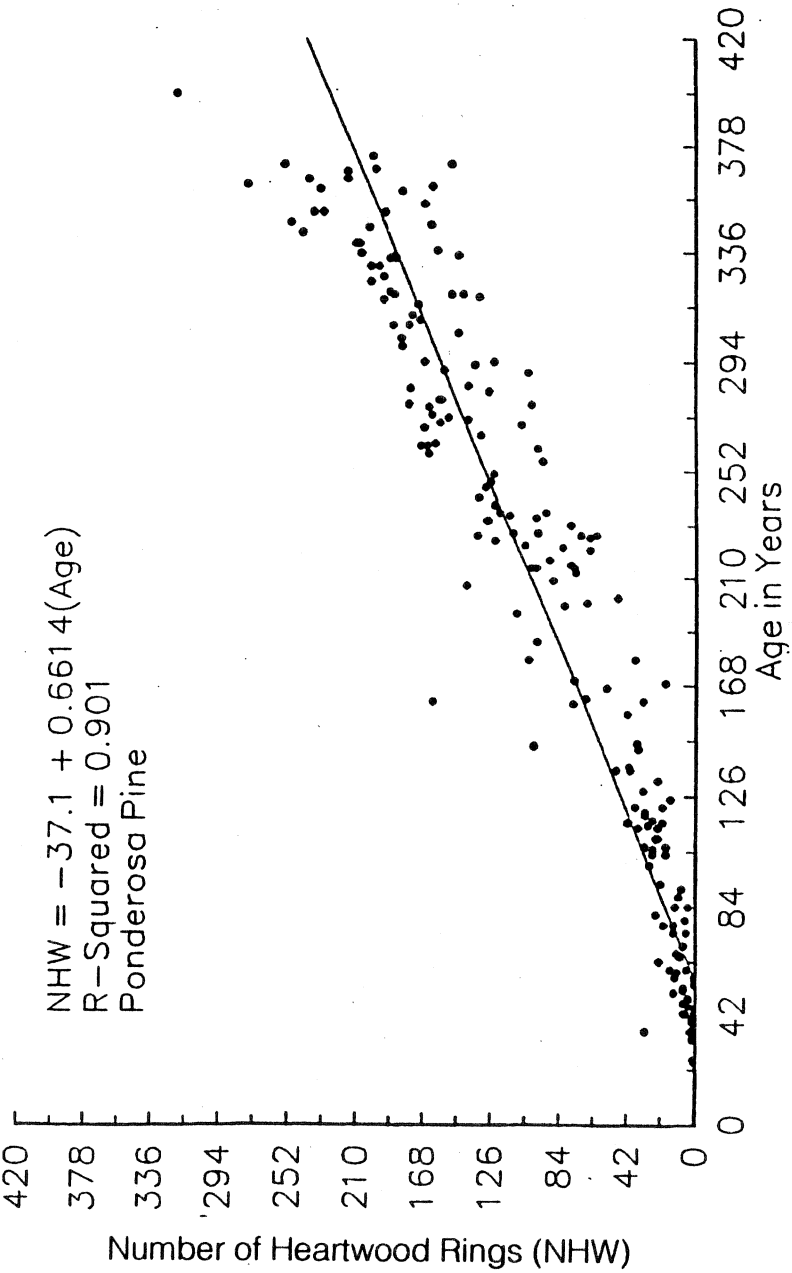

Figure 2. Number of Heartwood Rings vs. Tree Age, Ponderosa Pine.

This equation applies only to Douglas fir specimens with more than 96 heartwood rings present. Cutting-date estimates were calculated for 101 specimens.

4) Age = 0.8216(No. HW Rings) - 83.1

This equation applies only to ponderosa pine specimens greater than 170 years of age. Twenty-three cutting dates were calculated with this equation.

The astute reader will note that these equations are not those provided in the previous discussion of the general relationship between number of heartwood rings and tree age in ponderosa pine and Douglas fir. Equations 3 and 4 apply only to subsets of the overall dataset because equations from subsets of each database describe more accurately the relationship between heartwood and tree age. Summary statistics for the cutting dates provided by Equations 3 and 4 are provided in Table 5.

