TREE-RING BULLETIN

1979

PUBLISHED BY THE TREE-RING SOCIETY
with the cooperation of
THE LABORATORY OF TREE-RING RESEARCH
UNIVERSITY OF ARIZONA

TREE-RING DATING OF HISTORIC BUILDINGS IN ARKANSAS

DAVID W. STAHLE

Arkansas Archeological Survey
University Museum, Fayetteville

ABSTRACT

Twenty-four historic log and frame buildings in Arkansas have been dated by dendrochronology. The derived historic chronologies, ranging from A.D. 1598 to 1911, have improved and extended existing modern tree-ring chronologies for the state. Dated species are southern yellow pine (*Pinus* sp.), white oak (*Quercus* sp.), eastern red cedar (*Juniperus virginiana* L.), and baldcypress (*Taxodium distichum* L. Rich).

Three chronological studies integrating tree-ring, architectural, and documentary evidence offer examples of the relationship between tree-ring dates and historic records and demonstrate significant contributions which dendrochronology can make in the management of historic properties. Historic tree-ring collections should prove important in developing long term tree-ring chronologies in the eastern United States, due to widespread exploitation of living trees, the lower average age for many eastern species, and the availability of high quality tree-ring records in early historic structures.

Vingt-quatre constructions en bois et rondins situées dans l'Arkansas ont été datées dendrochronologiquement. Les chronologies qui en résultent s'etendent de 1598 à 1911. Elles ont permis d'améliorer et d'allonger les séries déjà obtenues dans l'Etat. Les espèces analysées sont: le "yellow pine" (*Pinus* sp.), le "white oak" (*Quercus* sp.); le "red cedar" oriental (*Juniperus virginiana* L.) et le cyprès chauve (*Taxodium distichum* L. Rich).

Trois études chronologiques intégrant des arguments dendrochronologiques, architecturaux et écrits, constituent des exemples des relations qui peuvent exister entre des dendrodatations et des documents historiques. Elles démontrent l'importante contribution que peut apporter la dendrochronologie dans la gestion des propriétés historiques. Etant donné l'importance des exploitations forestières, l'âge relativement bas de nombreuses espèces d'arbres et la possibilité d'obtenir des séries dendrochronologiques de haute valeur dans des structures historiques anciennes, ces dernières auront un rôle important à jouer pour développer de longues chronologies dans l'Est des Etats-Unis.

In Arkansas wurden 24 historische Block- und Fachwerkhäuser dendrochronologisch datiert. Mit den daraus erstellten Jahrringchronologien, die von 1598 bis 1911 reichen, konnten die bestehenden rezenten Chronologien dieses Landes verbessert und verlängert werden. Die Holzarten sind Yellow-Pine, Weißeiche, Bleistiftzeder und Sumpfzypresse.

Drei Untersuchungen zu chronologischen Fragen, die dendrochronologische und architektonische Befunde sowie archivalische Zeugnisse auswerteten, zeigen beispielhaft die Beziehungen zwischen dendrochronologischen Daten und historischen Aufzeichnungen und belegen den wichtigen Beitrag, den die Dendrochronologie für die Behandlung historischer Denkmale zu liefern vermag. Auch beim Aufbau langer Jahrringchronologien für die östlichen U.S. wird sich das Sammeln historischen Jahrringmaterials als wichtig erweisen, insbesondere wegen der weitgehend durchgeführten Exploitation lebender Bäume, dem niedrigen Durchschnittsalter vieler östlicher Baumarten und der Notwendigkeit von genauen Jahrringdaten für die frühe Geschichte.

INTRODUCTION

The development of long term tree-ring chronologies in the Midwest and eastern United States has been slowed by a lack of long-lived species and by widespread land clearing and timber exploitation since the 19th century. Fortunately, however, many old-growth trees cut from the virgin forests remain as structural timbers in historic buildings (e.g., Figures 1 and 2). These historic log and frame buildings are still fairly

Figure 1. A large collection of eastern red cedar logs in the Lancaster Barn. Six cutting dates between 1854 and 1867 indicate that this barn was built in part with re-used timbers following the Civil War.

Figure 2. Two white oak log pens of the Jacob King Cabin. Three cutting dates indicate that construction on the front pen began after the growing season of 1888.

abundant and have been recognized for some time as important potential sources of wood for the extension of modern tree-ring chronologies (Willey 1937, Hawley 1941, Schulman 1942). If enough modern chronologies can be extended to the 15th or 16th century it may then be possible to date the considerable wood and charcoal collections from prehistoric archaeological sites in the eastern United States.

Previous tree-ring research with living trees in the eastern United States has established the dendrochronological suitability of a variety of species, including pines, oaks, cedar, spruce, hemlock, beech, baldcypress, ash, and maple (e.g., Lyon 1936, Hawley 1941, Schulman 1942, Bell 1951, Fritts 1962, Estes 1970, Weakley 1971, Bowers 1973, Charton and Harmon 1973, Cleaveland 1975, Cook and Jacoby 1977, DeWitt and Ames 1978). While these studies have left little doubt that historic wood collections should be equally suitable for tree-ring dating, the extent and potential contributions of historic tree-ring dating in the East have not been examined in any detail.

The availability of modern tree-ring chronologies and numerous 19th century buildings make Arkansas an ideal location for historic tree-ring dating. This study examines the tree-ring dating potential of historic log and frame buildings primarily in the Ozark and Ouachita highlands of Arkansas. In addition, the chronological analyses of three houses are reviewed as specific examples of the interpretation of tree-ring dates from historic buildings and the potential role of dendrochronology in the management of historic properties.

HISTORIC BACKGROUND

The widespread exploitation of the great virgin forests of eastern North America is a sadly familiar American legacy (Lillard 1947, Smith 1976). Many European settlers saw the wilderness as a threat to safety and economic development and systematically cleared the forests and depleted the game, frequently at the expense of the Native Americans. In spite of the pervasive negative attitude of settlers toward the virgin forests (Hutslar 1972: 30-31), inaccessibility preserved many of the upland forests in Arkansas until the late 19th century, when railroads and new markets brought the rapid commerical exploitation of this resource. Commercial cutting began somewhat earlier in the lowland baldcypress and hardwood forests of the lower Mississippi Valley of eastern Arkansas, however, because of the greater accessibility by river (Moore 1967: 74).

Today undisturbed forests are extremely rare in Arkansas and elsewhere in the eastern United States. Nevertheless, the destruction of the native forests was not complete and small tracts of undisturbed or lightly disturbed forests have been fortuitously preserved in many eastern states (Waggoner 1975, Shepard and Boggess n.d.).

At the same time, a significant percentage of the timber cut from the virgin forests is still preserved in historic structures. Since the early settlers usually relied on local raw materials for construction, structural timbers in historic buildings should provide the basis for many regional tree-ring chronologies. In areas which have been extensively cleared or which lack undisturbed forests, historic buildings offer the only hope for the development of high quality tree-ring chronologies in the absence of significant archaeological or subfossil collections. Where undisturbed forests have been preserved, historic chronologies may improve the sample size and extend the length of modern tree-ring chronologies. Since modern chronologies from the eastern United States tend to be shorter than chronologies from the West, the potential role for historic chronologies in improving and extending modern chronologies takes on added significance.

In addition to the potential contributions to eastern dendrochronology, tree-ring dating of historic buildings can make important contributions to our knowledge of the history of early American buildings and settlements. The original construction dates of many historic structures may be accurately determined through the tree-ring dating of building timbers. The dating of structures within meaningful geographic or cultural areas may also help document the temporal and spatial distribution of settlements, construction techniques, and architectural styles.

Although detailed historic records are widely available in most areas, specific buildings or settlements of historic interest all too often lack even a minimum of documentation. Tree-ring dating may provide fundamental information for these poorly documented settlements. The historical interpretation of even well documented buildings may be significantly improved with the addition of tree-ring evidence (e.g., the Wolf House), and tree-ring dates may also be used as a fully independent check on the accuracy of historic documents referring to dated buildings.

Finally, the use of tree-ring dates from historic buildings and sites is subject to the same potential sources of error facing the interpretation of any tree-ring date derived from an artifact of human activity, i.e., the use of deadwood, stockpiling, or reuse of timbers; applying construction dates to non-construction remains; subsequent replacement with fresh timbers; and using non-construction dates (e.g., from firewood) to date construction (Bannister 1962). There is reason to believe, however, that most tree-ring cutting dates from historic log buildings in the East closely reflect actual construction dates. This is primarily because green wood was easier to work than thoroughly seasoned wood (Glassie 1974: 194, Hutslar 1972: 65, 75), although the immediate need for shelter may have been a factor as well. Nevertheless, when cutting dates do not accurately reflect the actual date of construction there is frequently objective dendrochronological or architectural evidence to that effect (Bannister 1962, Dean 1969). Dendrochronological evidence might appear in a spread of cutting dates or dating clusters, while architectural evidence might include old mortises, old paint, abutments and additions, or different construction techniques. With the introduction of saw mills, frame construction, and commerical marketing of lumber, however, the potential for a significant lag between the cutting date and the date of actual construction probably increases. Even in these cases, when subsequent replacement can be ruled out, cutting dates from structural elements will always establish the absolute maximum age for the building.

MATERIALS AND METHODS

Tree-ring specimens were collected from 32 historic buildings in Arkansas (Figure 3) between 1976 and 1978 as part of my thesis research (Stahle 1978a) and under contract with state and private agencies (Stahle n.d., 1978b). The five species identified in the collections are southern yellow pine (all probably *Pinus echinata* Mill. based on the species distribution), white oak (probably both *Quercus alba* L. and *Q. stellata* Wangenh., and possibly others), eastern red cedar (*Juniperus virginiana* L.), baldcypress (*Taxodium distichum* L. Rich.), and blackgum (*Nyssa sylvatica* Marsh.). White oak, pine, baldcypress, and cedar appear to be the species most commonly used in historic construction in Arkansas.

The collections consist primarily of cores 10 mm in diameter extracted with an electric drill and a Henson coring kit. Cross sections were cut whenever a structure was in ruin and occasionally at old door and window openings or at the corner notches of log buildings. The collecting procedure began with a thorough inspection of the construction timbers. When conditions permitted, sound specimens with the most annual rings, sensitivity, and bark or bark indicators were deliberately selected for collection. The specimens were extracted near the basal end of the log to obtain the oldest sequences possible. Detailed notes were recorded on the condition and architectural associations of the timbers sampled. Particular attention was paid to evidence for reuse or subsequent replacement.

All specimens were mounted and surfaced according to standard techniques (Stokes and Smiley 1968). The Douglass method of crossdating (Douglass 1941, Stokes

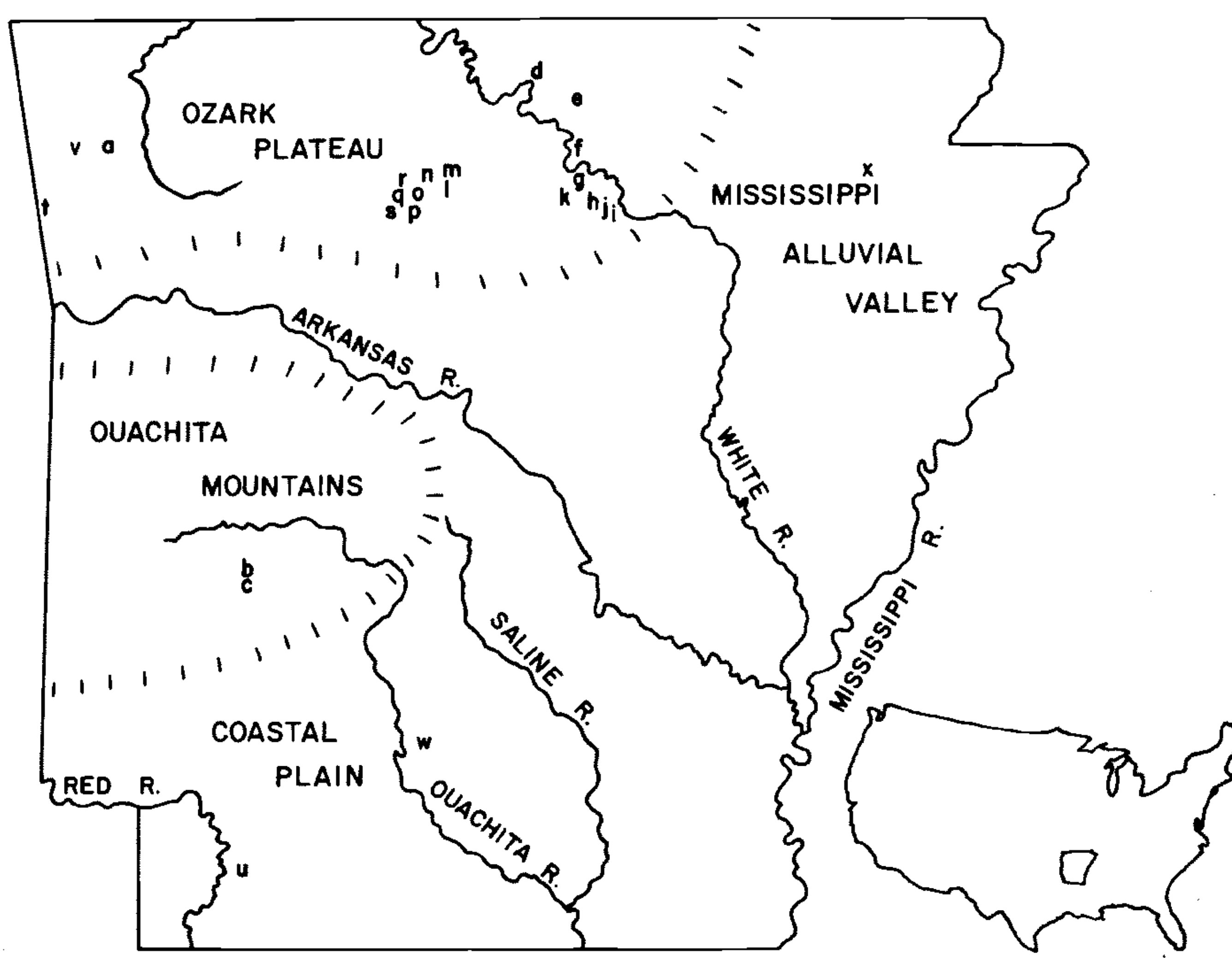


Figure 3. Locations of 32 historic tree-ring collection sites in Arkansas. The dated structures are listed in Figure 4.

a. Ridge House
b. Collier Cabin
c. McLean House
   McLean Storage Cabin
   McLean Caretaker Cabin
d. Wolf House
e. Trimble House
f. Mt. Olive Group:
   E. Jeffrey House
   E. Jeffrey Outbuilding
   A. C. Jeffrey Smokehouse
   Daniel House
g. Lancaster Cabin and Barn
h. Monroe Barn
i. Copeland House
j. Chitwood Barn
k. King Cabin
l. Horton House
m. Jackson Cabin
n. Steen House
o. Hendrix Cabin
p. Hardin Cabin
q. Ruff Barn
r. Magness Barn, north
   Magness Barn, south
s. Drury House
t. Dutch Mills Ruin
u. Lafayette County Jail
v. Borden House
w. Shaddock Barn
   Everett Barn
x. "Loch Bee Post Office"

and Smiley 1968) was used exclusively to date the specimens. All historic chronologies were absolutely dated against modern white oak and shortleaf pine chronologies from the Ozark and Ouachita Mountains. The modern chronologies were compiled by the University of Arizona Laboratory of Tree-Ring Research and made available through the International Tree-Ring Data Bank. The collectors of the modern chronologies include R. E. Bell, E. Schulman, E. T. Estes, C. W. Stockton, J. Harsha, and M. Ames. The entire historic collection was then submitted to the Laboratory of Tree-Ring Research for an independent check of the crossdating (Douglass 1934). The dating of all structures reported herein has been confirmed.

Eleven historic tree-ring collections of four species were selected for derivation of standardized tree-ring chronologies. The criteria used to select these chronologies included species, sample size, total length, and the quality of crossdating. The specimens were measured to .01 mm on a Bannister Incremental Measuring Machine and the measurements were randomly checked to assure accuracy. The computer programs RWLST and INDXA, developed at the Laboratory of Tree-Ring Research, were used to convert raw ring widths into tree-ring indices and to calculate the statistical parameters of the 11 historic chronologies. These standardized chronologies are on file with the International Tree-Ring Data Bank in Tucson.

RESULTS

The many specimens and sites dated during this research demonstrate that historic buildings may be routinely dated and can produce high quality tree-ring chronologies in Arkansas and no doubt elsewhere in the eastern United States. A total of 231 tree-ring specimens have been dated, or 50% of the specimens that were surfaced and analyzed (Table 1). Twenty-four of the 32 historic buildings sampled were dated, for a site dating percentage of 75%. Cutting dates from these buildings range from 1825 to 1911 and comprise 61% of all dated specimens. The collection sites are located in Figure 3 and a chronological summary of the dated sites is presented in Figure 4.

Two tree-ring dating regions were observed in the highlands of Arkansas. The pine and oak chronologies in the Arkansas Ozarks are generally distinct from chronologies of the same species in the Ouachita Mountains. Although most long term trends and certain individual years show correspondence between the two regions, crossdating is normally stronger within each area. The Mississippi Valley and the Gulf Coastal Plain are poorly represented in these collections and may constitute distinct dating regions as well. Particularly sensitive chronologies, however, may crossdate over the entire state and among different species.

The 11 historic chronologies selected for ring width standardization are plotted in Figure 5. Selected statistical characteristics for these chronologies are listed in Table 2 and may be used to compare the relative dendroclimatic potential of the four species (Fritts and Shatz 1975). DeWitt and Ames (1978) compiled a standardized set of 39 modern chronologies from eastern North America listing statistical summaries for three well represented species, the entire 39 chronology set, and a 102 chronology set from western North America. These summaries offer a convenient comparative framework and are included with summaries for the historic chronologies in Table 3. Finally, four historic collections were sufficiently replicated to allow analysis of variance. These results and a cross-correlation analysis are listed in Table 4.

