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American Antiquity, Vol. 50, No. 4 (Oct., 1985), 796-802.

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REPORTS

TREE-RING DATING OF BALDCYPRESS AND THE POTENTIAL FOR MILLENNIA-LONG CHRONOLOGIES IN THE SOUTHEAST

David W. Stahle, Edward R. Cook, and James W. C. White

The tree-ring dating of baldcypress has been achieved in the southeastern United States, and the first 500 to 600 year long baldcypress chronologies have been developed from remnant stands of old-growth trees. An 800 year long cypress tree-ring chronology based on living trees and extended with long dead submerged logs has recently been dated, demonstrating the feasibility for very long chronology extension using progressively older sources of preserved cypress wood from old-growth trees, historic buildings, prehistoric archaeological sites, and natural deposits of submerged and buried logs and stumps. The longevity, climate sensitivity, and excellent preservation of ancient baldcypress wood make this species the only realistic prospect for millennia-long tree-ring chronologies extending to the mid-holocene in the Southeast, with important potential applications to the tree-ring dating of prehistoric archaeological sites, paleoclimatic reconstruction, and the calibration of independent dating methods.

Baldcypress (*Taxodium distichum* L. Rich) is a slow-growing, long-lived species native to the alluvial floodplains of the southeastern United States (Figure 1), and has recently proven suitable for dendrochronology (Bowers 1973; Stahle 1979; Stahle and Hehr 1984; this report). We report here the first climate-sensitive tree-ring chronologies 500 to 600 years in length from remnant stands of old-growth baldcypress trees (Figure 2). We also discuss an 800 year long cypress chronology recently developed in southeast Missouri using living trees and long-dead relic or subfossil logs. The combination of longevity, climate sensitivity, and excellent preservation of ancient cypress wood in submerged or buried deposits is unique among species in eastern North America, and makes baldcypress the only realistic prospect for the development of continuous millennia-long tree-ring chronologies extending into the mid-holocene in the southeastern United States. Baldcypress promises to provide the only *annual* chronological and environmental records over 1,000 years long from terrestrial sources in the Southeast, and will have important interdisciplinary applications to archaeology, geochronology, paleoclimatology, and geophysics.

Well preserved baldcypress wood has been recovered from prehistoric archaeological sites in the Southeast (e.g., Porter 1969; Walker 1936), and offers considerable potential for the tree-ring dating of occupation remains and associated material culture. Actual tree-ring dating of archaeological deposits and tree-ring calibration of independent archaeological dating methods promise to substantially improve the accuracy and detail of the prehistoric cultural chronology in the Central Mississippi Valley and the Southeast (Stahle and Wolfman 1985). Although notable early attempts to establish the tree-ring dating of prehistoric archaeological remains in the eastern United States were not entirely successful (Bell 1951; Hawley 1941), these pioneering studies did not evaluate the potential of baldcypress.

Baldcypress is one of the few species worldwide with potential for millennia-long tree-ring chronologies. The longest continuously dated chronology now available is based on living trees and relic wood of bristlecone pine (*Pinus longaeva* D. K. Bailey) in California and extends back to 6700 B.C.