Cutting-date estimates for these modern cores tend to ***underestimate*** the actual, known cutting date. This is interesting: Given the statistical nature of least squares regression analysis, we expect the mean value (i.e., the regression line) to be overestimated about half the time and underestimated about half the time. This distribution obtains, but the data force us to explain why the summary statistics indicate that most of the cutting-date estimates underestimate the known cutting dates.

The answer seems to be that when a dendrochronologist uses an increment borer to sample a living tree, there is no guarantee that the fieldworker will strike pith. There is therefore no guarantee that a pith date (i.e., first year of growth of that tree) will be identifiable. The regression equations utilized in this analysis estimate cutting dates on the basis of the number of heartwood rings present on a specimen and, if pith is not present, an undetermined number of heartwood rings is missing. When that biased number of heartwood rings is used to estimate tree age, the cutting date will by definition be underestimated.

From an archaeological standpoint, this is not as much of a problem as it seems, because it is far better to underestimate the actual cutting date and to offer a chronologically minimal date than it is to provide overesti-

Table 5. Cutting-Date Estimate Summary Data, Living-Tree Cores.

Eq.	Description	N	Mean	Median	Std Dev	Low	High
Doug. fir	> 96 HwRings	101	-6.8	-8	16.5	-41	91
Pond. pine	>170 yrs	23	-9.0	-4	28.4	-76	36

mates of the actual cutting date. Two case studies that examine these issues are offered below, but a review of pertinent archaeological dating theory is necessary first.

Archaeological Dating Theory

Archaeology is by no means an exact science, and a body of archaeological dating theory has been developed to clarify the complex issues involved in evaluating individual site histories (Ahlstrom 1985:20-55; Dean 1978:223-4). Central to this theory is the "principle of contextual congruence," which assists the detection of "dating anomalies...on the basis of apparent inconsistencies between the dates and other archaeological data" (Dean 1978:250-1). With respect to cutting-date estimates, this means two things. First, logically inconsistent cutting-date estimates (i.e., those that fall ***earlier*** than the actual, known outer date offered by the dendrochronologist) may be discarded without reservation. Second, it means that functional interpretations offered by the archaeologist during sample collection must be given primary emphasis when evaluating a cutting-date estimate. This is discussed in greater detail below.

Dendrochronological dating theory also must consider another piece of contextual information, that of tree-ring date "clustering." A date cluster has been defined as "three or more dates falling in a brief time interval" (Ahlstrom 1985:59). The strength of a date cluster depends upon the number of dates in the cluster, the length of interval involved, and the relative number of noncutting and cutting dates (Ahlstrom 1985:60).

Several questions should be answered when considering estimated cutting dates in their prior context. First, it should be obvious that the entire suite of tree-ring dates from a given context must be considered together, for only in this way do we know the date distribution for that provenience. After cutting-date estimates are calculated, the new date-distribution for that provenience can be compared to the old.

When considering the before and after cutting date distribution tables, one should ask: How many cutting, noncutting, and estimated dates are there at each provenience? Has the relative ordering of the date distribution changed because of the estimates? Did the nature of clusters within that date distribution change, and, if so, how? Has a cutting-date estimate changed the apparent use or source of a particular beam? That is, does the cutting-date estimate suggest that what was thought to be reused timber may in fact be a repair beam?

The principle of contextual congruence, logic, and sheer common sense all come into play when considering these estimates. Accurate answers to the questions posed above enable the archaeologist to consider all data when evaluating the interpretive utility of a cutting-date estimate.

Case Study: Zuni Pueblo

A sample of archaeological specimens from Zuni Pueblo has been examined for this study. A total of 88 cutting-date estimates were made out of a total of several hundred samples considered. Most of those specimens removed from further analysis simply did not fit the criteria for any of the regression equations selected for use. Twenty-three of these 88 (28 percent) produced logically inconsistent cutting dates: estimated cutting dates that lie far outside the known date-distribution at that provenience or estimates that fell earlier than the actual, known noncutting date provided by the dendrochronologist. These logically inconsistent estimates were immediately removed from the analysis. The remaining 65 estimated cutting dates were then analyzed in light of their archaeological contexts to determine whether they enhance our ability to accurately date the site.

Table 6[2] lists the results of cutting-date estimates at Gahate House, Zuni Pueblo. Only three cutting dates were estimated, but the results served to tighten a (small) date cluster occurring in the late 1930s-early 1940s. It is not a very strong example, but it demonstrates that clustering can be developed without changing the relative order of a date distribution.

