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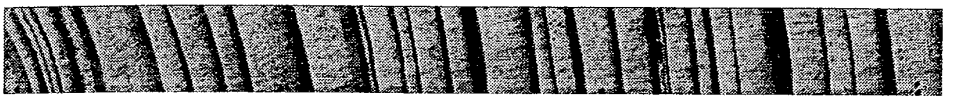

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DENDROCHRONOLOGY AND THE STUDY OF HUMAN BEHAVIOR

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ABSTRACT. Dendrochronology furthers the systematic study of human behavior in three ways: 1) dating the material remains of human activities; 2) elucidating cultural practices involving trees and wood; and 3) reconstructing past environmental conditions and changes that affected human populations. Although all three approaches have been applied throughout the world, the lack of general procedural and interpretive precepts and standards hinders evaluation and comparison of results. The refinement of principles for evaluating archaeological tree-ring dates, identifying human wood use practices and assessing the impact of environmental variability on human societies will materially advance the contribution of dendrochronology to the understanding of human behavior.

INTRODUCTION

Dendrochronology currently is one of the fastest growing scientific disciplines in the world. Hardly a month passes without the announcement of an advancement in technique or a new application of the method. New systems for capturing and analyzing tree-ring data are being developed, the dendrochronological potential of variables other than ring width and density are being investigated, species previously dismissed as useless are being proved serviceable, novel ways of looking at the information contained in tree-ring series are proliferating, and new questions are being asked of tree-ring data. Every year witnesses the expansion of dendrochronology into regions once thought to be unsuitable for the method. We routinely hear of successful tree-ring studies in the high Arctic, on the fringes of the southern ocean, in the tropics and in the most inauspicious regions of the continents.

Through all this development and expansion, the heart of dendrochronology has remained dating: the cross-matching of variations in individual ring series to assure the contemporaneity of individual rings and the synchroneity of ring sequences. Rigorous between-tree crossdating of various measures of ring morphology allows each ring in the series to be assigned to the exact calendar year in which it was grown. Rigid adherence to the principle of crossdating endows dendrochronology with the greatest accuracy, precision and resolution of any noncalendric dating technique. A major emphasis of the chronological aspect of the science has been the application of tree-ring dates to past events. The concern with dating includes the chronological placement of geologic, climatic, biologic and human events and elucidating the temporal parameters of the processes responsible for stability, change and evolution in natural and cultural systems.

Dendrochronology's connection with the dating of human activities began early in the development of the method by Andrew Ellicott Douglass (1929, 1935) in his search for long proxy climate records. The first dating of a behavioral event occurred in 1904 when Douglass, after studying the rings in a tree stump, astounded the landowner by correctly placing the tree's felling in 1894 (Douglass 1937: 7). In 1914, the realization by the eminent anthropologist, Clark Wissler, that Douglass's technique of tree-ring analysis might be used to assign calendar dates to construction beams from prehistoric Southwestern ruins triggered a 15-yr chain of events that established the archaeological value of tree rings. Three Beam Expeditions sponsored by the National Geographic Society—in 1923, 1928 and 1929—accumulated the wood samples necessary to build a floating archaeological tree-ring sequence and link it securely with the dated living-tree sequence to produce a continuous 1200-yr crossdated tree-ring chronology for the Southwest. This accomplishment marked the creation of the world's first independent archaeological dating technique, long before the proliferation

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of such methods after World War II. The subsequent tree-ring dating of tens of thousands of samples from thousands of sites has extended the continuous Southwestern sequence back to 322 BC, provided the Southwest with the finest prehistoric time controls in the world, and helped make the region one of the world's primary anthropological research laboratories.

Douglass's creation of a technique for dating prehistoric archaeological remains stimulated the expansion of dendrochronology into other regions. Scholars were quick to develop the method in the United States Great Plains (Weakly 1940), Alaska (Giddings 1941), Germany (Huber 1941), Scandinavia (Høeg 1956). After a hiatus caused by World War II, archaeological tree-ring dating was revitalized by the resumption of previous work and the initiation of research in other areas of North America (Weakly 1971), Europe (Baillie 1982; Eckstein and Wrobel 1983; Fletcher 1978; Hollstein 1980; Huber and Giertz 1970; Thompson 1967) and Asia (Kuniholm and Striker 1983, 1987). Continued expansion, especially since 1960, has made archaeological tree-ring dating virtually a global phenomenon. Numerous multimillennial tree-ring chronologies used for long-range climate reconstruction and the calibration of the ^{14}C timescale incorporate archaeological samples, including those from the Southwest (Dean and Robinson 1978), central Europe (Becker 1993; Pilcher et al. 1984) and the eastern Mediterranean region (Kuniholm 1992).