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American Antiquity, 50(4), 1985, pp. 796-802.
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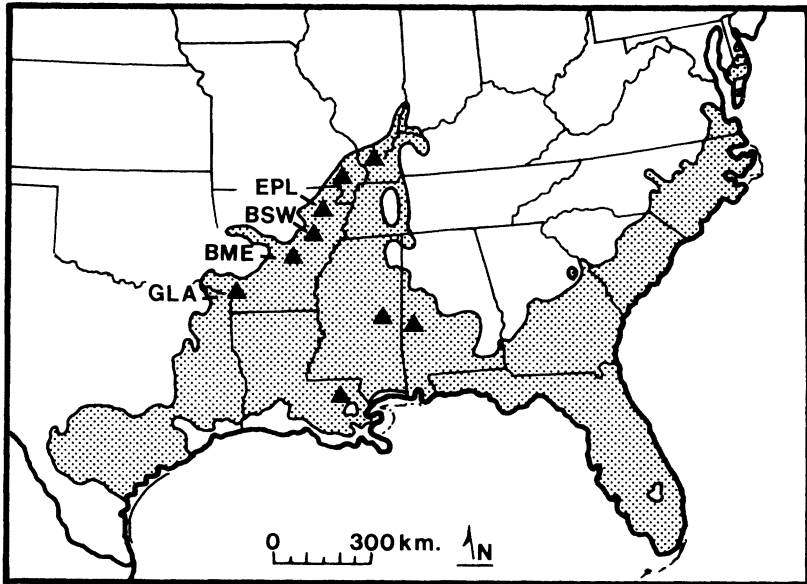


Figure 1. Location of baldcypress chronologies plotted in Figure 2 (lettered symbols) and other long cypress chronologies under development (unlettered symbols). The geographical distribution of baldcypress is shaded (Fowells 1965).

(Ferguson and Graybill 1983). Early tree-ring work with sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz) in California by A. E. Douglass resulted in a chronology 3,000 years long (Douglass 1919).

Very long oak (*Quercus* spp.) chronologies with a good chance for continuous dating back 7,000 years B.P. are being developed in southern Germany (Becker and Delorme 1978) and northern Ireland (Pilcher et al. 1977) from living trees, medieval structures, and subfossil wood from river gravels and peat bogs. Long subfossil oak chronologies may also be possible in northern Germany (Eckstein 1982) and European Russia (Bitvinskis 1982). The few additional species worldwide with potential for chronologies over 1,000 years long include Kauri (*Agathis australis*) in New Zealand, huon pine (*Dacrydium franklinii*) and pencil pine (*Athrotaxis cupressoides*) in Tasmania, austrocedrus (*Austrocedrus chilensis* (D. Don) Endl.) and araucaria (*Araucaria araucana* (Mol.) C. Kouch) in South America, and other conifers in western North America (e.g., *P. flexilis* James and *Juniperus* spp.), Turkey, and Asia. Archaeological wood and charcoal have helped extend the master chronology in the southwestern United States back to 322 B.C. (Robinson 1976) and the eventual development of a 5,000 year chronology based principally on archaeological timbers may be possible in Turkey (Kuniholm and Striker 1983).

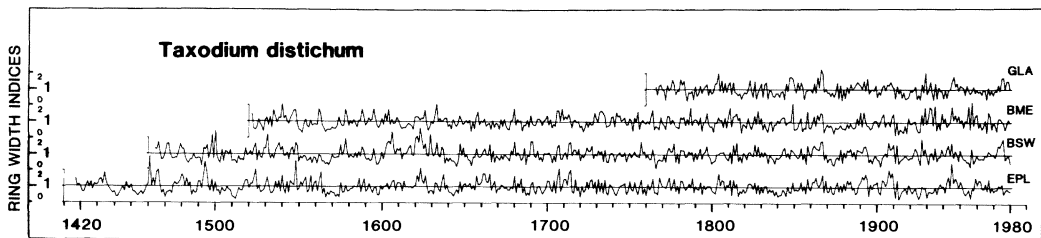


Figure 2. Crossdating of four baldcypress chronologies from Arkansas (Figure 1) based on the mean value function of ring width indices from at least 29 radii and 18 trees per site. The average correlation (r) between these chronologies for the common interval of 1766 to 1980 is .47 ($p = .0001$).

Table 1. Radiocarbon Dates for Buried Baldcypress Logs and Stumps from the Southeastern United States.