Room 8-3 at Upper Nutria (Table 7) provides a similar situation, but with one twist—the relative order of the dates has changed with new cutting-date estimates. Eight of the nine dates changed places in the ordering. A relatively weak cluster is developed in the mid-1890s, and a potentially reused beam (Zun 578) apparently changes function and becomes a repair beam. Original site reports and architectural drawings must be consulted before the plausibility of this conclusion may be evaluated.

Table 8 lists several examples from Zuni Pueblo in which the integrity of previously existing date-clusters were compromised by the estimation of cutting dates. Room 7 Feature 2 at Ojo Caliente has weak date clusters in the late 1920s and early 1940s; these clusters are destroyed by the cutting-date estimates. Similarly, Room 15-4 at Upper Nutria has a weak cluster in the 1920s destroyed by the estimates. Despite the fact that in these instances only weak, noncutting date clusters were compromised by the estimates, it should be noted that only in rare instances should cutting-date estimates be allowed to compromise the integrity of ***any*** date cluster present in a site's original date-distribution.

Table 6. Weak Cluster Developed by Cutting-Date Estimation, Zuni Pueblo: Gahate House

Trial #	Beam #	Outdate	Cutting-Date Estimate
Zun 95	6	1808vv	1808vv
Zun116	27	1811vv	1811vv
Zun 92	3	1815vv	1815vv
Zun110	21	1846+vv	1846+vv
Zun101	12	1854vv	1854vv
Zun 91	2	1859vv	1859vv
Zun109	20	1870vv	1870vv
Zun103	14	1877vv	1877vv
Zun102	13	1897vv	1897vv
Zun113	24	1907vv	1912vv
Zun105	16	1912vv	1916vv
Zun99	10	1916vv	1919vv
Zun112	23	1919vv	1922vv
Zun114	25	1919vv	1930vv
Zun 94	5	1922vv	1934vv
Zun 90	1	1930vv	1937vv
Zun106	17	1934vv	1937vv
Zun100	11	1937vv	1939est
Zun104	15	1937vv	1940vv
Zun 97	8	1940vv	1941vv
Zun106	17	1941vv	1944vv
Zun118	29	1943vv	1945est
Zun115	26	1944vv	1947est
Zun 98	9	1957+rG	1957+rG
Zun111	22	1957+rG	1957+rG
Zun 96	7	1957+r	1957+r
Zun117	28	1957+vv	1957+vv

As noted above, there are situations resulting from cutting-date estimation in which the apparent source or function of a beam (reuse, repair, etc.) seems to change, while date clustering is not affected. Table 9 lists the date distributions for several such examples. Room 20-2 at Ojo Caliente illustrates the problem quite well—the room has no dates after 1900, yet the cutting-date estimate for one of the specimens suggest a repair event in 1961! Obviously, contextual information and simple logic will confirm or deny the validity of this (probably) anomalous date. Similarly, Room 10-3 at Upper Nutria has a nice terminal cluster at 1935, but with the cutting-date estimations a possible reused beam (Zun 598) is best explained as a repair beam.

Table 7. Cutting-Date Estimates with Changed Relative Order of Dates, Zuni Pueblo: Upper Nutria.

Trial #	Beam #	Outdate	Cutting-Date Estimate
Zun572	8-3-2	1816vv	1875est
Zun578	8	1850vv	1876est
Zun576	6	1855++vv	1889est
Zun577	7	1880++vv	1893est
Zun571	1	1883vv	1894est
Zun575	5	1889vv	1895est
Zun574	4	1890vv	1899est
Zun579	9	1890vv	1905est
Zun573	3	1891vv	1906est

Table 8. Cluster Integrity Compromised by Cutting-Date Estimates, Zuni Pueblo.

Trial #	Beam #	Outdate	Cutting-Date Estimate
Zun545	7 ft 2	1796vv	1856est
Zun550	"	1838vv	1894+vv
Zun548	"	1894+vv	1897est
Zun553	"	1905vv	1913est
Zun551	"	1917vv	1919est
Zun549	"	1927vv	1927vv
Zun543	"	1928vv	1928vv
Zun547	"	1928vv	1937est
Zun552	"	1943B	1943B
Zun546	"	1943vv	1943vv
Zun544	"	1946+vv	1954est
Zun637	15-4-1	1771vv	1809est
Zun644	8	1780+vv	1829est
Zun645	9	1860+v	1860+v
Zun630	2	1917vv	1919v
Zun640	4	1919v	1920vv
Zun642	6	1920vv	1922vv
Zun643	7	1920vv	1923vv
Zun641	5	1922vv	1932est
Zun639	3	1923vv	1950est

Table 9. Apparent Change in Source or Function of Beams, Zuni Pueblo.