On the whole, the average ring width for most historic specimens systematically decreased as the tree aged. This typical age trend was usually well approximated by the negative exponential and straight trend lines which were used exclusively to derive

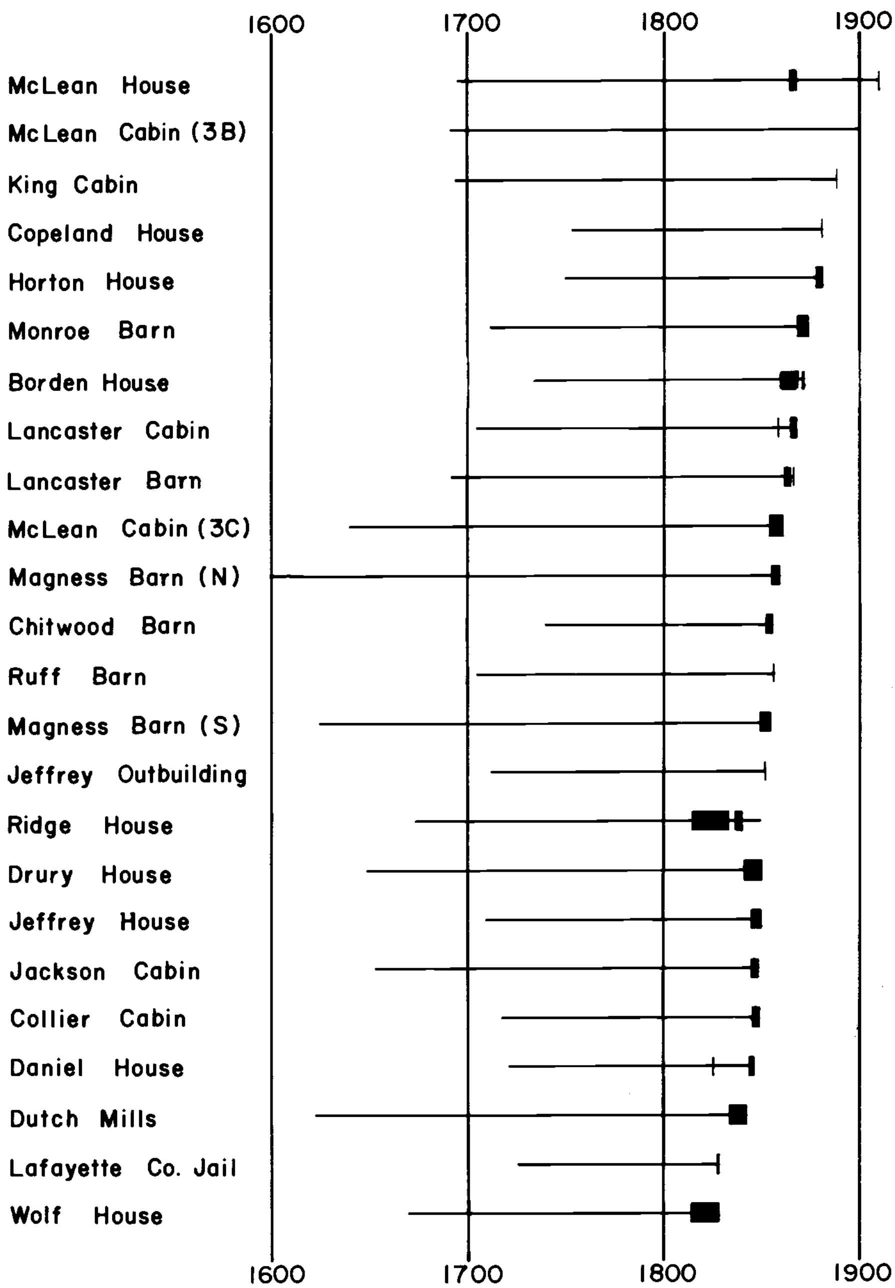


Figure 4. Chronological summary of 24 dated historic buildings from Arkansas. Horizontal lines indicate the total length of the derived chronology. Narrow vertical lines indicate single cutting dates, wide vertical bars indicate clusters of cutting dates.

Table 1. Summary of dated tree-ring specimens.

Species	Number	Dated Specimens	Dating %
southern yellow pine	209	101	48
white oak	174	87	50
eastern red cedar	71	38	53
baldcypress	6	5	83
blackgum	2	0	—
other	1	0	—
TOTAL	463	231	50%

the historic tree-ring indices. This contrasts with the disturbed ring series observed in many living trees in Arkansas which frequently display one or more growth releases due to lumbering or other artificial stand disturbance (Estes 1970: 306-308). The general absence of artificial growth disturbances in the tree-ring records from early historic buildings is a valuable asset of this material.

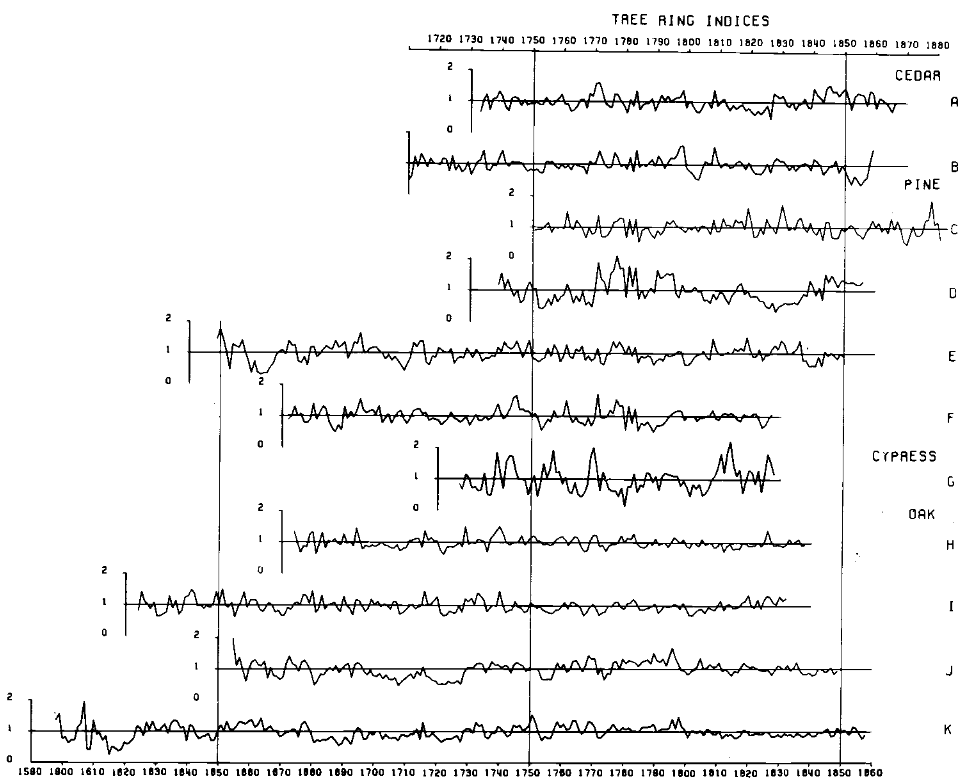


Figure 5. Crossdating among eleven standardized tree-ring chronologies of four species from historic buildings in Arkansas. The statistical characteristics of these chronologies are presented in Table 2. A. Lancaster Barns, B. Mt. Olive Group, C. Horton House, D. Chitwood Barn, E. Drury House, F. Wolf House, G. Lafayette County Jail, H. Ridge House, I. Dutch Mills Ruin, J. Jackson Cabin, K. Magness Barns (A,B = eastern red cedar; C-F = southern yellow pine; G = baldcypress; H-K = white oak).

The earliest inner dates for modern tree-ring chronologies in Arkansas are A.D. 1666 for shortleaf pine and A.D. 1642 for white oak, although most modern chronologies extend only as far as the 18th century. The chronologies derived from historic buildings provide modest extensions of the modern chronologies and significantly improve the sample size of specimens dating to the 17th, 18th, and 19th centuries.

White oak chronologies from ten structures average 196 years in length and together cover the period A.D. 1597-1900. White oak can be a difficult species to date simply due to complacency and the complex ring structure of the wood. Tyloses in the earlywood vessels tend to reduce the sharp contrast between annual rings, while wood rays may disrupt the rings and make it difficult to follow specific rings around the circumference of a specimen. These problems of ring identification are most severe in the narrow, complacent rings of old-growth specimens.

In spite of the complicated ring structure white oak specimens may usually be crossdated when at least 100 rings are present. Specimens with fewer rings may occasionally be dated, depending on the sensitivity of the series and the sample size of the collection. Especially wide rings in white oak may be as helpful in crossdating as narrow rings (Figure 6). Locally absent and false rings are extremely rare.

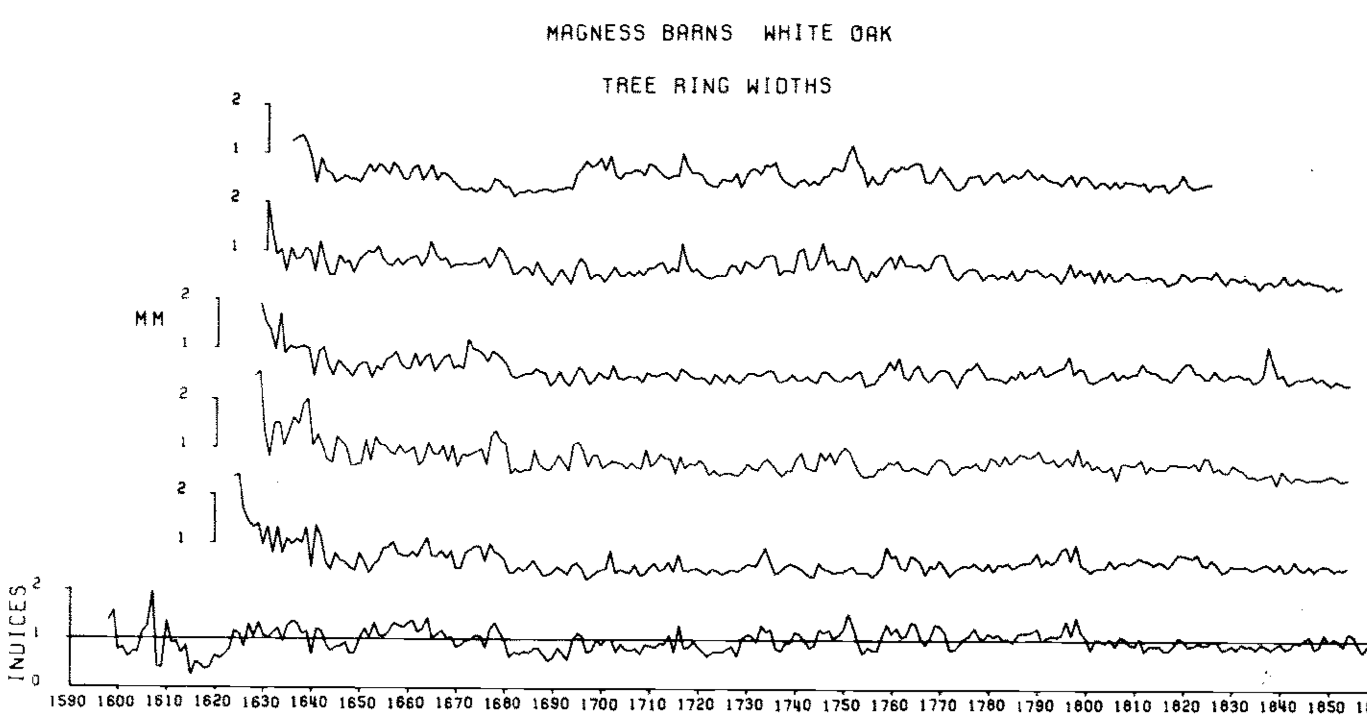


Figure 6. Crossdating among five white oak specimens (658112, -081, -051, -021, -091 from the top) and the mean index chronology (lower plot) from the Magness Barns.

A consistent feature evident in many historic white oak specimens is the decreasing ring width and variability as the tree aged. Juvenile and mature growth are much more variable and generally crossdate better than the frequently narrow and complacent old-growth portion of the specimen. This decreasing ring width and variability with increasing age is apparent in the plotted white oak chronologies (Figure 5h-k) and in the decreasing values of mean sensitivity and standard deviation and the decreasing correlation of all series calculated for the 20-year means of four standardized white oak chronologies (Stahle 1978a).

The white oak chronologies also have the least favorable statistics of the four historic species (Tables 2 and 3). Nevertheless, the historic white oak statistics closely resemble the average statistics for 16 modern white oak chronologies (Table 3). Also, the average percent variance attributed to the chronology (in Table 4) is 36% for the historic group compared with 31% for a group of 12 modern white oak chronologies (DeWitt and Ames 1978: 13). Estes (1970), however, examined a variety of chronology statistics for white oak, black oak (*Quercus velutina* Lamb.), and shortleaf pine in the central Mississippi Valley and found black oak to be the most climatically sensitive of the three species. Unfortunately, black oak was rarely used in the construction of historic buildings in Arkansas.

The southern yellow pine chronologies derived from eight historic buildings average 166 years in length and together cover the period A.D. 1648-1911. Locally absent or missing rings were occasionally encountered in the dated pine specimens but were easily recognized when crossdating controls were adequate. False rings in pine occurred in both the earlywood and latewood but were readily identified by the classic features of false rings (e.g., obscure outer boundary, discontinuity around the circumference, and interruptions by resin ducts [Stokes and Smiley 1968]). Although the quality of crossdating in pine varies considerably, specimens with as few as 50 rings have been dated.

A pine signature from the Ozarks in the 1780s was the most reliable ring width pattern observed (Figures 5a-g and 7). Narrow rings consistently occur at 1780, 1782, 1784, and 1789 in most dated pine and cedar specimens from the Ozarks. This pattern

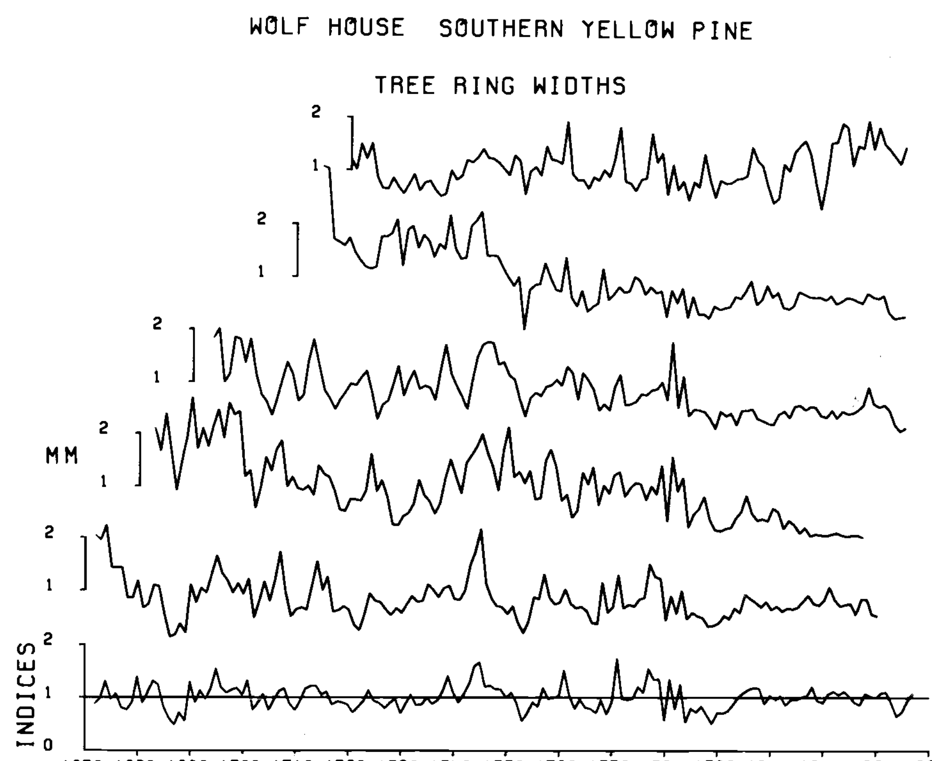


Figure 7. Crossdating among five southern yellow pine specimens (656041, -031, -051, -062, -071 from the top) and the mean index chronology (lower plot) from the Jacob Wolf House.

was essential to the accurate dating of several structures. It also occurs in the Lafayette County Jail baldcypress specimens and with some modification in the pine specimens from the Ouachita Mountains.

Five red cedar buildings along the White River in northern Arkansas were dated and together cover the period A.D. 1692-1867. These historic red cedar chronologies average 152 years in length. Because no modern red cedar chronologies were locally available the historic cedar collections were dated against both modern and historic pine chronologies from the Ozarks. Most historic cedar specimens show some visual crossdating with Bell's (1951) modern red cedar chronology some 180 miles north in Jefferson County, Missouri.

Eastern red cedar can be a difficult species to crossdate. False rings and poor circuit uniformity may render individual specimens or entire samples undatable. Locally absent rings were occasionally encountered in the historic specimens dated but were readily identified through crossdating. False rings are particularly common in the juvenile growth of red cedar (Weakley 1971: 11). As a result, chronological coverage prior to many suspected false rings was often too poor for a solution through

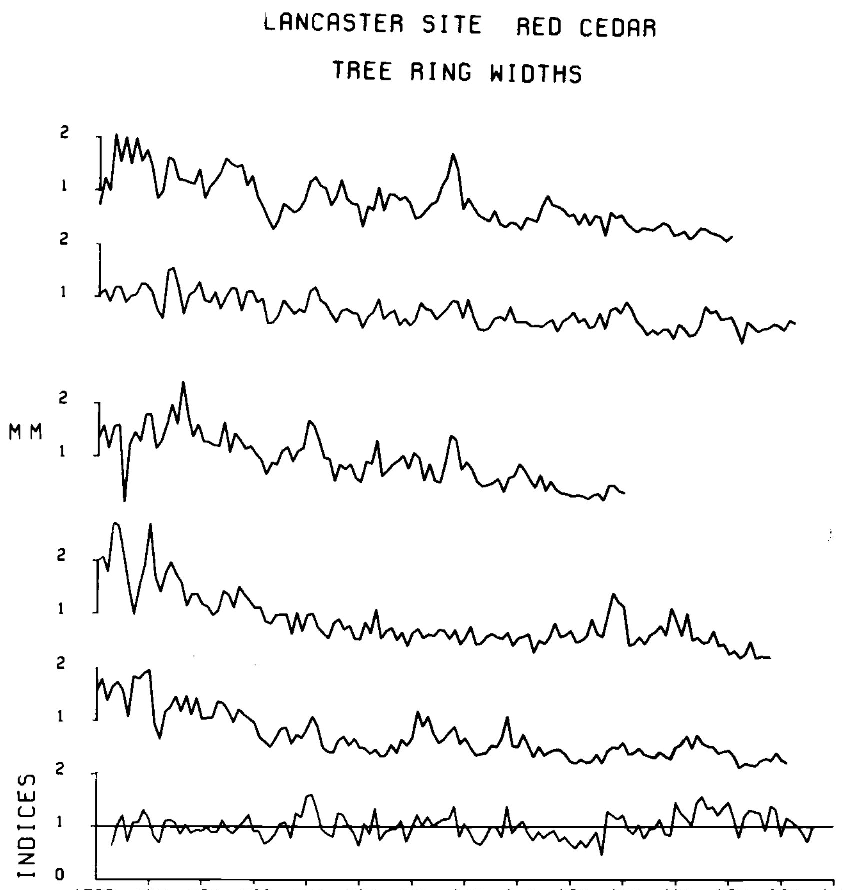


Figure 8. Crossdating among five eastern red cedar specimens (660031, -081, -041, -021, -071 from the top) and the mean index chronology (lower plot) from the Lancaster Cabin and Barn.

crossdating. In these cases simple ring counts were used for the undated sequence inside the problem ring(s). Fortunately, however, good specimens free of false rings and uniformity problems commonly occur in historic buildings in Arkansas and may frequently be dated (Figures 5a, b and 8).

The average chronology statistics for four measured historic pine chronologies (Table 3) are slightly higher but still well within the range of variation typical for modern shortleaf pine chronologies (DeWitt and Ames 1978: 10). The statistics for the two measured red cedar chronologies approximate the average modern and historic pine statistics (Table 3), as might be expected on the basis of the good crossdating among the two species. The relatively low mean correlation among trees and the high percent variance attributed to the cores for a single replicated red cedar chronology (Table 4) suggests the poor circuit uniformity which is obvious upon visual examination of many red cedar cross sections.

A single baldcypress chronology dating from A.D. 1726 to 1828 was derived from the Lafayette County log jail in southwestern Arkansas (Figure 5g). Since the two modern baldcypress chronologies previously available for Arkansas do not extend beyond the 19th century they did not provide enough overlap to date the Lafayette jail. Nevertheless, it was possible to date the structure because of good internal crossdating (Figure 9) and good agreement with upland chronologies available for other species elsewhere in Arkansas.

Baldcypress is a lowland and swamp grown species in the redwood family (taxodiaceae) (Harlow and Harrar 1937) and has only recently been used for tree-ring dating. However, the species is known to attain great age. Mattoon (1915) stated that baldcypress 400 to 600 years old were common, and that trees 600 to 900 years old were occasionally present in most virgin cypress forests. Bowers (1973, 1975) reported the crossdating of baldcypress and compiled a chronology (1800-1972) consisting of 10 trees from several widely dispersed sites in northeastern Arkansas. Munson is developing a 400-year modern baldcypress chronology for southern Illinois (Patrick Munson, personal communication) and Phipps is developing cypress chronologies in the Dismal Swamp of southern Virginia (Richard Phipps, personal communication). I compiled two short baldcypress chronologies in south-central Arkansas (1850-1977) and reviewed some of the evidence indicating that baldcypress produces annual rings (Stahle n.d.).