Uncalibrated C-14 Age	Date	Location	Reference or Laboratory No.
670 ± 140 years	1280 A.D.	Arkansas	LDGO-1581
1,225 ± 130 years	725 A.D.	Arkansas	LDGO-1579 ^a
1,750 ± 250 years	200 A.D.	Louisiana	Brown and Montz 1983
4,590 ± — ^b years	2640 B.C.	Louisiana	Brown and Montz 1983
5,600 ± 110 years	3650 B.C.	Mississippi	Grissinger et al. 1982
10,280 ± 350 years	8330 B.C.	Louisiana	LDGO-1580
12,520 ± 410 years	10,570 B.C.	Louisiana	Brown and Montz 1983

^a Surface log, probably exhumed from buried context and redeposited.

^b Sigma not available.

Baldcypress has several characteristics essential for the development of millennia-long tree-ring chronologies, including ring-width sensitivity, regional crossdating, climate sensitivity, longevity, decay resistance, and the frequent burial and long-term preservation of cypress wood. Baldcypress ring-width patterns are often highly variable (i.e., sensitive) and can exhibit strong correlation among trees locally, and between site chronologies separated by over 370 km (i.e., crossdating, Figure 2). As can be expected for any species, we and others have encountered dating problems with baldcypress specimens from certain sites (M. J. Duever, personal communication 1984), but with careful collection, preparation, and crossdating (Stokes and Smiley 1968) we have established the annual nature of the growth rings and the unequivocal dating of most baldcypress samples we have examined thus far. The accuracy of the four chronologies in Figure 2 has been verified by T. P. Harlan and M. J. Duever at the University of Arizona Laboratory of Tree-Ring Research (personal communications 1984).

The strong regional crossdating and actual correlations with climate data indicate a substantial climatic influence over the radial growth of baldcypress, in spite of frequently flooded site conditions. Response function analyses (Fritts et al. 1971) indicate a generally positive correlation with precipitation and negative correlation with temperature during the growing season. The physiological processes involved in this apparent moisture/temperature signal are not presently clear, but the monthly climate variables examined explained from 28 to 53% of the growth variance in the four chronologies analyzed to date (Figure 2). These observations suggest a considerable potential for paleoclimatic reconstruction with baldcypress.

Baldcypress has been heavily logged, but our fieldwork indicates that living cypress 400 to 600 years old are common in the old-growth stands that remain scattered throughout the South. We have found a few specimens with 600 to 850 annual rings, and baldcypress over 1,000 years old have been reliably reported (Mattoon 1915). The longevity of baldcypress far exceeds that of most other species in the South, and presents obvious potential for ultra long chronology development in light of the well known decay resistance (Harlow et al. 1979) and the frequent burial of baldcypress wood in riverine and alluvial deposits.

Many Southern swamps have developed deep accumulations of organic matter, including in some cases semi-stratified deposits of well-preserved baldcypress logs and stumps (Bartram 1791; Bibbins 1905; Carpenter 1839; Grissinger et al. 1982; Kolb and Van Lopik 1966; Lyell 1849; Mills 1978; Moore 1967; Sears and Couch 1932). Radiocarbon dates have been reported for several buried baldcypress deposits (Table 1), and these dates are adequate to document both the significant age of some buried cypress wood and the potential to recover baldcypress wood from progressively older deposits as far back as the late glacial. Pollen data (Delcourt et al. 1983a, 1983b) provide further documentation on the presence of baldcypress in portions of the Southeast since at least the late glacial, and indicate an apparent widespread increase in cypress habitat approximately 5,000 years B.P. (Watts 1971; Whitehead 1965).

Recovery of preserved cypress wood from ancient swamp deposits could allow development of

long "floating" chronologies of various ages that might eventually be linked together into a long, continuously dated time series suitable for archaeological dating, and paleoclimatic and geophysical investigation. The successful tree-ring dating of baldcypress collections of unknown age from historic buildings (Stahle 1979) and long-dead submerged logs at Allred Lake, Missouri, provide a classic demonstration of the feasibility for very long chronology extension using historic, prehistoric, and subfossil baldcypress wood. The 800 year Allred Lake chronology is based on short records from hollow living trees (≤ 300 years), which have been extended some 500 years back in time with overlapping specimens from old submerged baldcypress logs exposed on the swamp surface during a summer drought. This chronology dates from A.D. 1184 to 1983 and is presently the longest tree-ring chronology in eastern North America. The potential for further extension of the Allred Lake chronology remains high, however, because additional submerged cypress logs remain to be sampled and older buried cypress logs no doubt exist in the immediate vicinity.