Although climate reconstruction was Douglass's primary motivation in developing dendrochronology, progress on that front lagged behind that of dating applications because devices and techniques for capturing and analyzing tree-ring data remained rather rudimentary. Climate studies did not take dating applications until the 1960s, when three factors—the construction of biological models of tree growth, the development of powerful statistical analysis techniques, and the advent of high-speed computers capable of handling vast quantities of data—combined to stimulate a quantum leap forward in climate reconstruction (Fritts 1976). These dendroclimatic developments are in large measure responsible for the rapid spread of all facets of dendrochronology, including dating, during the last 35 yr.

Archaeological applications of dendrochronology

Since the inception of absolute archaeological tree-ring dating in 1929, dendrochronology has illuminated three general categories of information vital to the analysis of human behavior: chronology, behavior and environment.

Chronology is the most obvious contribution of tree rings to behavioral studies. Dendrochronology possesses the finest time resolution and produces the most accurate and precise dates of all independent dating techniques now available, and, in fact, often is used to calibrate other chronometric techniques such as radiocarbon, archaeomagnetic and thermoluminescence dating. Archaeological tree-ring dating (Dean 1986) allows the temporal placement of both concrete and abstract expressions of past human activity, including physical remains (*e.g.*, houses, sites, cathedrals, artifacts) and conceptual phenomena (*e.g.*, periods, stages, phases, ceramic types). Countless archaeological dating applications are exemplified in the global literature. Wherever applicable, the chronology afforded by dendrochronology illuminates the chronicle of human prehistory and history, elucidates the trajectory of sociocultural development, and elucidates the temporal aspects of cultural variation and change.

Behavioral information generally results from the analysis of tree-ring samples as artifacts rather than solely as chronological indicators. Much can be learned about past peoples' approach to a natural resource and their treatment of wood as a raw material for implements and structures. It proved possible to isolate the selection of specific tree species for particular purposes (Dean

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Breternitz 1976), the seasonal timing of wood procurement (Dean and Warren 1983), the differential use of freshly cut *versus* dead wood (Russell and Dean 1985) and the deformation of living trees to produce harvestable limbs (Nichols and Smith 1965). Marks on archaeological wood samples indicate the tools and techniques of tree felling, length reduction, debarking, limb removal and shaping (Dean and Warren 1983). Finally, archaeological tree-ring sample data provide information on a host of behaviors including wooden artifact manufacture, local and regional trade and interaction (Bonde and Christensen 1993), long-distance transport of logs (Betancourt, Dean and Hull 1986), the stockpiling (Dean 1969) and reuse (Ahlstrom, Dean and Robinson 1991) of building materials, and structure construction (Hollstein 1980), remodeling (Dean 1969) and repair (Dean 1969).

Environmental data derive from two sources: 1) the comparison of species assemblages in archaeological wood collections with modern plant distributions and 2) dendroclimatic analyses of the ring series in archaeological tree-ring samples. The first type of evidence has been used to assess human impact on the environment (Douglass 1935) and to identify continuities or changes in local environments (Dean 1969). Dendroclimatic reconstructions help evaluate the effects of past climatic variability on human adaptive behavior (Plog *et al.* 1988) and isolate possible human impacts on the environment.

The presentations in the Human Behavioral Adaptations sessions of the International Conference on Tree Rings, Environment and Humanity (this volume) were a microcosm of the types of analysis mentioned above. Archaeological dating applications ranged from England across Europe and Asia into North America, comprised works of art, sunken ships, Bronze Age settlements, Medieval buildings and towns, Siberian tombs and Navajo sites, and spanned the second millennium BC to the 20th century AD. Behavioral practices examined were the acquisition of building timbers, long-distance timber trade, shipbuilding methods and raw material sources, roof construction techniques and the pollarding of trees. Environmental topics included the impact of human behavior on trees and forests and past and future effects of environmental variability on human societies. The variety of scientific problems and methods covered in these presentations and the significance of the results augur well for further dendrochronological contributions to cultural and historical studies around the world.