Trial #	Beam #	Outdate	Cutting-Date Estimate
Zun408	2	1869v	1869v
Zun409	3	1888vv	1891vv
Zun415	9	1891vv	1892vv
Zun417	12	1892vv	1897vv
Zun411	5	1897vv	1897vv
Zun410	4	1897vv	1961est
Zun593	10-3-2	1804vv	1866est
Zun598	6	1926vv	1934est
Zun602	10	1927vv	1934vv
Zun596	4	1934vv	1934vv
Zun601	9	1934vv	1935vv
Zun593	1	1935vv	1935vv
Zun597	5	1935vv	1935vv
Zun599	7	1935vv	1935vv
Zun600	8	1935vv	1935vv
Zun603	11	1935vv	1935v
Zun595	3	1935v	1945est

These case studies illustrate the interpretive problems associated with the use of cutting-date estimates in date distributions from localized proveniences. It is important to remember that these estimates are statistical and that contextual information and logic must override cutting-date estimates, should they be clearly anomalous. In other words, the cutting-date estimate is necessarily "guilty" until proven "innocent."

Case Study: Walpi Pueblo

The second, larger scale case study comes from Walpi Pueblo on First Mesa in northeastern Arizona. In 1977, The Laboratory of Tree-Ring Research collected 1189 dendrochronological samples at Walpi Pueblo (Ahlstrom et al. 1991). Of these, 462 specimens were dated, and 39 percent (N=180) of these provided cutting dates. The chronological site history of Walpi Pueblo is far better known than that of most other archaeological, protohistoric, and historic sites, due to good dendrochronological and excellent textual data. However, 61 percent of the dated specimens at Walpi yield only noncutting dates. The Walpi material therefore constitutes an excellent case study in which to examine the behavior of cutting-date estimates at a site with an extensive, yet well-understood, date distribution.

During the Establishment Period at Walpi Pueblo (A.D. 1680-1709), a great deal of construction activity is indicated by the tree-ring date distribution (Figure 3). This distribution consists primarily of cutting dates (79 of 113, 70 percent); these tend to cluster between A.D. 1687 and A.D. 1700. Cutting dates were estimated for the 34 noncutting date specimens, and, although the individual dates are not provided here, the resulting date distribution is presented in Figure 4. The date distribution has not shifted in time, though the date clusters of 1694, 1696, 1698, and 1699 are strengthened. A few cutting dates have been added in the first decade of the 18th century and contextual information must be consulted to determine whether these specimens are repair beams.

If we examine the entire distribution of tree-ring dates from Walpi Pueblo, the peak in construction activity at the Pueblo during the 1690s is clear, though other clusters are evident also. Figure 5 presents the date distribution after cutting-date estimates are made on all information on all of the 282 noncutting-date specimens for which an estimate was possible. The cluster present in the late 1690s is again solidified, as are date clusters around the 1830s and the 1900s. This latter cluster occurs during the Readjustment Period, named because of changes resulting from the permanent association between the Hopi inhabitants of Walpi and Anglo-Americans (Ahlstrom et al. 1991:631). Indeed, both the pre- and post-estimate date distributions for this period indicate the intense remodeling that occurred during the Readjustment Period at Walpi (Figure 6).

The Walpi example illustrates that clusters of tree-ring dates may be strengthened by cutting-date estimates, but the critical reader may justifiably ask, "So what? The clusters were already present in the previous date-distribution." The necessary next question then must deal with interpretive changes. Are there any behavioral or interpretive changes warranted by the cutting-date estimates? The answer is ostensibly no, for the apparent construction phases outlined by Ahlstrom, Dean, and Robinson (1991) do not change. However, several things should be remembered about the selection of Walpi as a test case.