Given the recovery of specimens from old trees, historic buildings, and subfossil timbers, millennia long baldcypress chronologies are a distinct possibility. And without minimizing the many difficulties involved, baldcypress is one of the few species worldwide with some chance for continuous, or at least long floating chronologies extending into late glacial times. Because most subfossil oak deposits in Europe appear to be post glacial (Flint 1971; Smith and Pilcher 1973), the derived oak chronologies will probably not be extended substantially prior to 10,000 B.P. (Baillie 1982). The bristlecone pine chronology based on living trees has already been extended some 3,500 years with specimens from dead trees and relic wood, and the possibility for further chronology extension back to approximately 10,000 B.P. still exists. Dramatic extension of the bristlecone pine series prior to 10,000 B.P., however, seems unlikely. Because the subfossil oak chronologies in Europe have been developed largely on the basis of rather short and complacent (i.e., low ring-width variability) tree-ring specimens with an average length of only about 200 years (Baillie 1982), the prospects for long cypress chronologies seem comparatively bright considering the excellent sensitivity, crossdating, and age often found with baldcypress.

Millennia-long baldcypress chronologies would have important applications to archaeology, paleoclimatology, and geophysics. Long cypress chronologies should permit the tree-ring dating of prehistoric archaeological sites in the eastern United States where cypress wood and charcoal have been found (e.g., Troyville [Walker 1936], Cahokia [Porter 1969], and Dickson Mounds [Patrick Munson, personal communication 1979]). Several prehistoric baldcypress dugout canoes have been recovered as well (e.g., Kandare 1983; McGahey 1974), and some may prove to be suitable for tree-ring dating. It may also be possible to use baldcypress master chronologies to absolutely date certain high quality archaeological floating chronologies based on species other than cypress, because the tree growth-climate correlation for baldcypress during the growing season is typical of many upland species. In fact, a historic log structure built with cypress logs in Arkansas has already been dated against pine and red cedar chronologies (Stahle 1979). The dating of this structure was originally confirmed by independent analysis (Thomas P. Harlan, personal communication 1978) and with available historic information (Stahle 1978), and has since been substantiated against the four Arkansas baldcypress chronologies presented in Figure 2. The long Allred Lake chronology is already suitable for the tree-ring dating of late prehistoric (post A.D. 1300) and early historic remains in a portion of the central Mississippi Valley. The 500 year long Cache River chronology from southern Illinois currently under development has good potential for significant extension since many additional old-growth trees, fallen timbers, and submerged and buried logs remain to be sampled. This site is only some 32 km from Kincaid, where significant quantities of preserved wood and charcoal have been recovered from Mississippian period occupations (Bell 1951).

Realistically, the tree-ring dating of prehistoric sites in the Southeast will be limited by the availability of well preserved wood and charcoal from archaeological deposits. Nevertheless, a relatively few archaeological tree-ring dates could substantially improve understanding of the prehistoric chronology through direct tree-ring dating of occupation remains and the calibration of independent dating methods. Archaeomagnetic dating, for example, is potentially one of the most accurate and precise archaeological dating methods available and has wide application in the Southeast (Wolfman 1982), but absolute dating must be established through calibration with independent

dating methods (Wolfman 1984). The archaeomagnetic polar curve for the Southeast is presently calibrated primarily with radiocarbon dates, but the direct association of tree-ring dated wood or charcoal with suitable baked clay features at a few well placed time periods over the last 1,500 to 2,000 years is clearly feasible and will significantly improve the accuracy of archaeomagnetic dating in the Southeast. With tree-ring calibration, highly accurate archaeomagnetic dates with an associated precision of ± 20 to ± 40 years at the 95% confidence level could be produced in most situations (Wolfman 1984). This significantly exceeds the precision and accuracy of routine radiocarbon dating, and would greatly enhance chronological control over late Woodland and Mississippian period occupations in the Southeast. For these reasons, the potential archaeological significance of baldcypress wood and charcoal in historic or prehistoric sites, and in submerged or buried subfossil deposits should not be overlooked.