The annual rings of baldcypress are distinct with conspicuous latewood, inconspicuous rays, and no resin canals (Panshin and de Zeeuw 1970: 487-488). False rings and resin bands (non-annual) have been previously reported for baldcypress (Beaufait and Nelson 1957), but are usually easy to recognize when a proper surface has been prepared on the specimen (Stokes and Smiley 1968: 41, 46). The ring growth of baldcypress, however, has a tendency to be erratic. The width of the annual rings may be highly irregular around the circumference of the tree, particularly in the vicinity of the basal swell. Locally absent and missing rings appear to be more common in baldcypress than in the other three species examined. Some specimens approach hyper-sensitivity and cannot be crossdated. Severely depressed growth which may persist for several decades has also been observed in some long baldcypress ring series and may present problems for dating due to locally absent and missing rings. Nevertheless, the unaffected ring series on either side of the depressed growth may provide datable series.

In spite of the problems with erratic and depressed growth the crossdating of baldcypress can be excellent. Cypress specimens from the Lafayette County jail show a high degree of internal crossdating and the derived chronology corresponds well with

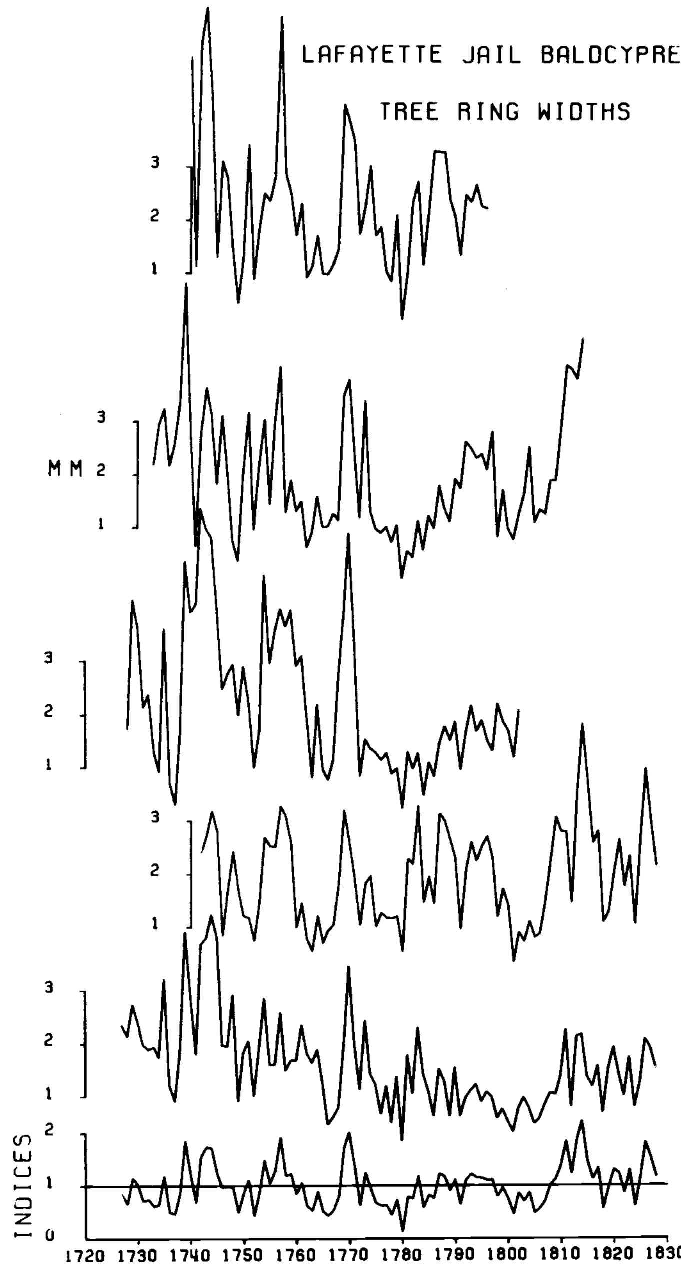


Figure 9. Crossdating among five baldcypress specimens (028311, -161, -231, -151, -041 from the top) and the mean index chronology (lower plot) from the Lafayette County Jail.

pine, oak, and cedar chronologies throughout Arkansas (Figure 5). The Dallas County living cypress (Stahle n.d.) crossdate with an upland white oak chronology some 80 miles to the west.

It is also apparent from Table 2 that the single historic cypress chronology, although consisting of only five specimens and 102 years, has the most favorable statistics of the 11 historic chronologies measured with the highest mean sensitivity, standard deviation, and mean correlation among trees. These baldcypress statistics are well above the averages for all other eastern species and are more similar to arid-site chronologies from western North America (Table 3). Furthermore, the baldcypress statistics Bowers (1973) and I (n.d.) reported are generally consistent with the Lafayette jail cypress data. Although great significance cannot be attached to this limited baldcypress data it does suggest an important dendroclimatic potential for this species.

The average chronology statistics for both the historic and modern chronologies examined from the eastern United States, with the possible exception of baldycpress,

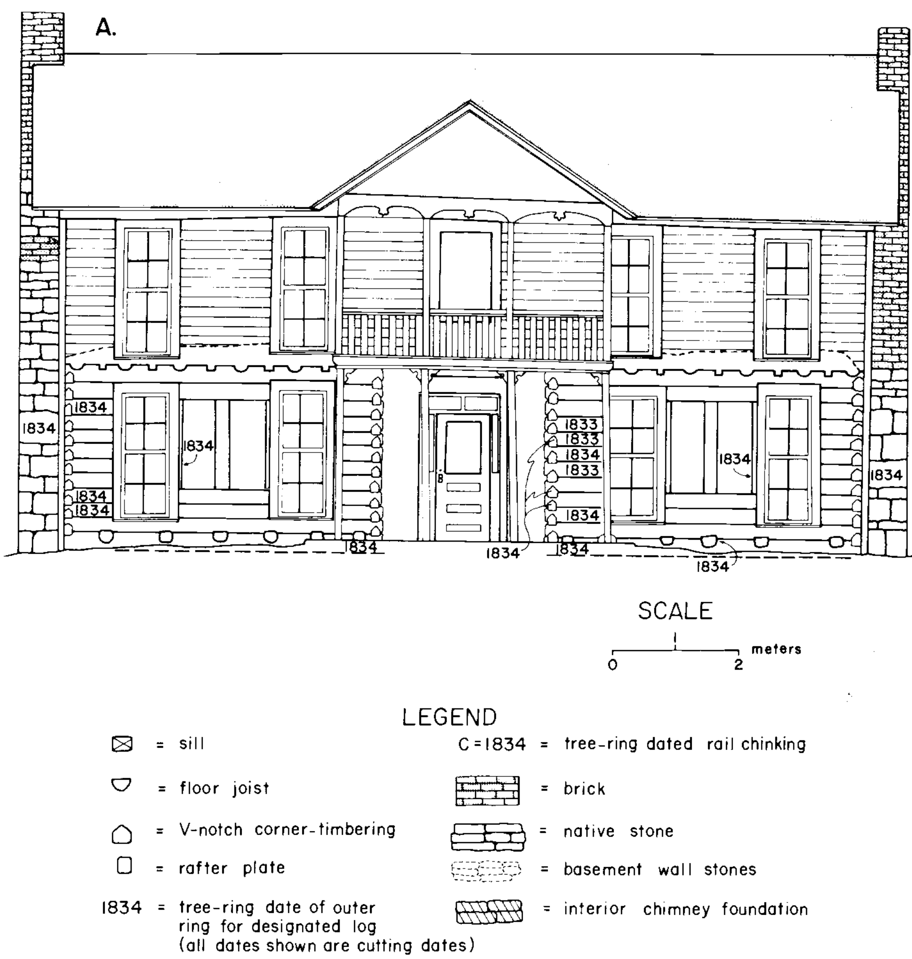
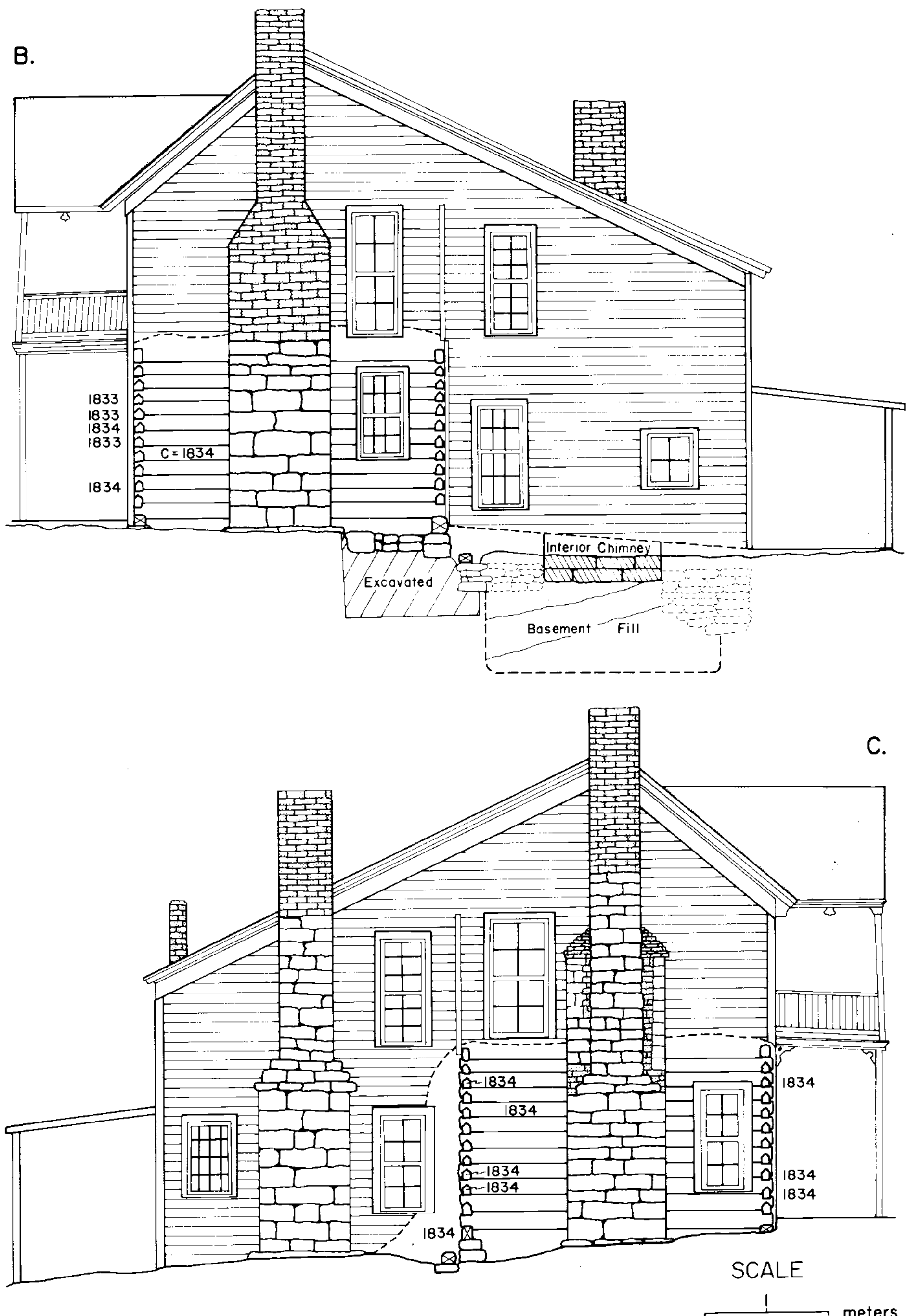


Figure 10. Three views of the Sarah Ridge House, Fayetteville, Arkansas, showing the original double-pen log house (dogtrot) and the location of dated tree-ring specimens inside the present structure. *A*, south elevation; *B*, east elevation; *C*, west elevation. Note that the interior chimney intrudes the basement wall and overlies the fill in the east elevation, and the two building episodes in the chimneys of the west elevation.

are well below the averages for arid-site chronologies from western North America (Table 3). DeWitt and Ames (1978: 15-16) point out, however, that the amount of climatic information from eastern tree-ring chronologies can be considerably improved to a level comparable with western chronologies by increasing the sample size to the vicinity of 40 trees. Since many historic log buildings in the East easily contain 40 or



more individual logs with long ring records generally free of artificial disturbances, these structures should yield high quality tree-ring chronologies suitable for climatic analysis.

Chronological Analysis of Three Dated Houses

Aside from the purely chronological applications, tree-ring dating can significantly improve the accuracy and detail of historic interpretations of early American buildings and settlements. The following three houses offer specific examples of the interpretation of tree-ring dates from historic buildings. The Ridge House analysis illustrates the interpretation of sequential tree-ring dates from distinct structural

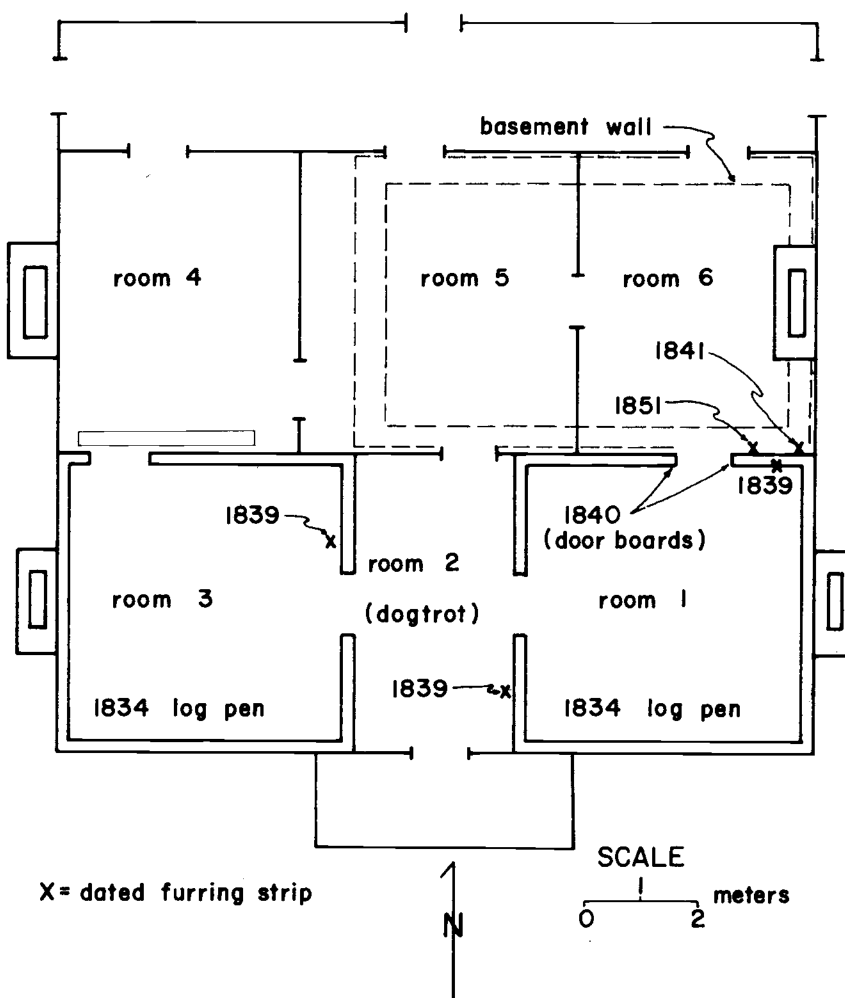


Figure 11. Plan view of the Sarah Ridge House (ground floor) showing the location of dated furring strips and door boards, and the association of the basement with the original double-pen log house. All dates shown are cutting dates except 1841 (non-cutting date) and 1851 (probable cutting date).

elements and the agreement of the derived dates with the available documentary records. The Wolf House illustrates the interpretation of dating clusters and the re-evaluation of documentary records in light of the tree-ring dates. The Borden House is an example of the tree-ring dating of milled lumber from a frame building and demonstrates the important contribution dendrochronology can make to the management of historic properties.

Ridge House

The Sarah B. N. Ridge House in Fayetteville, Arkansas, is a two-story salt-box style house on the National Register of Historic Places (Figures 10 and 11). Sarah Ridge was married to John Ridge, the son of a noted Cherokee chief. Her husband and father-in-law were instrumental in signing the Treaty of Removal in 1835 which led to the Trail of Tears and the removal of the Cherokee people to the Indian Territories west of the Mississippi River (Wilkins 1970). Mrs. Ridge moved her family to Fayetteville in 1839 or 1840 following the assassination of her husband and father-in-law by opposing factions of the Cherokee Nation. At that time she purchased the single floor, double-pen log house (dogtrot) which still stands inside the present two-story house (Volume B, Records of the Washington County Chancery Court, pp. 276-277).

Although they are not specific, the available documents indicate that Mrs. Ridge made several improvements on her house between 1840 and her death sometime in the late 1850s. The comparison of the 30 tree-ring dates from various structural timbers with the available documentary records, however, provides new evidence on the original construction and subsequent remodeling of the Ridge House (Figures 10 and 11).

Twenty-three cutting dates document the beginning of construction on the log dogtrot at 1833 and 1834 although the builder, M. H. Clark, did not obtain official title to the property until 1836 (Deed Book A, Washington County, Arkansas, pp. 345-346). Three cutting dates at 1839 from furring strips and one at 1840 on a door board indicate that the interior walls of the dogtrot were plastered, and the north door in room one (Figure 11) was built during or soon after 1840. The plaster walls indicate that the dogtrot was enclosed at this time, and the new door suggests that a rear addition was also added which probably included the large basement. This remodeling episode coincides with the purchase and "improvement" of the Clark property by Mrs. Ridge in 1840 (Donat 1973; First Probate Book, Benton County, Arkansas, Chancery Court). Two additional tree-ring dates at 1841 (non-cutting date) and 1851 (probable cutting date) from furring strips associated with the interior wall plaster of the rear addition (room 6, Figure 11) probably coincide with the 1853-1854 repairs referred to in a letter by Mrs. Ridge (Lemke 1951). The second-floor addition over the dogtrot was added in 1877 by a subsequent owner, Sheriff Pettigrew (*Fayetteville Democrat,* October 6, 1877, p. 3, col. 3).

Although the three tree-ring dated building episodes coincide with the available documentary references concerning the Ridge House, the documents alone do not specifically identify the type or extent of construction that took place. With the architectural associations of tree-ring dated timbers, however, it is possible to identify the results of early construction and remodeling at the Ridge House and to relate these events to the nonspecific recorded history of the building.