Walpi was selected as a test case for this analysis precisely because its chronometric status is unusual. No other site in the Southwest has been the focus of so much dendrochronological research, and the site and roomblock construction histories at Walpi are far better documented than anywhere else. The nature of the dendrochronological sample is truly unusual, for the date distribution is bolstered by a truly remarkable proportion of cutting dates. Additionally, the sample from Walpi included a large number (282) of noncutting-date specimens for which cutting-date estimates could be

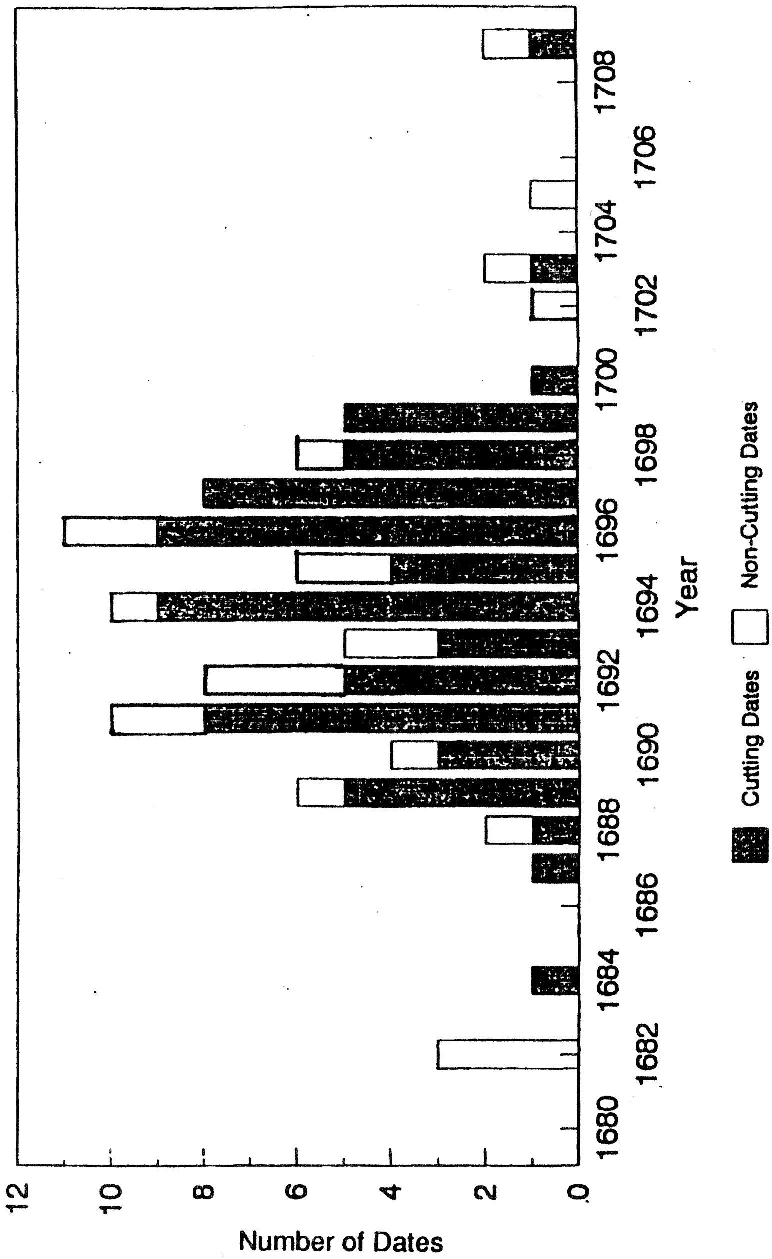

Figure 3. Establishment Phase Tree-Ring Date Distribution at Walpi Pueblo, A.D. 1680-1710.