CURRENT ISSUES IN ARCHAEOLOGICAL DENDROCHRONOLOGY

Despite past accomplishments and current successes, tree-ring dating practice exhibits weaknesses that should be corrected to ensure that this subdiscipline of dendrochronology keeps pace with the growth and development of the science as a whole. Dating practice is ripe for improvements that would contribute to its maturation as a scientific endeavor. Here, I identify some important needs in the dendrochronological placement of past natural and human events and make a few suggestions as how these needs could be met.

First is the problem of validating and verifying dates derived from samples that do not represent living trees and, thus, are not anchored in time by the known sampling date. I refer, of course, to old wood samples from geologic, biologic and human contexts. Such dates are derived by matching the ring variability in a sample of unknown age to that of a composite ring chronology in which all the increments are dated to the year in which they were produced. This procedure is the source of dendrochronology's strength as a chronometric technique of exceptional accuracy, precision and resolution. We can construct master chronologies and date unknowns by using a variety of ring characteristics, crossdating techniques and standards for the acceptance of a match. Crossdatable aspects of ring morphology include width, density, the distribution of multiple growth bands, isotopic composition and frost and fire scars. Crossdating techniques include visual inspection of the wood, visual

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matching of skeleton, ring-width or index plots, and the use of statistical dating systems based on various measures of ring variability and different computer programs. Acceptance standards range from the subjective assessment of agreement between records to reliance on specified statistical probabilities of correlation between series. Such diversity in methods creates a lack of uniformity among dating programs, hinders interlaboratory comparison and evaluation, and lowers confidence in the results. The strength of tree-ring dates lies in their accuracy, precision and resolution, and every precaution should be taken to prevent this strength from being undermined by doubt.

At present, this problem is more potential than actual, but it would be wise to anticipate and avoid trouble before it arises rather than react after it develops. Therefore, it may be time for the profession to give serious thought to specifying methods and standards for checking and validating the dates that are produced. Let me stress that I do *not* advocate a single, universal system for dating tree-ring samples. Because numerous methods clearly produce satisfactory results, because tree-ring data differ in character among regions, and because different laboratories are committed to different dating systems, such a draconian step is neither necessary nor practical. Rather, I suggest that we consider adopting uniform standards for verifying specific, individual tree-ring dates. Only a tiny fraction of dated samples would ever need be subjected to ratification, specifically, those whose validity has been challenged on archaeological, historical, geological, dendrochronological or other grounds.

Most dendrochronologists occasionally are required to answer the charge that particular dates do not conform to the archaeological, historical or geological contexts of the dated samples and therefore must be in error. Several responses to such challenges are possible. The least satisfactory is the flat assertion that the method is not capable of error and that the doubter is mistaken. Although such situations usually are resolved in favor of the tree-ring dating, stonewalling is unlikely to inspire confidence in doubters, disinterested observers, or believers. It is far better to systematically check and, if possible, verify the questioned dates. Whether the dating is confirmed or rejected, a rigorous response is likely to benefit both dendrochronology and other involved sciences. In fact, rejection often alters the interpretation of archaeological sites, or improves the practice of dendrochronology. For example, Douglass's (1946) meticulous response to Gladwin's (1943) attack on the "Douglass method", resulted in the standardization and codification of dating techniques and in permanent improvements in the ways in which tree-ring data and crossdating are presented in the literature.

Despite manifest improvements in dendrochronological method, individual tree-ring dates are sometimes questioned. Therefore, the field genuinely needs agreed-on techniques and standards for checking challenged determinations and accepting, rejecting or changing their placement. A standard process for dealing with challenges of this sort would improve relations with our colleagues in other disciplines, eliminate the impression held by some that tree-ring dating is an arcane operation immune to objective verification, and increase confidence in the dates.

I do not presume to dictate what form such a verification system would take; that is something that should be worked out by the international community of dendrochronologists. Some attributes of such a system can be suggested, however. Minimally, the system should include procedures and criteria that would persuade a panel of independent dendrochronologists of the strength or weakness of the crossdating and the accuracy or inaccuracy of the placement. Clearly, it would be impossible to create a sitting "grand jury" empowered to rule on all challenges. Rather, documentation would be distributed to impartial colleagues for evaluation against accepted criteria. This process could involve the statistical evaluation, using *a priori* standards (*e.g.*, established minimum correlation and/or t values), of quantified ring data (width, density, *etc.*) circulated among the [illegible]. Evaluation should not be limited to purely statistical testing and verification, however.