Wolf House

The Jacob Wolf House in Norfork, Arkansas, is a large two-story log house also on the National Register of Historic Places. The age and historical significance of the Wolf House, however, has been the subject of considerable disagreement. The Wolf House is frequently described as the oldest standing structure in Arkansas or as the oldest house in the Ozarks (*The Ozark Mountaineer* 1961). Shiras (1939: 61) believed the house was built ca. 1809 by Indians under Wolf's supervision. More recent studies, however, found that Wolf did not move to Arkansas until sometime in the early 1820s. Documents show that Wolf entered a claim on the Wolf House property on November

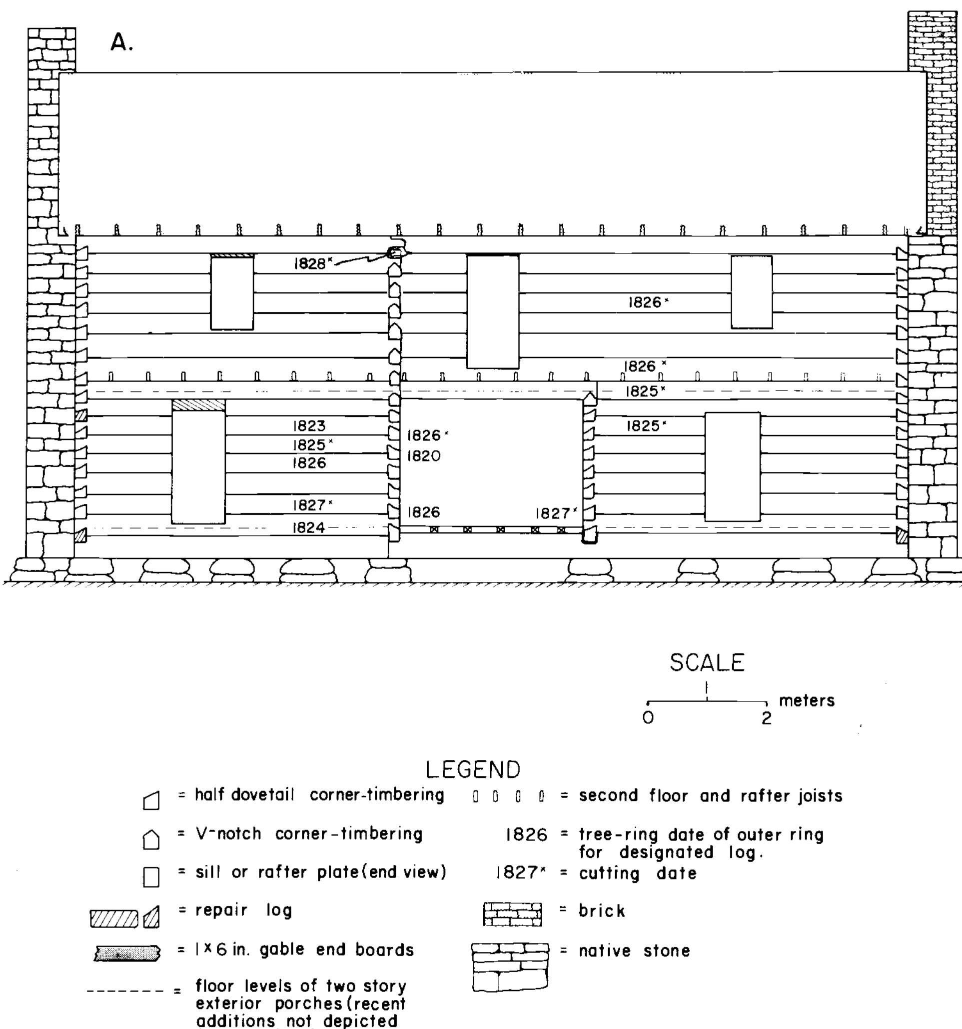


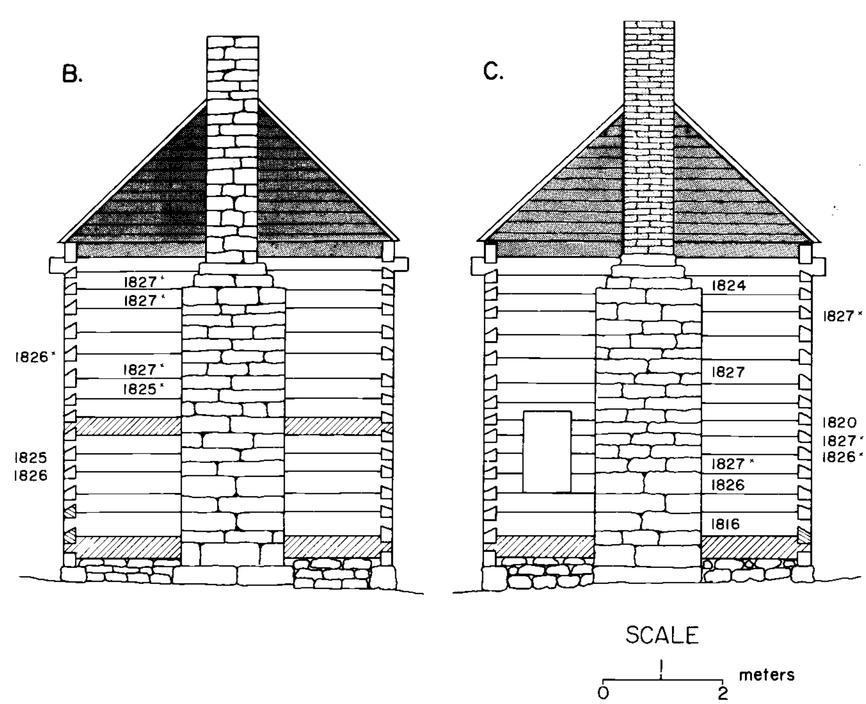
Figure 12. Three views of the Jacob Wolf House, Norfork, Arkansas. *A*, west elevation; *B*, north elevation; *C*, south elevation. Note the distribution of 1827 cutting dates and the single 1828 cutting date in the second-floor partition wall (west elevation).

15, 1824 (Baker 1978), and patented this land July 20, 1825 (Bearss and Carroll 1965). On October 27, 1825, the Arkansas Territorial Legislature created Izard County and designated the home of Jacob Wolf as the seat of justice (Bearss and Carrol 1965). On the basis of these records Bearss and Carroll (1965) reasonably concluded that the Wolf House was built ca. 1825 and served as the first courthouse for Izard County.

Re-evaluation of the documentary evidence in light of the 30 tree-ring dates derived from the Wolf House (Figure 12), however, implies a different interpretation of the early history of the Wolf House and Izard County. The tree-ring dates also offer some insight into Jacob Wolf's personal plans for the development of his property.

Three dating clusters and 18 cutting dates document tree-cutting activity both during and after the growing seasons of 1825, 1826, and 1827. But the Wolf House was not erected before late 1827 at the earliest because at least one 1827 cutting date was obtained from all four rooms of the house (Figure 12). A single cutting date after the growing season of 1828 suggests that the Wolf House was not actually assembled or completed until that year or soon thereafter. This date, however, is from the top wall log in the upstairs partition wall (Figure 12) and might have been a repair log used in 1828 or sometime thereafter. But since there is no architectural evidence suggesting replacement, I suspect that the substantial Wolf House was not finally completed until late 1828, when Wolf found it necessary to cut at least one additional log to complete the structure.

Although Wolf claimed the property in 1824 and the Territorial Legislature designated Wolf's home as the first courthouse for Izard County in 1825, the existing house was not standing before 1827 at the earliest. This conflict suggests that the Wolf family resided in another structure between 1824 and 1827 or 1828. This may have been the home of a relative or neighbor or, more likely, some sort of temporary dwell-



ing erected by Wolf on his property. Technically, it was this temporary home and not the existing house that was the first Izard County courthouse. Archaeological evidence for this postulated temporary dwelling may still exist in the immediate vicinity of the present Wolf House.

From a different perspective, the tree-ring and documentary evidence suggest that Jacob Wolf had well-formulated plans to construct the large two-story log house as early as the summer of 1825, before his home was designated as the Izard County courthouse. Three cutting dates with incomplete terminal rings indicate that Wolf began cutting trees to use in building the existing house during the spring or summer of 1825. In addition, the three dating clusters indicate significant tree cutting activity in 1825, 1826, and 1827. Assuming the logs were cut by Wolf or members of his household, which seems likely considering the frontier conditions, the cutting dates and dating clusters document a considerable amount of labor between 1825 and 1828 and may be seen as evidence for Wolf's long range plans to build the large log house. The logs were then stockpiled until actual construction on the house began in late 1827, 1828, or soon thereafter. Upon completion the Wolf House did finally serve as the courthouse for Izard County until the county seat was moved to Livingston's Mill in 1835 (Baker 1978).

Borden House

The Archibald Borden House is a two-story frame building on the site of the 1862 Civil War battle of Prairie Grove, Arkansas. The Borden House is depicted on a battlefield map drawn in 1863 (Logan 1957). Primary sources indicate that the Borden house held Confederate sharpshooters upstairs and wounded soldiers in the cellar (Joseph Cavanaugh, personal communication). The available architectural and documentary evidence, however, does not prove that the existing house was the structure actually present during the battle. The exact age of the Borden House became an important question when the Prairie Grove Battlefield State Park was buying the property and considering the restoration of the building. Consequently, an attempt was made to verify the association of the existing structure with the Civil War battle by dating it with dendrochronology.

The Borden House is a post and beam or balloon frame building. The sills, posts, and beams of the superstructure are hewn oak. Circular sawn 2 x 4 inch pine studs are mortised directly into the oak sills, beams, and rafter plates at two-foot intervals to frame the walls of the house. Architectural evidence, however, proves that the oak timbers and the (southern yellow) pine studs are contemporaneous (Stahle 1978b).

The oak superstructure consists of very young trees unsuitable for tree-ring dating. A surprising percentage of the pine studs and other framing materials, however, possess thin strips of bark along one edge (i.e., the waney edge) and an adequate number of annual rings for dating. Furthermore, it was possible to lengthen and improve the specimen depth of the pine chronology from the Borden House by sampling studs without bark which were instead sawn from the interior of the tree. The outer rings of the studs without bark (and in some cases without sapwood) frequently overlapped and matched with the inner rings of the studs with bark to provide a longer and more reliable ring record. By extending the Borden House composite in this manner, a 143-year chronolgy (1730-1872) was developed and was absolutely dated against modern shortleaf pine chronologies from elsewhere in Arkansas.

A total of 22 pine specimens were dated, including 12 cutting dates at 1867 from the 2 x 4 inch framing studs, a 2 x 12 inch floor joist, a 1 x 6 inch wall board, and a 2 x

6 inch diagonal brace. A single 1872 cutting date was derived from a 1 x 4 inch plaster lathing stud associated with the interior wall plaster. These tree-ring dates seem to indicate that the framing was erected in 1867 or soon thereafter, and that the lathing studs were added in 1872 or soon thereafter when the interior walls were plastered. The evidence at hand, however, is not conclusive and the framing may not have been erected until 1872 or soon thereafter, while the lathing stud could be a later replacement.

At any rate, there is no doubt that the existing Borden House was not present during the Civil War battle at Prairie Grove. This finding had important implications for the managers of the State Park. Since the existing structure was not present during the battle, an expensive restoration could not be justified on that basis. More important to the goals of the State Park is the location of the original Borden House. Since the existing structure is known to post-date the battle, efforts are now being directed toward locating the original house site believed to be in the immediate vicinity.

At the same time, the tree-ring dating of the Borden House primarily on the basis of 2 x 4 inch framing studs represents a relatively unique application of dendrochronology. These results are very encouraging and suggest that many historic frame buildings may be suitable for tree-ring dating in Arkansas and elsewhere.

COMMENTS

The potential development of long term tree-ring chronologies in the eastern United States is more favorable than might be expected in view of the drastic historical changes that have taken place in the native forests. Small undisturbed and lightly disturbed remnants of the former virgin forests still exist in many eastern states. Federal and state agencies have recently inventoried many of these "natural areas," nominating the most nearly pristine areas for permanent federal protection (Waggoner 1975, Goodwin and Niering 1975, Lindsey and Escobar 1976, Shepard and Bogess n.d., Arkansas Natural Heritage Commission 1978). Many of these areas contain virgin and old-growth timber that should provide the basis for a fairly dense eastern chronology network. Even in areas of heavy disturbance populations of certain commercially marginal species (e.g., post oak) were left uncut and can provide perfectly suitable chronology material. Modern chronologies 200 to 300 years long should be routinely available with several hardwood and conifer species. The 39 modern chronologies compiled by DeWitt and Ames (1978) are a major contribution to the eastern chronology network and should be expanded to provide more uniform coverage.

Eastern red cedar and baldcypress have wide distribution in the eastern United States and show particular promise for the development of very long term chronologies. Although both species have been heavily exploited since European settlement, many early historic structures built with these species still remain and preserve valuable tree-ring records in their construction timbers. Furthermore, both species are capable of attaining great age and may still be recovered from isolated remnants of their former environments.

Many old-growth red cedar which may produce sensitive chronologies still exist on steep, relatively inaccessible bluffs and exposed ridges throughout the midwest and easten United States (Bell 1951, Weakley 1971). Bell (1951) located several specimens over 400 years old on cedar bluffs in Missouri and I have collected individuals 250 to 350 years old from cedar bluffs in northwest Arkansas. In addition, old stumps, dead snags, and relic ground litter of the hard and very durable red cedar can persist for many years on cedar bluffs. Red cedar has also been recovered in significant quantity from prehistoric archaeological sites in the eastern United States (Bell 1951, Hamilton 1952), and archaeological specimens have been crossdated in Illinois (Bell 1951) and South Dakota (Weakley 1971). Coupled with the red cedar specimens available in historic buildings, these sources of living and relic red cedar wood should contribute to the development of very long term tree-ring chronologies.

A similar species, ashe juniper (*Juniperus ashei*), is generally distributed from southern Missouri to Mexico and may also be suitable for tree-ring dating. Individuals up to 500 years old have been reported from southwestern Missouri (Charles Stockton, personal communication) and the north-central Arkansas Ozarks (Dwight Moore, personal communication).

Baldcypress was also a preferred building material and is very common in historic buildings throughout the southeastern United States. Although baldcypress has been efficiently harvested since the 18th century with the aid of annual and semi-annual flooding in the lower Mississippi Valley (Moore 1967: 10-11), small remnants of the once extensive cypress brakes still remain in areas with poor access to the main waterways, on protected private lands, and as cull trees in heavily timbered areas. Baldcypress is an extremely durable wood as well and has been recovered from riverine and swamp deposits throughout the South (Moore 1967: 4, Mills 1978: 18-22). Baldcypress specimens have also been excavated from prehistoric archaeological deposits (Walker 1936, Porter 1969), and subfossil baldcypress have been reported from the upper Chesapeake Bay north of the present range of the species (Bibbins 1905: 53). These historic, archaeological, and relic or subfossil wood remains provide the classic sources for the extension of both the modern baldcypress and red cedar chronologies well into prehistory.

Post oak (*Q. stellata*) should also be included among the more promising species for long term chronologies primarily because relatively undisturbed old-growth stands are still widely distributed in the Midwest. Post oak is a drought resistant species common on xeric, upland sites throughout its range, and pure stands of virgin trees still exist in the prairie transition region of central Oklahoma and Texas (Dyksterhuis 1948). Even in heavily timbered areas the frequently stunted post oak were not profitable and were often left uncut. I have dated living post oak over 250 years old in Arkansas and Harlan has dated sensitive post oak in central Texas which are 300 years old (T. P. Harlan, personal communication). Post oak samples from living stands and historic buildings in the prairie transition region should provide good chronologies for the last 300 to 400 years.

Bur oak (*Q. macrocarpa* Michx.) is another drought resistant oak and may reach ages of 300 to 400 years (Fowells 1965: 565). Bur oak is widely distributed in the Midwest and should be especially valuable for tree-ring chronologies in the northern plains.

Whatever the prospects for very long term chronologies may be, historic timbers can readily provide high quality tree-ring chronologies for the 17th, 18th, and 19th centuries in Arkansas and probably elsewhere in the East. In fact, by concentrating on certain species or areas it may very well be possible to obtain longer historic chronologies and more significant extensions than those obtained during this research. Historic tree-ring materials, therefore, still offer an important potential link between modern and archaeological tree-ring chronologies in the eastern United States.

ACKNOWLEDGEMENTS

This research was supported in part by the Arkansas Archeological Survey, the University of Arkansas Research Reserve Fund and Department of Anthropology, the Prairie Grove Battlefield State Park, and the New Hope Archeological Project sponsored by Dames & Moore. I would like to thank the many landowners whose hospitality and cooperation made this research possible. The cooperation of the University of Arizona Laboratory of Tree-Ring Research, the University of Arkansas Computer Center, the Arkansas Historic Preservation Program, and the Washington County Historical Society is gratefully acknowledged. I am indebted to the following people for their assistance and advice during the preparation of this paper: Mary Printup, Susan and Howard Houston, Tom Harlan, Linda Drew, Dan Wolfman, James Burns, Karen Anderson, Jim Toney, and Donna Van Kirk. Any errors of fact or interpretation, however, are mine alone.

REFERENCES

Arkansas Natural Heritage Commission
1978 *Progress report, October 1978.* Arkansas Natural Heritage Commission, Little Rock.

Baker, R. P.
1978 Jacob Wolf. *Arkansas Historical Quarterly* 37 (2) 184-192.

Bannister, B.
1962 The interpretation of tree-ring dates. *American Antiquity* 27 (4) 508-514.

Bearss, E. C. and O. W. Carroll
1965 Evaluation study of the Wolf House, Norfork, Arkansas. Report submitted to the Regional Director, Southeast Region, National Park Service. Manuscript in the files of the Arkansas History Commission, Little Rock.

Beaufait, W. R. and T. C. Nelson
1957 Ring counts in second-growth baldcypress. *Journal of Forestry* 55: 588.

Bell, R. E.
1951 Dendrochronology at the Kincaid site. In *Kincaid: a prehistoric Illinois metropolis,* edited by F. C. Cole, pp. 233-292. University of Chicago Press.

Benton County Courthouse, Bentonville, Arkansas
Benton County Chancery Court, First Probate Book.

Bibbins, A.
1905 The buried cypress forests of the upper Chesapeake. *Records of the Past* 4 (2) 47-53. Records of the Past Exploration Society, Washington, D.C.

Bowers, L. J.
1973 Tree-ring dating of the bald cypress in the Mississippi Valley. M. S. Thesis, Arkansas State University, Jonesboro.
1975 Bald cypress dendrochronology in the Cache River-Bayou De View area. In "The Cache River archeological project: an experiment in contract archeology," assembled by M. B. Schiffer and J. H. House, pp. 243-248. *Arkansas Archeological Survey Research Series* 8.

Charton, F. L. and J. R. Harman
1973 Dendrochronology in northwestern Indiana. *Annals of the Association of American Geographers* 63 (3) 302-311.

Cleaveland, M. K.
1975 Dendroclimatic relationships of shortleaf pine (Pinus echinata Mill.) in the South Carolina Piedmont. M. S. Thesis, Clemson University, Clemson, South Carolina.

Cook, E. R. and G. C. Jacoby, Jr.
1977 Tree-ring-drought relationships in the Hudson Valley, New York. *Science* 198: 399-401.

Dean, J. S.
1969 Chronological analysis of Tsegi Phase sites in northeastern Arizona. *Papers of the Laboratory of Tree-Ring Research No. 3,* University of Arizona Press, Tucson.

DeWitt, E. and M. Ames
1978 Tree-ring chronologies of eastern North America. *Chronology Series* 4, *Vol.* 1, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

Donat, P., editor
1973 Letter from Sophia Sawyer to Rev. D. Green, January 20, 1841. *Flashback* 23 (4) 10.

Douglass, A. E.
1934 Editorial. *Tree-Ring Bulletin* 1 (1) 2-3.
1941 Crossdating in dendrochronology. *Journal of Forestry* 39 (10) 825-831.

Dyksterhuis, E. J.
1948 The vegetation of the western cross timbers. *Ecological Monographs* 18: 325-376.

Estes, E. T.
1970 Dendrochronology of black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.), and shortleaf pine (*Pinus echinata* Mill.) in the central Mississippi Valley. *Ecological Monographs* 40 (3) 295-316.

Fayetteville Democrat
1877 October 6, page 3, column 3. Microfilm 136, Mullins Library, University of Arkansas, Fayetteville.

Fowells, H. A.
1965 *Silvics of forest trees of the United States.* Agriculture Handbook No. 271, USDA Forest Service, Washington, D.C.

Fritts, H. C.
1962 The relation of growth ring widths in American beech and white oak to variations in climate. *Tree-Ring Bulletin* 25: 2-10.

Fritts, H. C. and D. J. Shatz
1975 Selecting and characterizing tree-ring chronologies for dendroclimatic analysis. *Tree-Ring Bulletin* 35: 31-40.

Glassie, H.
1974 The variation of concepts within tradition: barn building in Otsego County, New York. In *Man and cultural heritage: papers in honor of Fred B. Kniffen,* edited by H. J. Walker and W. G. Haag, pp. 177-235. Louisiana State University Press, Baton Rouge.

Goodwin, R. H. and W. A. Niering
1975 *Inland wetlands of the United States evaluated as potential registered national landmarks.* National Park Service, Washington, D.C.