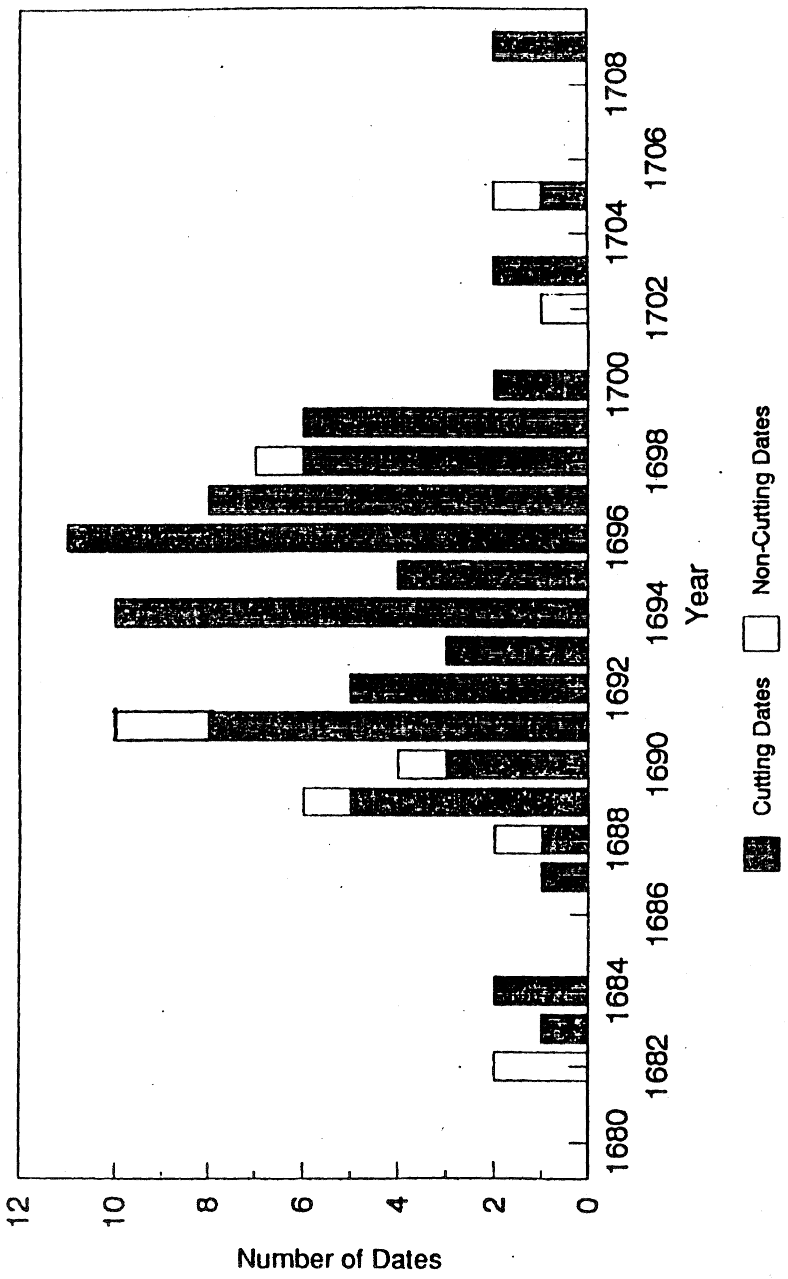

Figure 4. Estimated Establishment Phase Tree-Ring Date Distribution at Walpi Pueblo, A.D. 1680-1710.