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crossdating is manifested in many attributes that are not captured by quantitative measurements, qualitative criteria such as the character of the earlywood or latewood, the distribution and appearance of intra-annular growth bands, the occurrence of fire scars or frost rings and other unquantifiable features should not be excluded from the process. The circulation of photographs of the questioned samples and of relevant samples from the master sequence could, perhaps, facilitate nonquantitative evaluation. Finally, the method ultimately must be grounded in the character of the original wood or charcoal rather than in plots, measurements or other secondary records of ring variability. Original samples (as opposed to other data) probably would be needed only infrequently, but should be available for verifying uncertain results based on secondary data.

The ultimate dependence of dating and verification on the inspection of actual wood and charcoal samples implies the permanent curation of original samples. Saving tree-ring samples from nonliving tree contexts is one of the thorniest problems facing dendrochronology. Frequently, complicated, technical and expensive conservation and storage procedures must be applied to these samples. The time, personnel and space required for the maintenance of large numbers of tree-ring samples can create considerable pressure for the dismantling and dispersal of such collections. Although rarely containing material of intrinsic or artistic merit, tree-ring collections are enormously valuable data sources that can be used repeatedly as new research questions are raised and new analytical techniques developed. For example, re-analysis of the Laboratory of Tree-Ring Research's Southwestern archaeological tree-ring collections increased the number of dates and dated sites by >600%. Because tree-ring collections are necessary to validate dates, and because they are unequalled and incompletely tapped repositories of research materials, dendrochronologists should uncompromisingly advocate permanent maintenance of such collections as irreplaceable research resources.

A problem that inhibits international communication, interlaboratory comparison and consistent application of archaeological dates is the lack of a standard nomenclature for characterizing tree-ring dates and a notation system for their documentation. The relevance of a tree-ring date to an archaeological feature is determined by the nature of the date and is indicated by certain attributes of the sample. Although tree-ring dates are absolute and accurate to the year, some are more relevant than others to archaeological dating. This circumstance leads to the distinction between dates that apply to the deaths of trees ("cutting dates") and those that do not ("noncutting dates"). A noncutting date, whose outermost ring predates the death of the tree by an unknown number of years, is created when rings are removed from the exterior of the sample by debarking, shaping, weathering, burning or careless handling in the field or laboratory. Obviously, cutting dates are more relevant to dating an archaeological feature than are noncutting dates, and archaeologists should receive information that distinguishes these types of date.

The easiest way to indicate relevant sample attributes is by appending standardized symbols to each date. An adequate notation system must contain enough information to enable researchers to discriminate cutting from noncutting dates and to identify other important sample characteristics. Minimally, symbols that unambiguously specify attributes of the sample (such as the presence or absence of the pith ring, waney edge, bark, or beetle-larvae galleries, the consistency around the circumference of the outermost ring and the degree of erosion) and of the ring series (such as the degree of circuit and radial uniformity and indications of trauma) must be developed. This information is vital to understanding the character of the dating and is critical to relating tree-ring dates to the past human events to which they apply. Standard notation would help dendrochronologists assess the technical aspects of the dating and help other scientists evaluate the dates within the contexts of their disciplines.

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More theoretical problems exist with regard to evaluating archaeological tree-ring dates within contexts of past human behavior. We need to devise ways to identify, eliminate or correct anomalous dates (Dean 1978). Anomalous dates are not the same as erroneous dates, which are comparatively rare. Rather, anomalous dates, although perfectly accurate, do not apply to the past events of interest to date. For example, the date of a repair beam in a room is only marginally relevant to dating the room's construction and is anomalous relative to that event. Similarly, the date from a long branch is anomalous relative to the construction of the hearth where it was burned as fuel. Floating dates are anomalous because the date of the exterior ring does not record the year the tree was felled for use.

Enhancing our ability to identify anomalous dating situations would be of immense value in relating tree-ring dates to the events specified by the features with which they are associated. Because human behavior toward trees and wood is the principal source of anomalous dates (Dean 1996), [illegible] theoretical and empirical models of the wood-use behavior that introduced the wooden elements at the archaeological sites. Such models isolate potential behavioral sources of dating anomalies, [illegible] the likely patterning of anomalous dates in the affected sites. In addition, standardized and comprehensive data on the provenience, associations, functions and physical attributes of the dated elements provide information useful for identifying and explaining anomalous dates. Both features should be integrated into a generally accepted program for recognizing and eliminating anomalous dates, and thereby enhancing the value of dendrochronology for dating human events.