Hamilton, H. W.
1952 The Spiro Mound. *Missouri Archaeologist* 14: 1-276.

Harlow, W. M. and E. S. Harrar
1937 *Textbook of dendrology.* McGraw-Hill Company, Inc., New York.

Hawley, F.
1941 *Tree-ring analysis and dating in the Mississippi drainage.* University of Chicago Press.

Hutslar, D. A.
1972 *The log architecture of Ohio.* Ohio Historical Society, Columbus.

Lemke, W. J., editor
1951 Excerpts from old letters. *Flashback* 1 (6) 21.

Lillard, R. G.
1947 *The great forest.* Alfred A. Knopf, New York.

Lindsey A. A. and L. K. Escobar
1976 *Eastern deciduous forests, volume 2, beech-maple region. Inventory of natural areas and sites recommended as potential natural landmarks.* National Park Service, Washington, D.C.

Logan, R. R.
1957 Addresses at dedication of Prairie Grove Battlefield Monument, December 7, 1956. *Arkansas Historical Quarterly* 16 (3) 257-280.

Lyon, C. J.
1936 Tree-ring width as an index of physiological dryness in New England. *Ecology* 17 (3) 457-478.

Mattoon, W. R.
1915 The southern cypress. *U. S. Department of Agriculture Bulletin No. 272.*

Mills, G. B.
1978 *Of men and rivers.* U. S. Army Corps of Engineers, Vicksburg, Mississippi.

Moore, J. H.
1967 *Andrew Brown and cypress lumbering in the old Southwest.* Louisiana State University, Baton Rouge.

Ozark Mountaineer, The
1961 Wolf House, Ozark's oldest, saved for posterity. *The Ozark Mountaineer* 9 (10) 2.

Panshin, A. J. and C. de Zeeuw
1970 *Textbook of wood technology, Volume 1.* McGraw-Hill Book Company, New York.

Porter, J. W.
1969 The Mitchell site and prehistoric exchange systems at Cahokia: A. D. 1000±300. In "Explorations into Cahokia archaeology," *Bulletin No. 7, Illinois Archaeological Survey, Inc. University of Illinois, Urbana.*

Schulman, E.
1942 Dendrochronology in the pines of Arkansas. *Ecology* 23 (3) 309-318.

Shepard, R. D. and W. R. Boggess
n.d. The oak-hickory forest region of the eastern deciduous forest including an inventory of significant natural areas. Unpublished manuscript submitted to the U. S. Department of Interior, National Park Service, Washington, D. C.

Shiras, F. H.

1939 *History of Baxter County.* Mountain Home, Arkansas.

Smith, D. M.

1976 Changes in eastern forests since 1600 and possible effects.. In *Perspectives in forest entomology,* J. F. Anderson and H. K. Kaya, editors. Academic Press, New York.

Stahle, D. W.

n.d. The 1977 New Hope tree-ring survey. In "New Hope: an archeological assessment of a strip mine tract in southern Arkansas," assembled by T. C. Klinger. *Arkansas Archeological Survey Research Report* (in preparation).

Stahle, D. W.

1978a Tree-ring dating of selected Arkansas log buildings. M. A. Thesis, University of Arkansas, Fayetteville.

1978b Tree-ring dating of the Archibald Borden House, Prairie Grove, Arkansas. Report submitted to the Prairie Grove Battlefield State Park.

Stokes, M. A. and T. L. Smiley

1968 *Introduction to tree-ring dating.* University of Chicago Press.

Waggoner, G. S.

1975 *Eastern deciduous forests, volume 1, southeastern evergreen and oak-pine region. Inventory of natural areas and sites recommended as potential natural landmarks.* National Park Service, Washington, D. C.

Walker, W. M.

1936 The Troyville Mounds, Catahoula Parish, Louisana. *Bureau of American Ethnology Bulletin* 113.

Washington County Courthouse, Fayetteville, Arkansas

Records of the Washington County Chancery Court.

Washington County Deed Book A.

Weakley, W. F.

1971 Tree-ring dating and archaeology in South Dakota. *Plains Anthropologist, Memoir* 8.

Wilkins, T.

1970 *Cherokee tragedy: the story of the Ridge family and the decimation of a people.* The MacMillan Company, New York.

Willey, G. R.

1937 Notes on central Georgia dendrochronology. *Tree-Ring Bulletin* 4 (2) 6-8.

Table 2. Selected statistical characteristics of 11 historic tree-ring chronologies from Arkansas (species abbreviations defined in Table 3).

SITE NAME	ID	Species	N of trees	N of cores	N of years	Mean ring width (mm)	Percent missing rings	Mean sensitivity	Serial correlation	Standard deviation	Mean correlation among trees	Average standard deviation of cores	Standard error	Total chronology
Ridge House	655819	WO	22	22	165	61.2	0	.153	.253	.169	.292	.28	.065	1674-1838
Jackson Cabin	657810	WO	8	16	196	75.8	0	.158	.637	.309	.470	.30	.081	1654-1849
Magness Barns	658819	WO	15	23	261	58.5	0	.157	.447	.213	.413	.32	.058	1598-1858
Dutch Mills	659810	WO	13	26	219	68.0	0	.166	.350	.194	.325	.29	.059	1624-1842
Wolf House	656849	YP	25	27	156	93.0	.03	.194	.361	.226	.444	.36	.064	1672-1827
Chitwood Barn	661849	YP	4	4	118	89.1	0	.254	.583	.366	.563	.46	.123	1739-1856
Horton House	663849	YP	9	9	132	97.1	0	.234	.182	.236	.251	.37	.106	1750-1881
Drury House	664849	YP	9	9	202	102.7	0	.206	.511	.257	.335	.33	.097	1649-1850
Lancaster Barns	660830	RC	11	22	134	78.5	.04	.202	.384	.230	.386	.35	.078	1733-1866
Mt. Olive Group	665839	RC	10	12	150	95.2	0	.199	.405	.230	.303	.37	.090	1710-1859
Lafayette Jail	028979	BC	5	5	102	199.7	0	.363	.476	.411	.621	.48	.138	1727-1828

Table 3. Average statistical characteristics of 11 historic chronologies compared with 39 eastern and 102 western North American modern chronologies (after DeWitt and Ames 1978).

	HISTORIC[a]				MODERN[b]			HISTORIC[c]	EASTERN[d]	WESTERN[e]
Characteristic	WO	YP	RC	BC	QUAL	PIEC	PCRU	TOTAL SET	TOTAL SET	TOTAL SET
Mean Sensitivity	.158	.222	.200	.363	.157	.202	.158	.208	.175	.365
Serial Correlation	.422	.409	.394	.476	.468	.533	.540	.417	.496	.415
Standard Deviation	.221	.271	.230	.411	.213	.277	.236	.258	.238	.380
Number of Chronologies	4	4	2	1	16	9	5	11	39	102

[a]Historic chronologies stratified by species:

- WO = white oak (Quercus sp.)
- YP = southern yellow pine (Pinus sp.)
- RC = eastern red cedar (Juniperus virginiana L.)
- BC = baldcypress (Taxodium distichum L. Rich)

[b]Eastern modern chronologies stratified by species:

- QUAL = white oak (Quercus alba L.)
- PIEC = shortleaf pine (Pinus echinata Mill.)
- PCRU = red spruce (Picea rubens Sarg.)

[c]Combined set of 11 historic chronologies from Arkansas

[d]Combined set of 39 modern chronologies from eastern North America

[e]Combined set of 102 modern chronologies from western North America

Table 4. Cross-correlation and analysis of variance results for four replicated historic chronologies.

Site Name	ID	Species	XCORR and ANOVA period	Mean correlation within trees	Mean correlation between trees	Mean correlation among tree chronologies	Error of Y	Percent Variance		
								Chronology	Trees	Cores
Jackson Cabin	657810	WO	1745-1820	.700	.454	.470	.061	42	23	35
Magness Barns	658819	WO	1635-1730	.666	.392	.413	.088	38	31	30
Dutch Mills	659810	WO	1675-1815	.617	.313	.325	.056	29	32	39
Lancaster Barns	660830	RC	1755-1830	.514	.379	.386	.064	37	13	50

RESPONSE OF TREE-RING DENSITY TO CLIMATE IN MAINE, U.S.A.

LAURA E. CONKEY

Laboratory of Tree-Ring Research
The University of Arizona

ABSTRACT

Cores of red spruce (*Picea rubens* Sarg.) from three upper-elevation sites in Maine, U.S.A., were X-rayed, and minimum and maximum wood densities as well as ring widths were mechanically recorded. The 200- to 300-year series of maximum densities at the three sites show remarkable inter-site similarity. Maximum density and total ring-width series from one site, Elephant Mt., were standardized. Response functions, which measure tree-growth response to climatic variables, were calculated for each of these two series. The ring-width response function explained 66% total variance, of which 34% was explained by climate. The maximum density response function explained 70% total variance, 67% of which was explained by the same climatic variables. Thus, the climate signal from maximum densities is stronger, and perhaps more season-specific, than that of ring widths.

Des échantillons de "red spruce" (*Picea rubens* Sarg.) de trois stations situées à la plus haute altitude dans le Maine ont été étudiés par les méthodes densitométriques (RX). Les densités maximales et minimales ainsi que l'épaisseur totale de chaque cerne ont été mesurées. Les séries longues de 200 à 300 ans montrent d'un site à l'autre, une similitude remarquable des densités maximales. Ces densités maximales et les séries d'épaisseur des cernes d'une site, Elephant Mt., ont été standardisées. Les fonctions de réponses qui mesurent la réponse de la croissance aux variables climatiques ont été calculées pour chacune de ces séries. La fonction de réponse fournie par l'épaisseur des cernes expliquait 66% de la variance totale dont 34% étaient expliqués par le climat. La fonction de réponse obtenue en utilisant la densité maximum explique 70% de la variance totale, dont 67% sont expliqués par les mêmes variables climatiques. En conclusion, le signal climatique transmis par la densité maximum est plus puissant et peut être plus spécifique d'une saison que celui fourni par l'épaisseur totale de cerne.

Bohrkerne aus Rotfichten von drei hochgelegenen Standorten in Maine/U.S.A. wurden röntgenografisch untersucht und daraus die minimale und maximale Holzdichte sowie die Breite der Jahresringe abgeleitet. Die 200 - 300 jährigen Zeitreihen der maximalen Jahrringdichte zeigten zwischen den drei Standorten eine beachtliche Ähnlichkeit. Die Reihen der Maximaldichte und Jahrringbreite der Fichten des Standortes Mt. Elephant wurden standardisiert. Für beide Zeitreihen wurden "response functions" (Reaktionsmuster) berechnet, die einen Ausdruck für die Reaktion des Baumwachstums auf Klimaeinflüsse darstellen. Die Funktion für die Ringbreiten erklärt 66% der Gesamtstreuung, wobei 34% auf das Klima zurückgehen. Die Funktion für die maximale Dichte erklärt 70% der Gesamtstreuung, wobei 67% durch klimatische Faktoren verursacht wurden. Somit ist das klimatische Signal in der maximalen Holzdichte stärker und eventuell mehr jahreszeitenspezifisch als das der Ringbreiten.

INTRODUCTION

Dendroclimatic studies in the American Southwest have been successful in part because of the growth-limiting effects of low precipitation and high temperatures. There is thus a strong climate/growth relationship which is visible in the year-to-year variations in tree-ring widths. In contrast, the northeastern U.S. enjoys ample precipitation for most of the year, and temperatures are usually moderate in the summer. Tree growth is more commonly limited by competition from surrounding trees for sunlight, moisture, and nutrients, and the tree-growth/climate relationship is harder to establish. Thus, dendroclimatic studies using ring widths from eastern U.S.

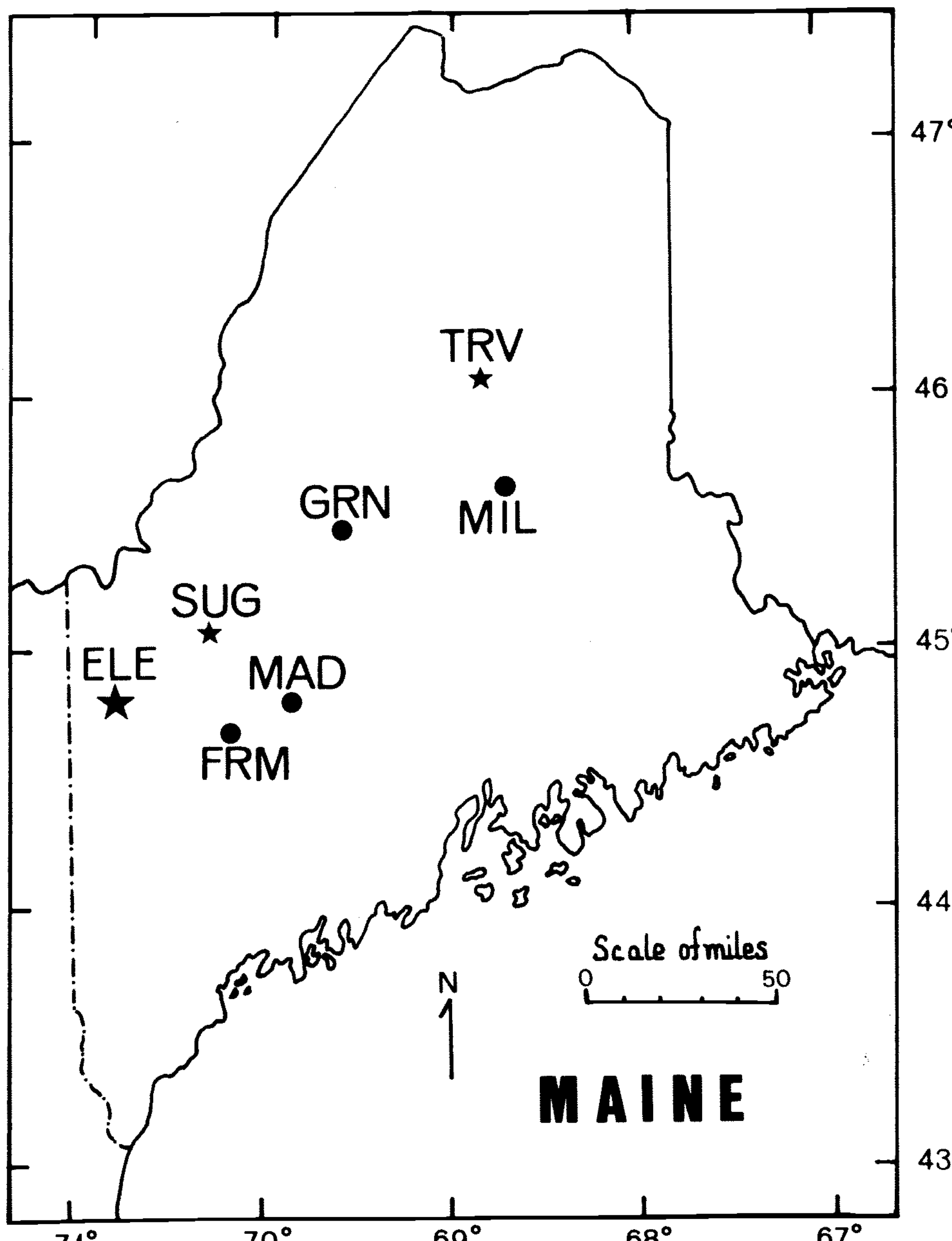


Figure 1. Location of tree-ring chronologies (stars) and stations of climatic data (dots), Maine, USA.

Tree-ring sites:	TRV	=	Traveler Mountain
	SUG	=	Sugarloaf Mountain
	ELE	=	Elephant Mountain
Climatic stations:	MIL	=	Millinocket
	GRN	=	Greenville
	MAD	=	Madison
	FRM	=	Farmington

trees have been few, hampered largely by a lack of belief in the climatic potential of tree-ring widths from humid areas.

And yet, reconstruction of the past few hundred years of climate over North America cannot be complete without the eastern picture. Reconstructions of eastern U.S. climate from a grid of western U.S. tree-ring chronologies have been attempted (Fritts, Lofgren, and Gordon 1979), but they are not as reliable as they would be if as many data were available from the East. I have previously tried to reconstruct temperature and precipitation in the East from several well-replicated eastern ring-width chronologies: the results are encouraging, but stronger growth/climate correlations are desirable (Conkey 1979).

Recent dendroclimatological studies in areas of ample moisture have included measurements of tree-ring density, as well as widths, of high-altitude conifers. Maximum (latewood) density values were found to be highly correlated with mean maximum August temperatures and runoff in Canada (Parker and Henoch 1971). The values of yearly maximum density in Swiss alpine trees were found to be related to summer temperature (Schweingruber et al. 1978). Although the eastern U.S. is not as cold or as high in elevation as either of these sites, moisture levels are similar, and there is obvious variation in latewood densities. I therefore felt this technique should be applied and tested with eastern U.S. conifers. This paper presents preliminary results obtained in a study of the contribution of tree-ring densities to analyses of climate in the eastern U.S.

THE SITES

Location of three sites of tree-ring collections in Maine, U.S.A., are indicated by a star on Figure 1: (1) Traveler Mountain, north of Katahdin in Baxter State Park, (2) Sugarloaf Mountain, a well-known ski resort near Kingfield, and (3) Elephant Mountain, actually on the col between Elephant and Blue Mountains along the Appalachian Trail north of Rumford. The Traveler and Sugarloaf Mountain sites are at the upper elevational limit of upright tree growth and thus approximate the environmental conditions of the Swiss conifers. Circles on the map (Figure 1) denote climatic stations, data from which were made available by Harold Borns and W. R. Baron from the University of Maine at Orono. Monthly precipitation totals and temperature averages extending back into the late 1800's are the data from Millinocket, Greenville, Madison, and Farmington. The site I have worked with so far is Elephant Mountain, in conjunction with data from Farmington. In addition, I am screening all the climatic data for temporal and spatial homogeneity.

The Elephant Mountain site is in direct contrast to the typical southwestern tree-ring site. Rainfall averages 40 or more inches (1016 mm) per year, little sunlight can penetrate the canopy to dry things out, the ground is not steeply sloped to allow for rapid run-off, the trees are not stunted by severe conditions, and they do not show the "spike top" of old age that is common in western North America. And yet the trees are old by eastern standards: the chronology is over 300 years long.

METHODS

Cores of red spruce, *Picea rubens* Sarg., were collected from the three mountainous sites in Maine. The cores were prepared and analyzed densitometrically at the Swiss Federal Institute of Forestry Research, Birmensdorf, Switzerland. The cores are first carefully sawn and acclimated to assure constant size and hygroscopic conditions, and they are then x-rayed. A narrow beam of light is then passed through the x-ray films, ring by ring, and the brightness is recorded. The measured densities are calibrated to represent actual wood density. (see Schweingruber et al. 1978 for a summary of procedural details.) Five parameters of each yearly ring were recorded mechanically: (1) maximum latewood density, (2) minimum earlywood density, (3) earlywood width, (4) latewood width, and (5) total ring width.

One of the three sites has been further analyzed. The two parameters of total ring width and maximum density were separately standardized, producing two series of indices, and these were analyzed in cross-correlations and analyses of variance. Each chronology was also used in a modified form of multiple linear regression called a "response function", determining possible ring-width or density response to various climatic variables (Fritts 1976). The results of these preliminary analyses are presented here, as an indication of what more we may learn about eastern U.S. climate in the past 300 years through the study of the tree rings' density instead of, or in conjunction with, their widths.

RESULTS AND DISCUSSION

A photomicrograph (Figure 2) of part of one core shows a complacent ring-width series, fairly typical for the eastern U.S.; there is little variation in width from year to year. But the density profile of the same rings in the lower portion of Figure 2 shows much greater variation. The wood of the ring for each year exhibits a steady increase in density: the cells in the earlywood are large and thin-walled, and they decrease in size and increase in wall thickness as the season progresses. In the case of spruce, maximum density is reached near the end of the growing season, and the break in density from one year to the next is an abrupt change from high to low values. The values of the yearly peaks of maximum density change from one year to the next, showing more variation than the ring widths. This variation is remarkably constant from one tree to the next within each site, allowing for crossdating much easier than with ring widths alone. Variation in density thereby represents a stronger signal of climate.