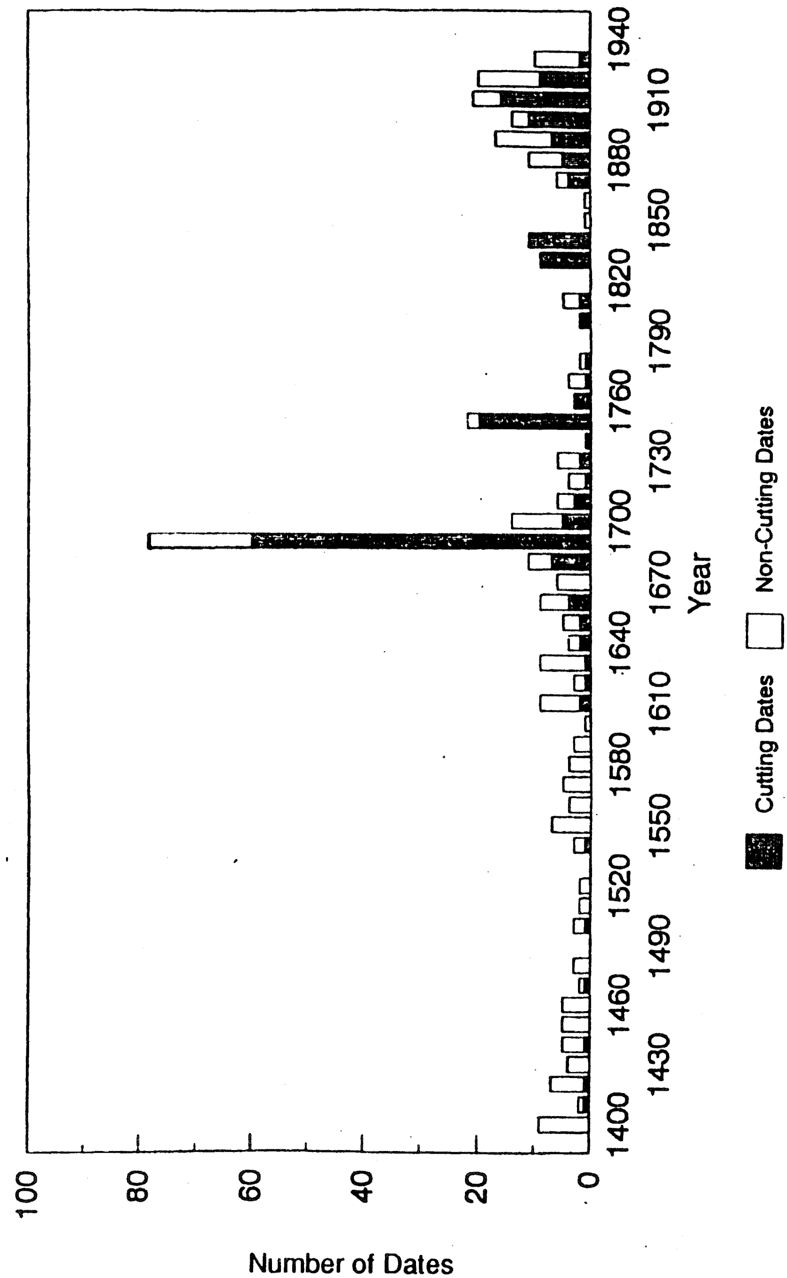

Figure 5. Walpi Pueblo Total Tree-Ring Date Distribution by Decade, A.D. 1400-1940.