An additional need is for a well-defined set of assumptions and principles for evaluating tree-ring dates from archaeological contexts. One aspect of this requirement is the recognition and correction of anomalous dates, but several other issues are involved as well. Often, simplifying assumptions must be made about general relations between tree-ring dated wooden elements and the features with which they are associated (Dean 1969, 1978). For example, it sometimes is possible to discount the likelihood of extensive repair activity due to the circumstances of site location or duration of occupation. Principles for applying dates to past human events can be developed through the analysis of consistent relations between wooden elements and human behavior, between such elements and archaeological contexts and between the contexts and physical attributes of the samples. Standardization of standardized interpretive principles would enhance both comparability among analysts and the contribution of dendrochronology to understanding human behavior.

Finally, we need to develop specific models of the human behavioral systems in which wood is embedded (Dean 1996). We need to better understand the effects of different attitudes and [illegible] toward forests, trees and wood on the distribution of wooden elements in archaeological contexts, the production of dating anomalies, and on our assumptions and rules for evaluating dates. [illegible] we understand the behavior involved in wood procurement, use, discard and consumption, [illegible] able we will be to assign unambiguous dates to human events. Some progress has been made, but much more remains to be done to specify culture-specific wood-use behavior patterns.

Resolution of some or all of the above issues would enhance communication among those engaged in the production or use of archaeological tree-ring dates and, thereby, the contribution of dendrochronology to understanding past and present human behavior. More systematic and [illegible] integration of tree-ring dating into the study of human behavior would refine knowledge of [illegible] cultural change and development and illuminate the natural and cultural processes that drive [illegible] ence and limit the evolution of human culture and society.

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FUTURE TRENDS AND DEVELOPMENTS

Given the accomplishments, shortcomings and needs enumerated above, what might be the future of dendrochronology in the systematic study of human culture and behavior as coherent adaptive phenomena? It is safe to predict that the geographic and topical growth of dendrochronology that has characterized the last decade will continue as students persist in expanding the frontiers of the discipline. Undoubtedly, archaeological dating will be extended farther into regions and time ranges that heretofore were thought beyond its scope. Scholars also will continue to dazzle us with sophisticated and clever applications of the method in the realms of chronology, behavior and environment. New theoretical approaches to the study of sociocultural stability, change and evolution, in particular, and of the operation of complex adaptive systems, in general, will continue to make new demands on dendrochronology as a primary source of knowledge about natural and cultural chronology, past human behavior and environmental variability over a wide range of temporal and spatial scales. I am confident that world dendrochronology will prove capable of meeting these challenges.

In contrast to this rosy picture, I also see a real danger that the purely dating aspect of dendrochronology will be shunted into secondary status in the rush to apply this powerful technique to the pressing environmental problems that beset the planet. It is not too far out of line to assert that, historically, the dating component has been the repository of the greatest strength of dendrochronology, its ability to assign exact calendar dates to past environmental and human events. It would be a mistake to relax the chronological rigor that endows our science with so much of its power and appeal to pursue research that is not based on solid dating. Therefore, the profession must continue to insist on rigorous crossdating as the basis of all dendrochronological research and continue to advocate support for the facilities and skilled personnel necessary to establish and document crossdating.

Equally unfortunate would be to relinquish control of another crucial factor in current and future environmental crises, human behavior. No one questions the urgent need to more fully understand ecological conditions and changes, climatic variability across time and space, and global climate change in order to navigate humanity's course through the troubled times that lie ahead. Nor should we question the imperative need to more fully understand how societies respond to small- and large-scale environmental changes so that we may ease humanity's passage through the difficult sociocultural transformations that will be required. Such understanding comes through increasingly sophisticated and intensive historical, anthropological, sociological and archaeological studies of human adaptive behavior at all times and in all regions. The unique temporal resolving power of dendrochronology is vital to the refined studies of past adaptive situations and behavioral responses that are necessary to provide the intellectual and operational knowledge for effecting major sociocultural change with the least possible social and human disruption. Effectively engaged, dendrochronological dating has a definitive role to play in the world's efforts to cope with major and largely deleterious environmental changes.

In conclusion, vigorous, varied and widespread archaeological tree-ring dating is crucial to exploiting the full potential of dendrochronology and to more fully understanding environmental changes and human behavioral adaptation to these changes. Tree-ring dating is most effective and most productive within the contexts of broad dendrochronological programs in which the various components share theory, perspectives, methods and data. Because of the productive intellectual cross-fertilization that takes place in such contexts, the tree-ring dating of natural and cultural phenomena is an integral and vital component of a well-rounded, comprehensive and productive program in dendrochronology.

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