In addition, this yearly variation in magnitude of maximum density is coherent among all three sites, even at distances of more than 200 km. Figure 3 shows maximum density averaged over all the cores at each site for the last 125 years of record. The similarity is striking, and is much greater than between any two series of eastern tree-ring width chronologies that I have seen. Similarity at such wide distances is due to large-scale environmental factors, such as climate.

Two parameters of ring data, total ring widths and maximum densities, were selected from the Elephant Mountain site for further study. Each series was standardized, deriving indices by fitting exponential or polynomial curves in the case of the ring widths, and straight lines to the densities, and then dividing by the value of the curve (Fritts 1976). The indices were averaged for the two sampled cores from each tree and for all trees to produce each of the two chronologies (Figure 4). At present there is considerable debate among dendrochronologists about the validity of deriving indices from polynomial curve fits. Because of statistical constraints of polynomial curve derivation, the curve does not always adequately match tree growth, and climatic information may also be inadvertently removed. For some species, decrease in ring width with age approximates a negative exponential curve, so that such a curve has some biological meaning, but polynomial curve-fitting, now standard procedure with non-arid-site trees, is being reexamined and improved upon. The maximum density series showed very little of the narrow and wide periods of growth seen in the ring widths, and I was able to merely standardize with straight lines, an advantage amid controversies.

The upper time series in Figure 4 shows the ring-width indices. Both high- and low-frequency variation are visible, and persistence is strong. Conditions which cause a ring to be narrow in one year tend to carry over their effect on growth of following years, and the first-order serial correlation (the correlation of one series with itself at one lag) for this series is 0.61.

The lower time series in Figure 4 shows the maximum density indices. Compared to the ring-width series, the maximum densities show less low-frequency variance, less persistence. Indeed, the first-order serial correlation is only 0.18. When serial correlation is high, increased difficulties are encountered in assigning a climatic cause in any one year to the ring of that year. Density does not integrate conditions over such a long time as ring widths seem to, and yearly values appear to be more specific.

Each series was subjected to an analysis of variance. This analysis, as adapted for tree-ring work, separates the total variance of a chronology into three components: (1) that variance which is in common to the whole site, to all samples together, approx-

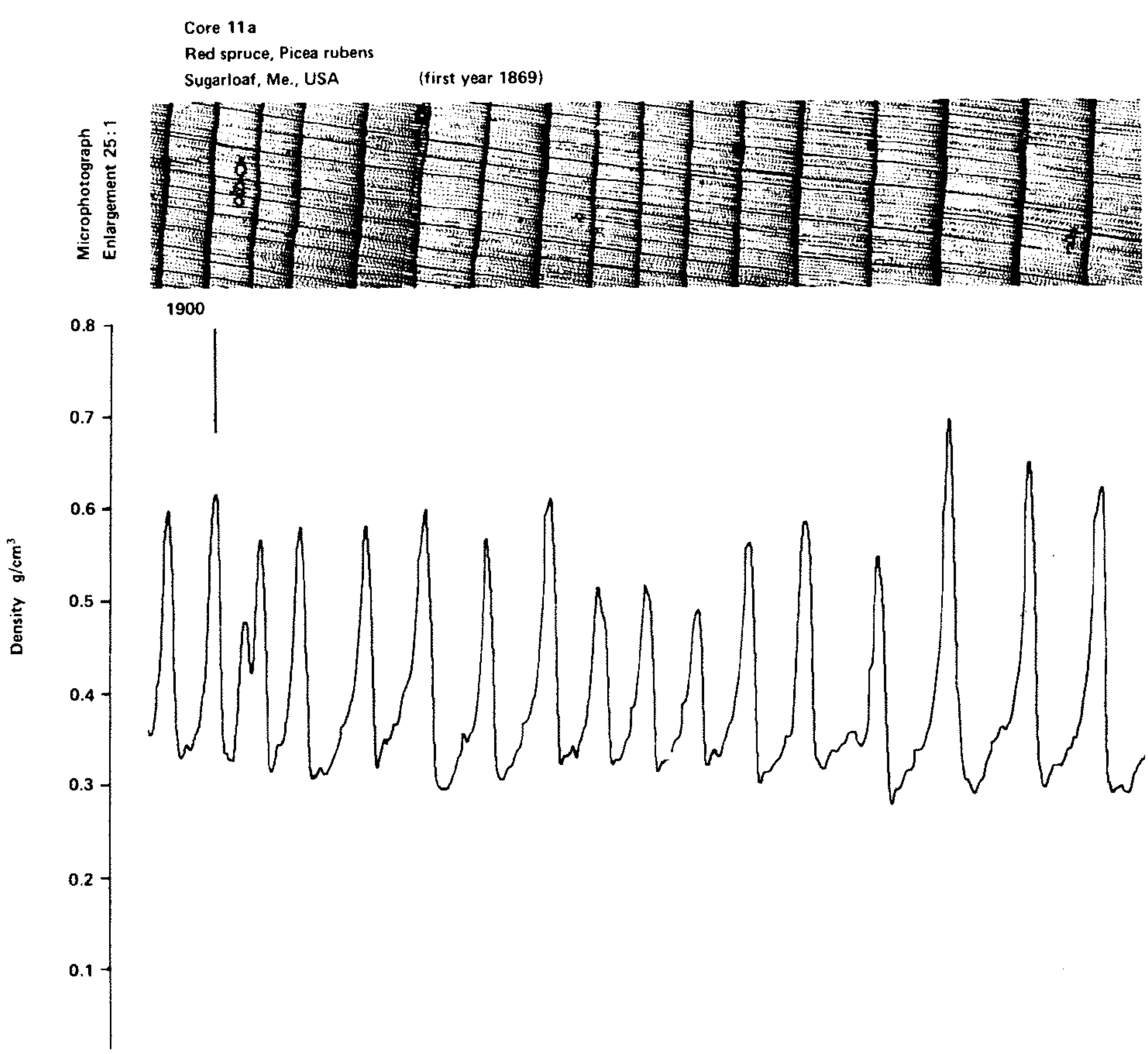


Figure 2. Density profile of a section of a core from Sugarloaf Mountain *Picea rubens*. The line plot (below) is of density in grams per cubic centimeter, and is aligned with a photomicrograph (top) of that core. Reduced for reproduction.

imating the climatic signal of the chronology, (2) that variance which is in common only to an average of the samples for individual trees (usually two cores per tree), and (3) that variance which is individual to the samples within the trees (Fritts 1976). Typical values for the variance common to the group, or climatic component, for ring-width data in the East average 28.9% (DeWitt and Ames 1978). At Elephant Mountain for ring widths it is 39%, and for the maximum density chronology it is 47%. This latter figure compares favorably to the average of 60% in stressed, arid-site ring-width chronologies (DeWitt and Ames 1978).

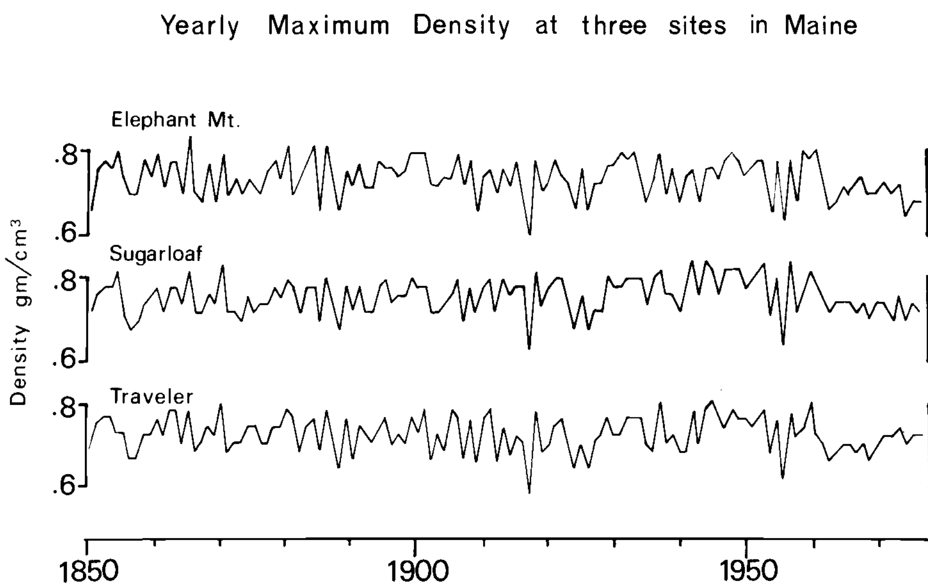


Figure 3. Yearly maximum density at three sites in Maine, USA. Each series is the average maximum density.

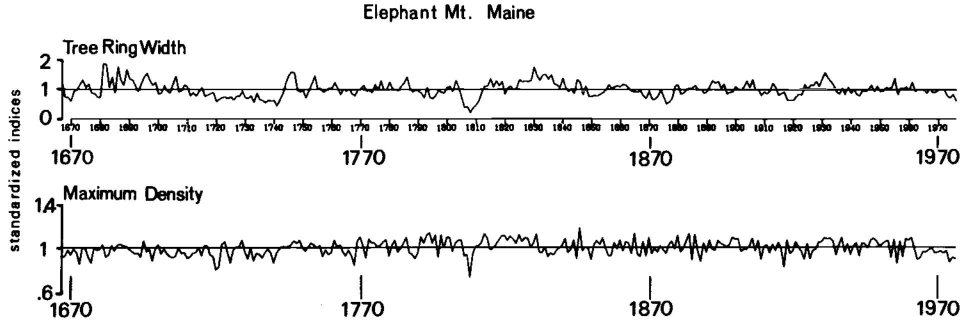


Figure 4. Time series of the standardized indices of the tree-ring widths (top) and tree-ring maximum densities (bottom) from the Elephant Mountain site, Maine, USA. Note the difference in vertical scale of the two series.

A response function was calculated for each of the two chronologies from Elephant Mountain (Fritts 1976). In the first instance, the *ring-width* indices of Elephant Mountain comprised the dependent variable for 72 years of data, 1905-1976. This was regressed on principal components of monthly temperature and precipitation values from Farmington (distance = 50 km.), for 16 months prior to and including each growing season, June of year *t-1* (where *t* is the year of calibration) through September of year *t*, plus three values of prior tree-growth indices from years *t-1, t-2,* and *t-3.* The step of the regression shown in Figure 5 accounted for 66% of the total variance, of which 34% was described by the climatic elements. Vertical bars are the 95% confidence limits for each response function estimate. Those months of temperature or precipitation that relate significantly to growth (i.e., those values whose confidence limits do not cross the zero line), either negatively or positively, indicate which climatic variables are most likely to be important to the growth of the rings. This response function indicates that large rings are correlated with low temperatures in July, August, and October of the previous year (an inverse relationship), and with high temperatures in December and January, and May, July, and September of the current growing season (a direct relationship). Precipitation shows a significant correlation to growth only in the previous year. The strongest influence on growth is related to the high first-order serial correlation we saw before; prior growth at one lag shows a high, direct correlation to ring width.

Figure 6 shows the response function for Farmington temperature and precipitation and Elephant Mountain *maximum density* indices. The total variance explained at this step of the regression is 70%, slightly higher than the ring-width analysis. However, 67% of the maximum density variance is due to these climatic variables, as opposed to only 34% of the ring-width variance seen in Figure 5. Prior density values have little importance, again reflecting the low first-order serial correlation.

I expected to find that maximum density would be responsive to late growing season conditions since it occurs at the end of the yearly ring, and, indeed, there is a positive response to August and September temperature and a negative response to August and September precipitation. High maximum density occurs, then, under hot, dry conditions in late summer, conditions probably related to water stress within the tree (Kramer 1964). The unfavorable water balance possibly discourages cell enlargement, and the photosynthates go instead into cell-wall thickening (Zahner 1963). Schweingruber and others (1978) also report a direct response of maximum density in the Swiss Alps to summer temperature, but a somewhat weaker inverse response to precipitation in late summer than I find at Elephant Mountain.

It is interesting to note that there are responses at other times of the year as well. A strong response is seen in May, positive to both temperature and precipitation. Maximum density is high when springs have been warm and wet — a different type of relationship than that seen in late summer. Explanations may be tied to still-untested relationships of maximum density to earlywood widths or minimum densities. It is reasonable that conditions which allow production of high amounts of photosynthates to contribute to latewood cell density result from optimal photosynthetic conditions earlier in the growing season (Larson 1969). Maximum density is also inversely related to June temperatures of the previous year and to December and January precipitation, and directly to temperatures in February and April. These could represent various preconditioning phenomena.

The response functions of the total ring widths (Figure 5) and maximum densities (Figure 6) do not contradict one another in any monthly response. The widths

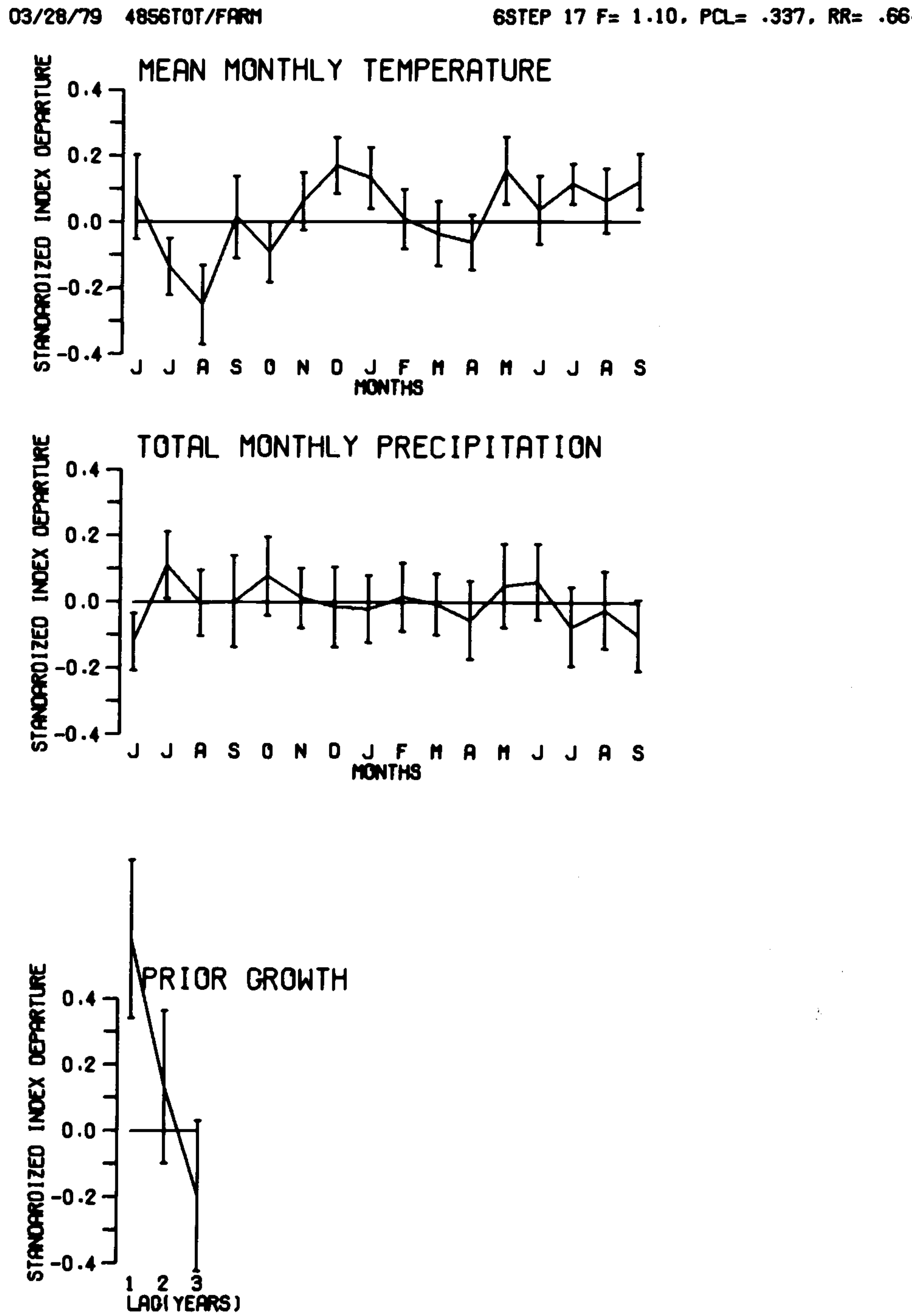


Figure 5. Results of step 17 of a response function analysis: total ring width indices from Elephant Mountain, Maine, regressed on principal components of monthly temperature and precipitation values from Farmington, Maine, and three years of prior growth indices. The vertical bars are the 95% confidence limits. Total variance at this step is 66%; that variance due to climatic factors alone is 34%.

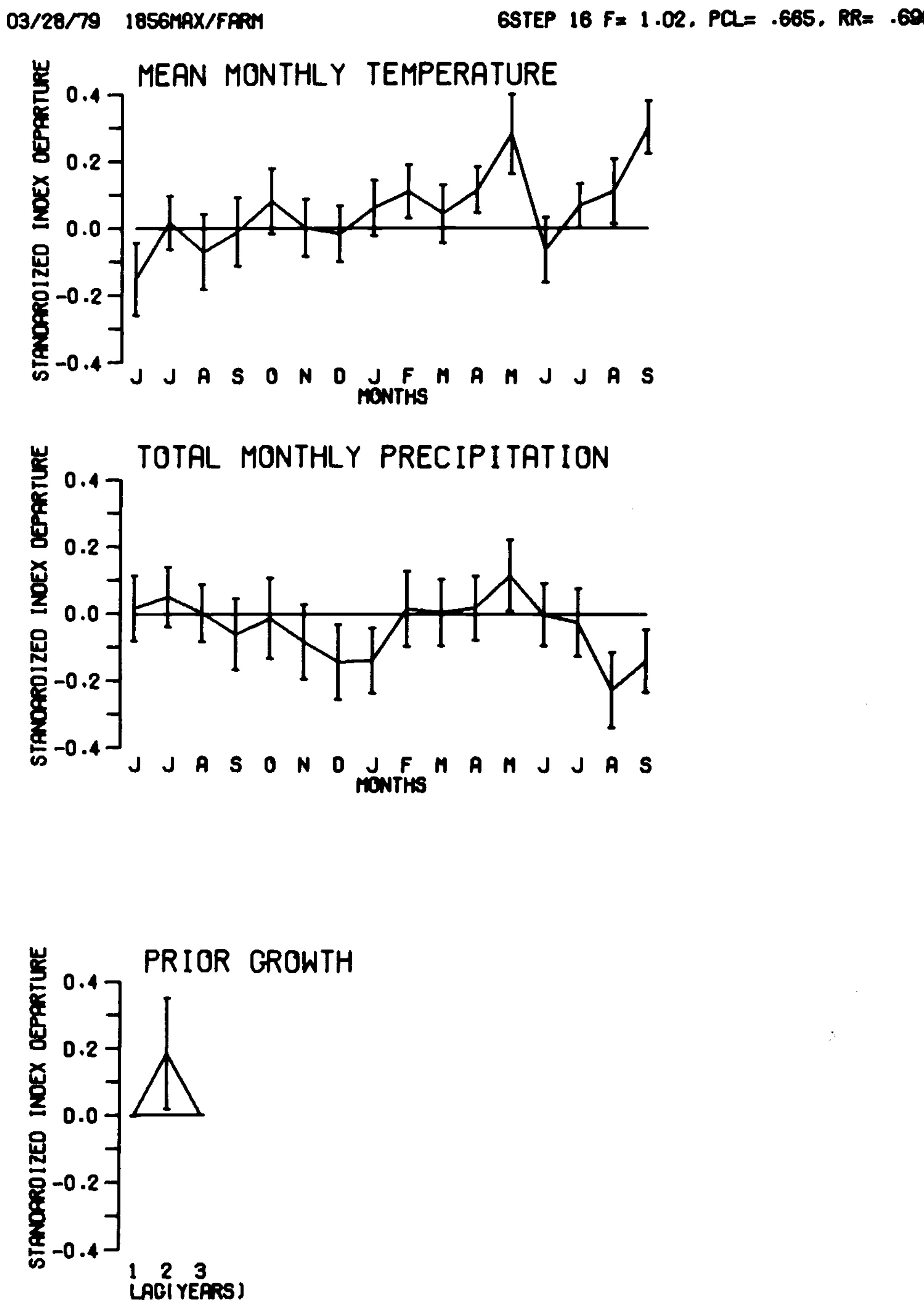


Figure 6. Results of step 16 of a response function analysis: yearly maximum density indices from Elephant Mountain, Maine, regressed on principal components of monthly temperature and precipitation values from Farmington, Maine, and three years of prior maximum density indices. The vertical bars are the 95% confidence limits. Total variance at this step is 70%; that variance due to climatic factors alone, 67%.

integrate conditions over a larger time period and the densities have a more specific response; both together may be able to provide a more complete picture of past climate in the East than we now have from ring widths alone.