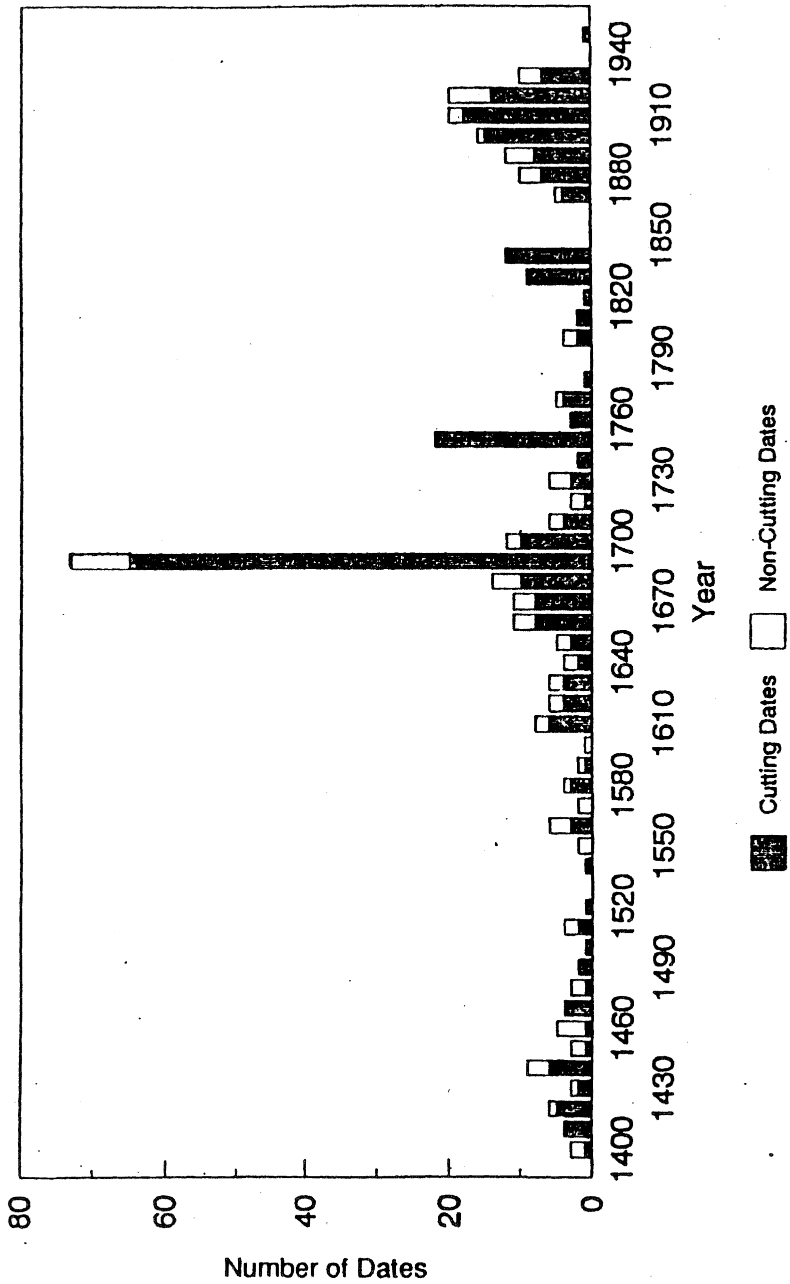

Figure 6. Estimated Walpi Pueblo Total Tree-Ring Date Distribution by Decade, A.D. 1400-1940.

attempted. This case illustrates that even in the best-case scenarios (i.e., excellent contextual information, large sample size, good relative proportions of cutting to noncutting dates), the cutting-date estimation technique developed here does not provide results that affect site interpretation, at least at this "macro" level. Analyses are underway to examine the Walpi date-distributions at the "micro" level (like the Zuni case study above), but this complex analysis is not yet completed.

Discussion and Conclusions

This paper has attempted to do three things: 1) provide descriptions of the heartwood/sapwood/tree-age relationship in two archaeologically important tree species; 2) utilize the described relationships in calculating statistically reliable regression equations that allow cutting-date estimation on the basis of the number of heartwood rings on a sample; and 3) test the interpretive utility of the cutting-date estimates on modern cores and on small- and large-scale archaeological case studies.

The first two tasks listed above were satisfactorily completed: The relationship between tree growth parameters is sufficiently structured in the two species examined that significant regression equations were derived. Unfortunately, tests of the interpretive utility of the cutting-date estimates produced results worse than expected.

More testing is obviously necessary, but these preliminary results point to some problems in the cutting-date estimation method. Regression analysis assumes that the data are independent, normally distributed, and that residuals are normally distributed about a mean value. (The first task of this paper was to describe an empirical relationship between two variables known to be dependent, therefore violation of the first assumption is not important here.) Cutting-date estimates derived via regression analysis are therefore statistical estimates of a mean value; they have a certain probability of being correct, but they are ***not*** "dates" in any absolute sense. Dendrochronological data, on the other hand, are absolute: "[They] place an event in a definite, circumscribed interval on a temporal time scale. In statistical terms, there is a probability of 1.0 that the stated interval includes the true date of the event" (Ahlstrom 1985:23). It is important to note that, while the numbers offered by dendrochronologists and the cutting-date estimation method may appear similar, their true nature is radically different.

The case studies presented above suggest that, because of the differences in type of data offered by crossdating and statistical estimation, the current best use of the estimation technique is on samples from sites like Walpi. In Walpi there is a large sample with a majority of noncutting dates but with sufficient cutting dates so that the date distributions with and without cutting-date estimates may be evaluated in light of archaeological contexts with some degree of confidence. In this manner, cutting-date estimates should be considered within decadal boundaries (i.e., the 1690s at Walpi), rather than as individual "dates," as in the Zuni Pueblo applications.

The results of this preliminary "supply-sided" exploration of the heartwood/sapwood relationship for cutting-date estimation have been at once encouraging and sobering. Due to the disparate natures of dendrochronological and statistical data, the technique provides misleadingly precise estimated cutting "dates," which should not be considered alone. Further testing is necessary to determine whether the technique is still useful for considerations of aggregate date-distributions, wherein dendrochronological and statistical sets of data may more profitably meet.

Notes

[1]It should be noted that the heartwood/sapwood relationships described here are important to other sciences. Foresters and tree physiologists require this information for timber quality assessments and the development of forest management plans. Dendroclimatologists may utilize these data if the heartwood/sapwood relationship is found to be related to forest stand microenvironments. These applications are being considered, and will be presented in the future.

[2]In the tables below, the original date distribution is listed on the left, and the date distribution after cutting-date estimation is listed on the right. Lines are drawn between the estimated cutting date on the right and the original noncutting date on the left.

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