Long cypress chronologies provide a basis for estimating the long-term mean and variance of regional climate variables correlated with cypress growth, which include temperature and rainfall. Subfossil cypress offers potential for very long proxy climate records extending as far back as the climatic optimum and perhaps across the glacial-postglacial boundary in a climatic province fully distinct from the environment of bristlecone pine in the Great Basin or of oak in Western Europe. Current understanding of holocene climate in the Southeast is based primarily on pollen data, so the seasonal to annual climate estimates possible with long baldcypress chronologies promise confirmation and considerable elaboration of contemporaneous climate trends deduced from the longer but less well dated pollen records.

A very long baldcypress chronology could extend the continuous tree-ring calibration of the radiocarbon timescale beyond the present limit of 6700 B.C. achieved with bristlecone pine. Extending this calibration would improve radiocarbon dating accuracy in the newly calibrated period and provide additional data on the secular variation of atmospheric C-14 and solar activity through changes in the influx of cosmic rays. A continuous cypress chronology bridging the glacial-postglacial boundary could provide unique information on solar activity at the termination of the glacial period. While a continuous baldcypress chronology some 14,000 years long is clearly only a distant possibility, the development of long floating chronologies prior to 5000 B.P. is much more probable and could be quite useful. For example, a long floating chronology in the 8500 B.P. range could, with an acceptably small error, extend the usable record of atmospheric C-14 variations by "wobble matching" of high-precision radiocarbon measurements in the floating series with secular variations of the inner portion of the continuously dated bristlecone pine chronology (J. R. Pilcher, personal communication 1984). Measurements of stable hydrogen and oxygen isotopes in the wood cellulose from continuous or floating baldcypress series may also provide estimates of the local surface water isotope ratios. This information could place constraints on models of the continental climate in the southern United States during the early holocene. Such measurements have already been made using wood from the Two Creeks deposit in Wisconsin (Yapp and Epstein 1977).

Whatever the chances of developing continuous or long floating baldcypress chronologies in the pre-5000 B.P. range may be, absolutely dated baldcypress chronologies 1,000 to 5,000 years long are definitely feasible in the Southeast. Several cypress chronologies over 500 years long have already been developed from living trees, and the dating of the Allred Lake collection demonstrates the feasibility of significant chronology extension using natural deposits of submerged or buried baldcypress logs. These results indicate that millennia-long master chronologies suitable for tree-ring dating of Mississippian and possibly Woodland period sites should soon be available. Long paleoclimate reconstruction with baldcypress will also provide the detailed framework necessary, but currently not available, to investigate the interaction between climate trends and settlement-subsistence activities for the past 1,000 to 5,000 years in the Southeast.

Acknowledgments. We thank G. G. Hawks for assistance, Daniel Wolfman for helpful comments, and Thomas P. Harlan for confirming the dating of the four baldcypress chronologies in Figure 2. We also thank Mr. and Mrs. Wayne Wiggins, Mr. and Mrs. Dean Harper, the Hempstead County Hunting Club, the Arkansas Game and Fish Commission, and the Missouri Department of Conservation for permission to sample baldcypress on their property. The research was sponsored by the National Science Foundation, Climate Dynamics Program, grant number ATM 8006964 and ATM 8120615 to the University of Arkansas. Lamont-Doherty Geological Observatory Contribution No. 3855.

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