ACKNOWLEDGEMENTS

This research has been undertaken with support from a Fulbright-Hays — administered, Swiss Government Grant for predoctoral research to the author, from National Science Foundation Grant No. ATM/77-19216 A01 to The University of Arizona (H. C. Fritts, principal investigator), and from the School of Forest Resources and the Institute of Quaternary Studies, University of Maine at Orono. I would like to thank Fred Knight, Harold Borns, and Bob Baron of the University of Maine for climatic data and logistical support, Bob Brakenridge for field assistance, Fritz Schweingruber and staff at the Swiss Federal Institute of Forestry Research for guided use of their facilities, and Linda G. Drew and staff for keypunching and computer help at The University of Arizona. Drafts of the manuscript were thoughtfully reviewed by Harold C. Fritts, William R. Boggess, Bob Brakenridge, Marvin A. Stokes, and Marna Ares Thompson.

REFERENCES

Conkey, L. E.
1979 Dendroclimatology in the northeastern United States. M. S. thesis, The University of Arizona, Tucson, Arizona.

DeWitt, E. and M. Ames, editors
1978 Tree-ring chronologies of eastern North America. *Laboratory of Tree-Ring Research, Chronology Series* 4, Vol. 1.

Fritts, H. C.
1976 *Tree rings and climate.* Academic Press, London.

Fritts, H. C., G. R. Lofgren, and G. A. Gordon
1979 Variations in climate since 1602 as reconstructed from tree rings. *Quaternary Research* 12: 18-46.

Kramer, P. J.
1964 The role of water in wood formation. In *The Formation of Wood in Forest Trees,* edited by M. H. Zimmermann. Academic Press, New York.

Larson, P. R.
1969 Wood formation and the concept of wood quality. *Yale University School of Forestry Bulletin* 74.

Parker, M. L. and W. E. S. Henoch
1971 The use of Englemann spruce latewood density for dendrochronological purposes. *Can. J. For. Res.* 1 (2) 90-98.

Schweingruber, F. H., H. C. Fritts, O. U. Bräker, L. G. Drew, and E. Schär
1978 The x-ray technique as applied to dendroclimatology. *Tree-Ring Bulletin* 38: 61-91.

Zahner, R.
1963 Internal moisture stress and wood formation in conifers. *Forest Prods. J.* 13: 240-247.

DENDROCHRONOLOGICAL INVESTIGATIONS IN IRAN

NILI LIPHSCHITZ
Y. WAISEL
and
S. LEV-YADUN

Department of Botany
Tel-Aviv University, Israel

ABSTRACT

Dendrochronological research on *Juniperus polycarpos* growing in west and central Iran reveals that the radial growth in this species depends mainly on the amount of precipitation in the more arid regions. When the amount of rain is sufficient, i.e. above 450 mm, the prevailing summer temperature seems to become the limiting factor.

Favorable conditions which prevailed during the periods 1685-1695 and 1790-1800 resulted in better width growth, while less favorable conditions which prevailed during the years 1725-1735 and 1855-1865 resulted in narrow rings.

Des recherches dendrochronologiques portant sur *Juniperus polycarpos* croissant dans l'Iran occidental et central, démontrent que la croissance radiale de cette espéce dépend de la quantité de précipitations dans les régions les plus arides. Lorsque la pluviosité est sufficante (au-dessus de 450 mm), la température estivale semble devenir le facteur limitant.

Les conditions favorables qui prévalaient durant les périodes 1685-1695 et 1790-1800 ont provoqué une meilleure croissance en diamétre, tandis que les conditions moins favorables qui ont régné durant les années 1725 à 1735 et 1855 à 1865, correspondent à des cernes étroits.

Dendrochronologische Untersuchungen an dem Wacholder Juniperus polycarpos in West; und Central-Iran zeigen, daß das Dickenwachstum dieser Baumart in den trockneren Gebieten vor allem von den Niederschlägen abhängt. Wenn die Regenmenge dagegen ausreicht, d. h. mehr als 450 mm pro Jahr beträgt, wird die Sommertemperatur zum Minimufaktor.

Günstige Witterungsbedingungen in der Zeit von 1685 bis 1695 und von 1790 bis 1800 führten zu breiteren Jahrringen, während ungünstigere Bedingungen in den Jahren von 1725 bis 1735 und von 1855 bis 1865 enge Jahresringe zur Folge hatten.

INTRODUCTION

Dendrochronology is one of the best sources for past climate information and provides an accurate tool for the understanding of regional climatic systems. Reconstruction of long climatic records is of interest not only for climatologists and botanists, but may be of help also in predicting climatic changes in the future, a prediction which has become recently so important.

However, despite its considerable importance, only few dendrochronological analyses have been made in the Middle East. Mainly this is due to the scarcity of old trees and of specimens with distinct annual growth rings (cf. Fahn et al. 1963; Liphschitz and Waisel 1967, 1969:91; Felix 1968; Tamari 1976; Liphschitz et al. 1979; Waisel and Liphschitz 1968).

Juniperus polycarpos, however, is a coniferous species which seems to be suitable for dendrochronological analysis. *Juniperus* trees produce distinct growth rings and attain old age. *J. Polycarpos* is indicative for semiarid regions and trees appear in Turkey, southeast Arabia (Muscat), Iran, Caucasus, Baluchistan, Afganistan, northwest Himalaya, Transcaspia, and Turkestan (Townsend and Guest 1966 :91-92).

According to Dallimore and Jackson (1954), this species forms the link between the East Asiatic Chinese Juniper (*J. chinensis)* and the Western Grecian Juniper (*J. excelsa)* of the Mediterranean region. *J. polycarpos* seems to be closely related to the latter and was considered by some authors (Zohary 1963) to be synonymous.

The tree is one of the dominant species of the *Junipereto-Pistacietea* steppe forest dominated chiefly by *Juniperus polycarpos, Pistacia Khinjuk,* and *Pistacia atlantica.* In Iran, the stands of *Juniperus polycarpos* are limited mainly to southern slopes of the Elburz Mountains, but single stands occur also as far as the mountains (27° N lattitude) near Bandar Abbas (Zohary 1963). Dendrochronological investigation in west and central Iran is of special interest since this area constitutes the most eastern district of the Middle East and Asia Minor and little information is available concerning past or present climate in this region (cf. Kinsley 1970).

Dendrochronological research on *Juniperus polycarpos* growing in the Elburz Mountains was therefore undertaken.

The precipitation in the investigated area ranges between 250 and 550 mm with 237 mm annual amount in Tehran. Rains in north Iran are mostly distributed over nine months; during July to September the total amount is very small or negligible. The temperatures range between an absolute maximum of 42°C and mean maximum of 29.9°C in July and an absolute minimum of -20°C and mean minimum of 3.8°C in

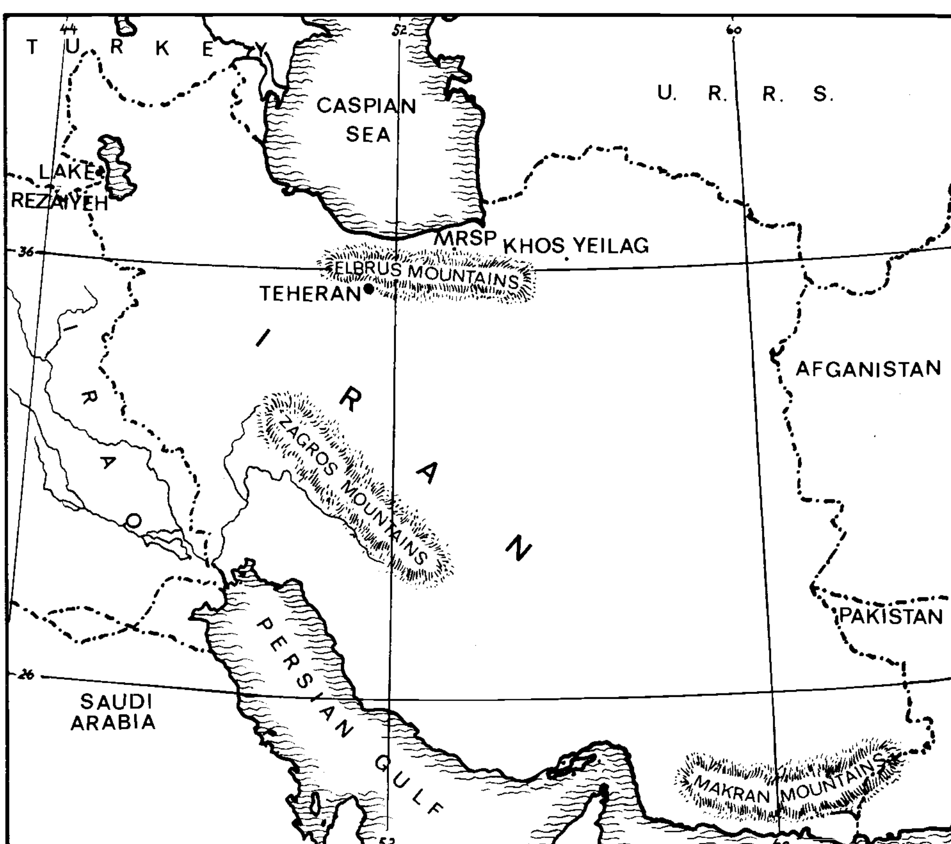


Figure 1. Map of Iran.

Table 1. Distribution according to ages. Correlation coefficients between individual trees and the master chronology of each of the three *J. polycarpos* populations.

Sampling site	Tree No.	Age	r	N	t
Khosh Yeilag	3	148	.525	148	7.445
	9**	254	.317	101	3.329
	10**	158	.308	158	4.042
	11	233	.402	232	6.660
	12	263	.447	263	8.066
	13	318	.624	298	13.735
	16	248	.432	248	7.503
	17	234	.449	234	7.657
	23	191	.462	191	7.167
	24	197	.554	197	9.300
	27	188	.344	188	4.996
	29	240	.344	235	5.593
	30	243	.393	239	6.579
	31	314	.409	314	7.920
	32*	150	.335	150	4.331
	41	261	.343	261	5.885
	42	261	.579	261	11.442
	43	295	.515	295	10.292
Mohamed Rizah	50	194	.567	192	9.494
Shah Park	51*	109	.748	109	11.657
	55	220	.385	220	6.162
	56*	304	.779	304	21.609
Lake Rezaiyeh	101	141	.502	141	6.836
	102	83	.493	83	5.101
	103*	138	.826	138	17.112
	104	104	.703	104	9.979
	105	84	.572	84	6.318

r = correlation coefficient
N = No. of years in correlation
t = Students "t" value
* - a core
** - Not included in the master

January, as recorded in Tehran (World Weather Records 1960; Iran Meteorological Records 1973).

MATERIALS AND METHODS

Twenty-three cross sections and four increment cores were collected in north Iran during the autumn of 1973. The samples were obtained from five stands: three of them at Khosh-Yeilag at approximately 10 km apart (55° 30'E, 36°45'N); one site at Mohamed Rizah Shah Park (=MRSP) (53°30' E, 37°15' N) and another site on one of the islands on Lake Rezaiyeh (45°15' E, 38°15' N) (Figure 1 and Table 1). Whenever possible, cross sections were taken for examination. Cores were collected only on sites where trees could not be felled.

The width of the annual growth rings was measured on the smoothed surface of the cross sections. Measurements were made with a stereoscope and a micrometric ocular along three radii of each section, from the periphery towards the center. A curve was fitted to the data and the value of the ring widths were calculated as indices (Fritts

1963; Fritts et al. 1969). The indices are based on the relationship each year between the actual measurements and a value given to the very same year by the fitted curve.

After the indices of each of the trees were calculated, the growth curves of the trees were crossdated, and a master chronology was constructed. A master chronology represents the growth pattern of the entire population at one site.

The nearest meteorological station to all sampling sites that has available records for a long period of time (up to 66 years) is Tehran (Figure 1). Meteorological records were therefore obtained from this station.

Correlation coefficients between the master chronology and climatic variables such as precipitation (annual, monthly, and seasonal amounts) and temperatures (mean monthly minimum and maximum) were calculated.

RESULTS

The radial growth patterns of *Juniperus polycarpos* trees are presented in Figures 2-4.

Two populations of trees — one sampled at Khosh Yeilag and the other sampled at Mohamed Rizah Shah Park (=MRSP) showed a similar pattern of radial growth (Figures 2-3). A different pattern of growth was distinguished in trees which were sampled at Lake Rezaiyeh (Figure 4).

A period of wide ring production was seen in trees sampled at Khosh-Yeilag during the period 1670-1690 and 1790-1820. A period with narrow ring production occurred around the years 1690-1740 and 1835-1865.

A period of wide ring production occurred in trees sampled at MRSP during the years 1690-1725, 1795-1805 and 1945-1955. Narrow rings were formed at this site around the years 1725-1735 and 1865-1915.

A period of wide ring formation occurred in trees which were sampled at Lake Rezaiyeh around the years 1865-1885 and 1955-1970. Narrow rings were produced by these trees around 1850-1865 and 1930-1940.

Correlation between annual amount of precipitation and the growth indices of the four populations examined was insignificant.

For trees sampled at Khosh-Yeilag, a correlation coefficient of 0.307 was obtained for the correlation between the indices of the master chronology and the precipitation of March; correlation coefficients values ranging between -0.379 and -0.467 were obtained for correlations between the master indices and temperatures of June, July, August, and October (Table 2).

For trees sampled at MRSP a correlation coefficient of 0.615 was calculated between the master indices and a precipitation for September and a value of -0.505 was obtained when the temperature of June was correlated with the indices (Table 2).

Correlation coefficient values varying between 0.409 and 0.596 were obtained for trees sampled at Lake Rezaiyeh for the master indices and the temperatures of August, September, and October. No correlation was obtained with monthly precipitation (Table 2).

DISCUSSION

The data represented above suggest that the radial growth of *Juniperus polycarpos* trees depends mainly on the amount of precipitation in the more arid regions, i.e. in Khosh-Yeilag and MRSP districts, which receive about 150-200 mm of mean annual rainfall. When the amount of rains was sufficient, i.e. above 450 mm, the prevailing

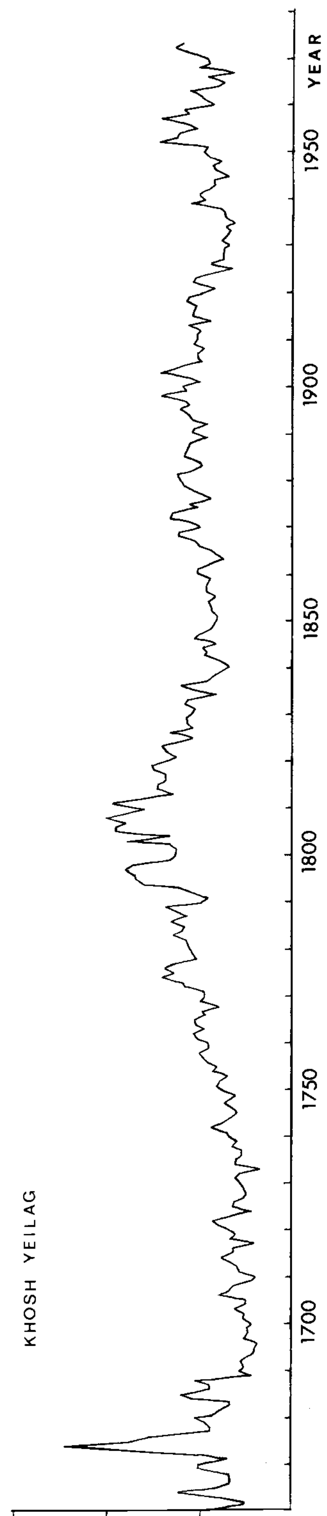


Figure 2. The master chronology for the Khosh Yeilag site.

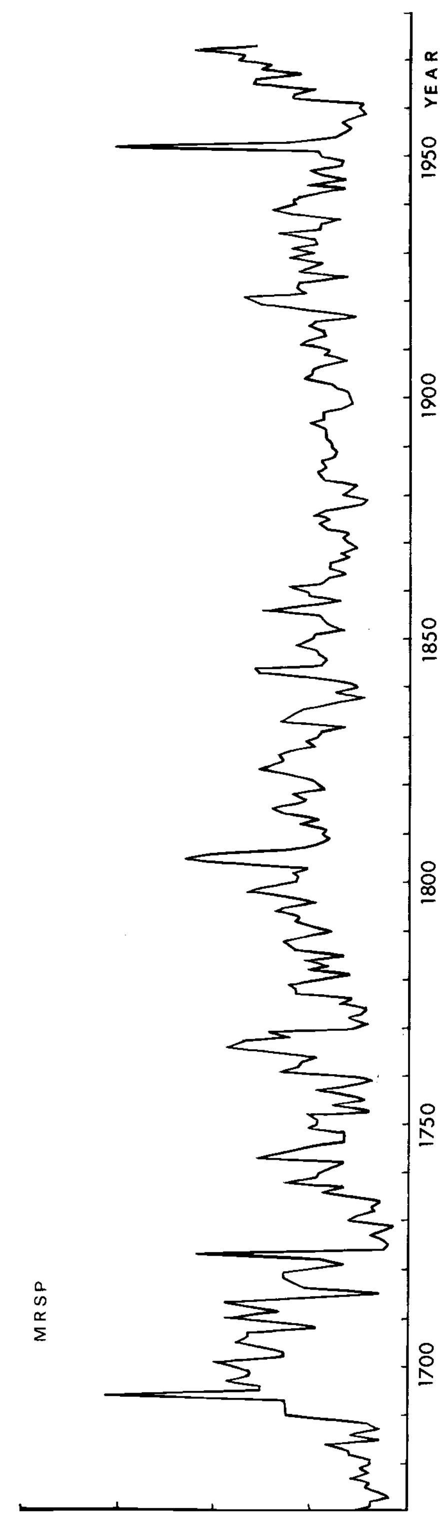


Figure 3. The master chronology for the MRSP site.

Table 2. Correlation coefficients between climatic parameters and radial growth indices of the master chronology of the three populations sampled.

Sampling site	Climatic Parameter	r	t	N
Khosh Yeilag	precipitation - March	.307	2.495	59
	mean min. temp. June	-.454	2.040	18
	mean min. temp. July	-.389	1.690	18
	mean max. temp. July	-.467	2.113	18
	mean max. temp. August	-.379	1.637	18
	mean max. temp. August-October	-.395	1.664	18
Mohamed Rizah Shah Park	precipitation - September	.615	5.894	59
	mean min. temp. June	-.505	2.342	18
Lake Rezaiyeh	mean min. temp. August	.409	1.795	18
	mean min. temp. September	.446	1.931	18
	mean min. temp. August-October	.531	2.528	18
	mean max. temp. August	.534	2.161	18
	mean max. temp. September	.487	1.900	18
	mean min. temp. August-October	.596	2.876	18

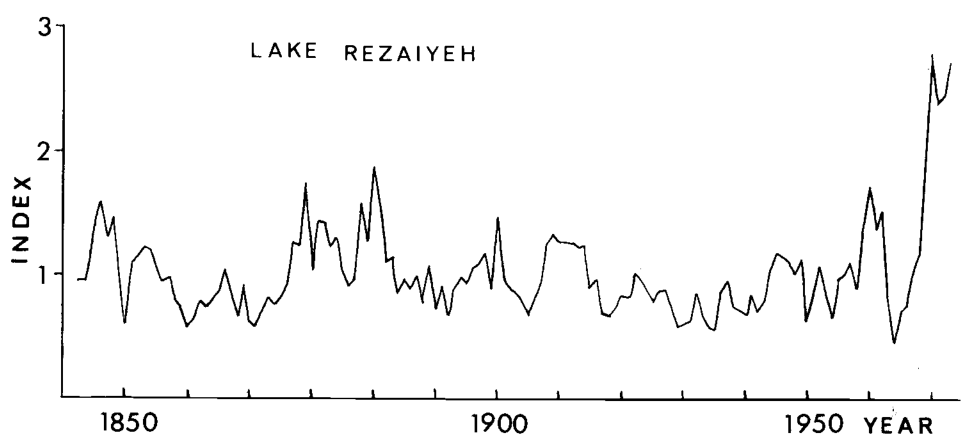


Figure 4. The master chronology for the Lake Rezaiyeh site.

temperature seems to become the limiting factor, especially during some months. Radial growth patterns of *J. polycarpos* trees from Lake Rezaiyeh — a cooler district, which receives above 450 mm of mean annual rainfall — seem to depend on summer temperature only. Wider rings were produced by those trees during years with relatively high summer temperature.

The growth patterns of *J. polycarpos* trees from Khosh-Yeilag and MRSP districts in the last 300 years suggest that during the period 1685-1695 and 1790-1800 temperate climate prevailed in the area, which enabled the production of wide rings, i.e. a more humid period with lower summer temperatures. During the years 1725-1735 and 1855-1865 less favorable conditions prevailed, which resulted in narrow ring production. These periods were rather more arid with relatively high summer temperatures. The second unfavorable period, i.e. 1855-1865, influenced also the trees which grew in the more humid district of Lake Resaiyeh, and probably conditions were more severe with less available water.

It is interesting to note that there is a clear similarity between the growth patterns of *Juniperus polycarpos* from Khosh-Yeilag (36°31′ N Lat.) and those of *Pinus nigra* of southwest Turkey (36°30′ N. Lat.) (cf. Liphschitz et al. 1979). A period of wide ring production occurred in southwest Turkey during the years 1670-1710 and 1800-1820. A drop in the growth curve due to narrow ring formation took place around the years 1720-1740 and 1830-1850.

ACKNOWLEDGEMENT

The authors thank Mr. M. Agami and Dr. I. Szwarcbaum-Shaviv for their help during the field trips.

REFERENCES

Dallimore W. and B. D. Jackson
1954 *A handbook of coniferae,* 3rd edition. E. Arnold, London.
Fahn, A., N. Wachs, and C. Ginzburg
1963 Dendrochronological studies in the Negev. *Israel Exploration Journal* 13; 291-299.
Felix, J.
1968 Tree and forest of the Golan. *Teva Va-aretz* 10: 168-178 (in Hebrew).
Fritts, H. C.
1963 Computer programs for tree-ring research. *Tree-Ring Bulletin* 25-2-7.
Fritts, H. C., J. E. Mosimann, and C. Bottorff
1969 A revised computer program for standardizing tree-ring series. *Tree-Ring Bulletin* 29: 15-26.
Kinsley, D. B.
1970 A geomorphological and paleoclimatological study of the playas of Iran. US Geological Survey, Department of Interior, Washington, D.C.
Liphschitz N. and Y. Waisel
1967 Dendrochronological studies in Israel. I. *Quercus boissiei* of Mt. Meron region. *La-Yaaran* 17: 78-91.
1969 Dendrochronological investigations in north Sinai. In "Proceedings of the 8th Symposium of Soc. Adv. Sci. Jerusalem
Liphschitz, N., S. Lev-Yadun, and Y. Waisel
1979 Dendrochronological investigations in the Mediterranean Basin - *Pinus nigra* of South Anatolia (Turkey). *La-Yaaran* 27: 3-11, 33-36.
Tamari, A.
1976 Climatic fluctuations in the eastern basin of the Mediterranean based on dendrochronological analysis. Doctoral thesis, Tel-Aviv University, Tel-Aviv.
Townsend, C. C. and E. Guest
1966 *Flora of Iraq,* Vol. 2, Ministry of Agriculture, Baghdad.
Waisel, Y. and N. Liphschitz
1968 Dendrochronological studies in Israel. II. *Juniperus phoenica* of north and central Sinai. *La-Yaaran* 18: 1-22, 63-67.
Zohary, M.
1963 Geobotanical structure of Iran. *Bulletin of the Research Council of Israel* 11D, Supplement.

TREE-RING SKELETON PLOTTING BY COMPUTER

JOHN PHILIP CROPPER

Laboratory of Tree-Ring Research
The University of Arizona

ABSTRACT

Skeleton plotting is an established manual technique for representing the relative narrowness of tree rings in a single radius. These plots can be used as a visual aid to crossdating. This paper describes a method for deriving these plots by computer. The method uses a low-pass digital filter, running means, and standard deviations of ring-width measurements.

When the manual and computer plots are compared for the same series, approximately 85% agreement is found.

Examples of results are presented for specimens from sensitive, moderate, and complacent sites. FORTRAN program listings are included for two subroutines for (a) identifying small rings and (b) producing the plot.

La technique du "Skeleton plot" est une méthode manuelle pratiquée pour mettre en évidence la minceur relative des cernes observés suivant un rayon. Les graphiques ainsi obtenus constituent une aide visuelle pour l'interdatation des échantillons. Le présent article décrit une méthode permettant de construire, par ordinateur, ces graphiques. La méthode utilise un filtre digital passe-bas, des moyennes courantes et les déviations standard des mesures de cernes. Lorsque des séries manuelles sont comparées à fournies par l'ordinateur, on constate approximativement 85% de concordance. L'édition des programmes FORTRAN est jointe pour deux sous-routines: (a) identification des petits cernes (b) production du graphique.

Die Anfertigung von sog. "skeleton plots" oder Minimum-Diagrammen ist ein bewährtes manuelles Verfahren zur Veranschaulichung der relativen Breite von schmalen Jahresringen eines Radius. Diese Diagramme können als visuelle Hilfe bei der Synchronisierung von Jahrringfolgen dienen. Der vorliegende Beitrag beschreibt die Möglichkeit, derartige Diagramme mit Hilfe eines Computers anzufertigen. Die Methode benutzt einen Zahlenfilter,, der die kurzwellige und hochfrequente Streuung einer Jahrringfolge eliminiert, ferner die gleitende Mittelwertbildung und die Standardabweichungen der Jahrringbreiten.

Beim Vergleich von "skeleton plots" derselben Jahrringfolgen, die sowohl manuell als auch vom erstellt Computer wurden, ergab sich eine Übereinstimmung von 85%. Es werden Beispiele für Holzproben gezeigt, die von Standorten stammen, wo die Bäume Jahrringfolgen mit starken, mittleren und geringen jährlichen Schwankungen ausbilden. Zudem sind die FORTRAN-Versionen für zwei Unterprogramme enthalten, die schmale Jahrringe erkennen und das Minimum-Diagramm anfertigen.

INTRODUCTION

Over the past ten years the computer and other machines have increased in their importance to the science of dendrochronology. The use of such technical aids has resulted in an ability to process many more specimens with limited manpower. The workers at the University of Washington, College of Forest Resources, have made advances in linking a cassette recorder to a measuring machine and bypassing the necessity (and possibly error-prone step) of card-punching (Brubaker 1979, personal communication). Other workers using X-ray densitometry work with a totally different aspect of the ring (i.e., density rather than total ring width) (Parker et. al. 1976; Polge 1966; Milsom and Hughes 1977). In Virginia at the U. S. Geological Survey, the actual viewing of the wood has been made easier by magnifying the microscope image onto a color television using a close-circuit camera installed into the microscope (Phipps 1979, personal communication). Most of the advancement in the science has been made possible by the speed at which the computer can accomplish complex mathematical manipulations of vast amounts of data. Examples of such programs are the standardizing program INDXA (Fritts et al. 1969) and the response function program (Fritts et al. 1971). Programs that are useful at earlier stages in chronology building have been written and these include computer crossdating programs. Crossdating programs have been in use since 1965 with varying degrees of success. All of them basically use a system involving cross-correlation techniques (Fritts 1963; Parker 1967; Baillie and Pilcher 1973; Wendland 1975).

At the Laboratory of Tree-Ring Research another crossdating aid called skeleton plotting is used. In chronology development at this Laboratory, the recommended procedural steps are to (1) skeleton plot the samples and then (2) go through the pattern-matching process to actually crossdate the wood. Normally only after each ring has been assigned to the calendar year is (3) the wood measured. The author envisages that by changing the order of the above procedure (to 3, 1, 2) and by using a computer program as described below, consistent skeleton plots can be produced with considerable timesaving. This program is *not* for crossdating and does *not* replace the practical experience of many years of examining diverse wood samples, but should be considered an aid to crossdating.

METHOD

Skeleton plotting has been practiced manually at the Laboratory of Tree-Ring Research, Tucson, Arizona, since 1927 (Douglass 1935). This paper demonstrates that in certain circumstances a statistically developed computer skeleton plot can be produced from undated ring widths as an aid to the crossdating procedure. In this procedure, each ring in the tree-ring series is assessed for its narrowness when compared to its immediate neighbors. Each narrow ring is then represented on a linear plot as a line of increasing length proportional to its narrowness. Thus, a series of ring widths can be represented by a piece of graph paper with the significant (narrow) rings indicated. Plotting a series of such lines for different specimens makes matching the significant patterns and thus crossdating the samples considerbly easier (Schulman 1942; Giddings 1942; Schulman 1944; Lyon 1953; Stokes and Smiley 1968; Ferguson 1970).

The author accepts that in some instances the computer skeleton plotting procedure would be of little or no use. For example, when skeleton plotting is used for dating archeological specimens, such as roof timbers or charcoal, then the date itself is the only information the technician is seeking. In such cases the ring widths would not necessarily be measured and a computer-processed skeleton plot would only involve unnecessary work. However, many other dendrochronological analyses, such as dendroclimatology, require measurement of the ring widths in order to form the final chronology.

The skeleton plotting program is designed to accomplish what a dendrochronologist does when he microscopically examines a piece of wood and makes a decision on narrowness based on the comparison of each ring with its immediate neighbors. In programming the computer for this comparison, the running mean and standard deviations are determined, and these two parameters are used to make the decision on relative narrowness. The number of rings averaged and the best critical level for narrowness (the number of standard deviations smaller than a ring must be to be considered narrow) depend to some extent upon the sensitivity (year-to-year variability in ring width) of the specimen.

There is an "end" effect such that narrowness cannot be determined for the rings at the extreme ends of the series. The number of rings involved is equal to the number of years used in the mean minus one; thus, using a mean of five years there would be the loss of two years data from each end. The actual process of computing the standard deviation of a mean of three numbers prevents two small rings occurring consecutively from being recognized as narrow. Thus, two skeleton marks will not appear next to each other on plot (c) (Figures 1, 2, and 3). Because of the potential problems of double small rings occurring together, it is suggested that means of five or more

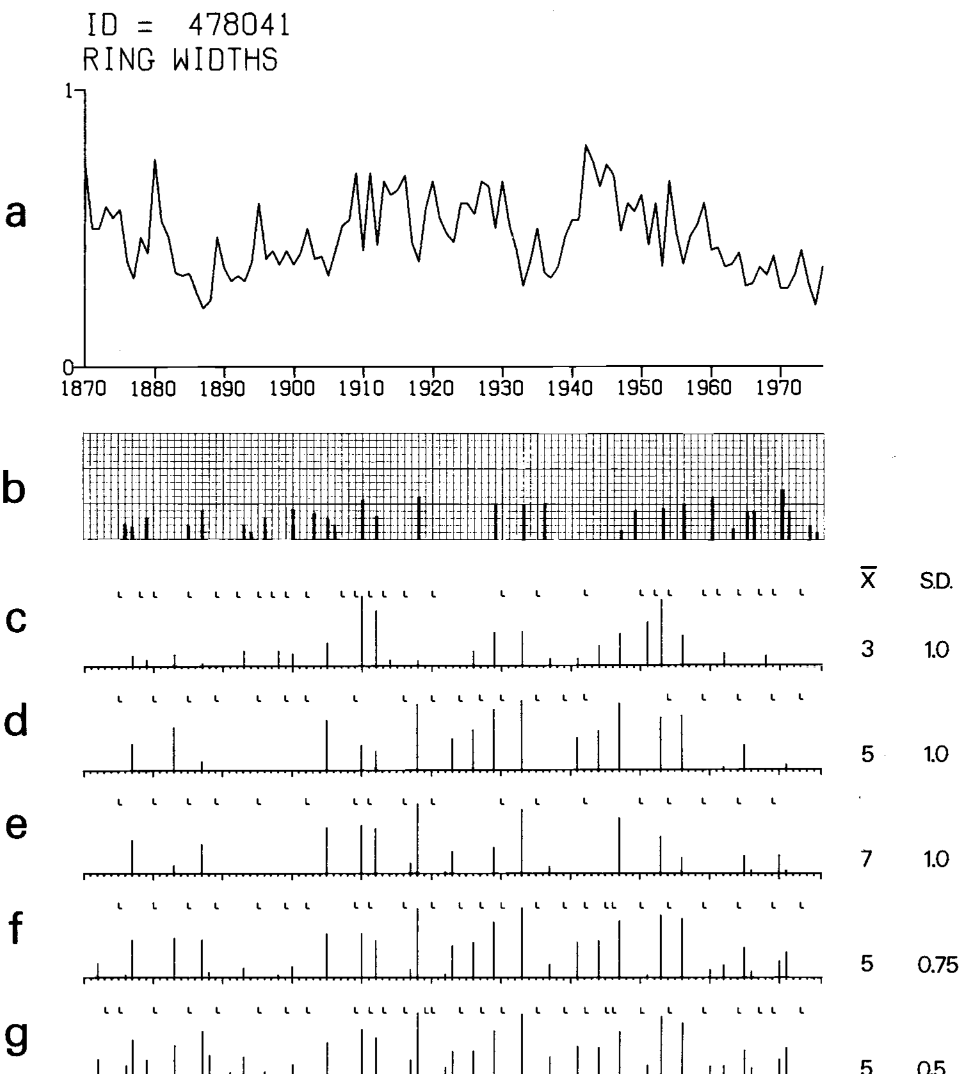


Figure 1. Series 478041. A moderately sensitive series of white spruce (*Picea Glauca*) from Labrador. (a) graphic plot of ring widths in 100ths of millimeters. (b) manually derived control skeleton plot. (c) - (g) computer-derived skeleton plots using varying numbers of years in the running mean (X̄) and varying multiples of standard deviations (S. D.) for the critical levels beyond which a ring is defined as large or small.

years be used for developing the plots. In order to obtain more skeleton marks for use in the dating process, the reduction of the critical level to 0.75 standard deviations considerably increases the number of "significantly small" rings. Even more marks are obtained with a reduction of the critical level to 0.5 standard deviations.

For example, suppose the mean of five rings is 2.0 mm with a standard deviation of 0.75 mm and the critical level is chosen to be 0.5 standard deviations. Then if the central ring is smaller than (2.0 - (0.5 * 0.75)), it is plotted as a narrow ring. If the central ring is greater than (2.0 + (0.5 * 0.75)), it is marked as a large ring (L). If the ring width falls between these two limits, it is ignored and plotted as zero. For small

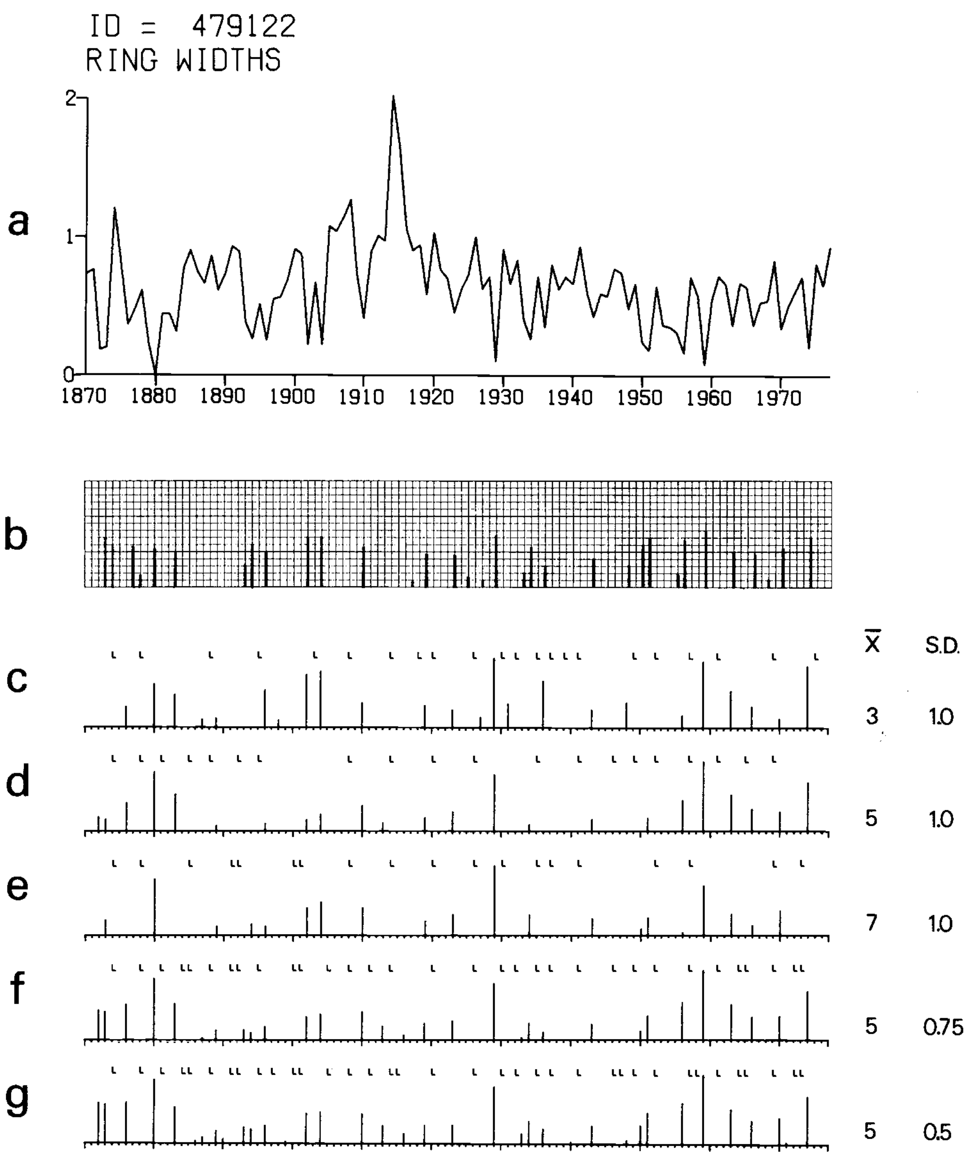


Figure 2. Series 479122. A highly sensitive series of white fir (*Abies concolor*) from Nevada, U.S.A. (a) - (g) same as Figure 1.

rings, then, the difference between the lower bound of the critical level and the actual ring size is stored in an array. Once the whole series has been analyzed, the smallest ring (i.e., that ring which deviates furthest from the critical level) is scaled such that is will be plotted as a 2 cm line. All the other small rings are subsequently scaled by the same factor before being plotted.

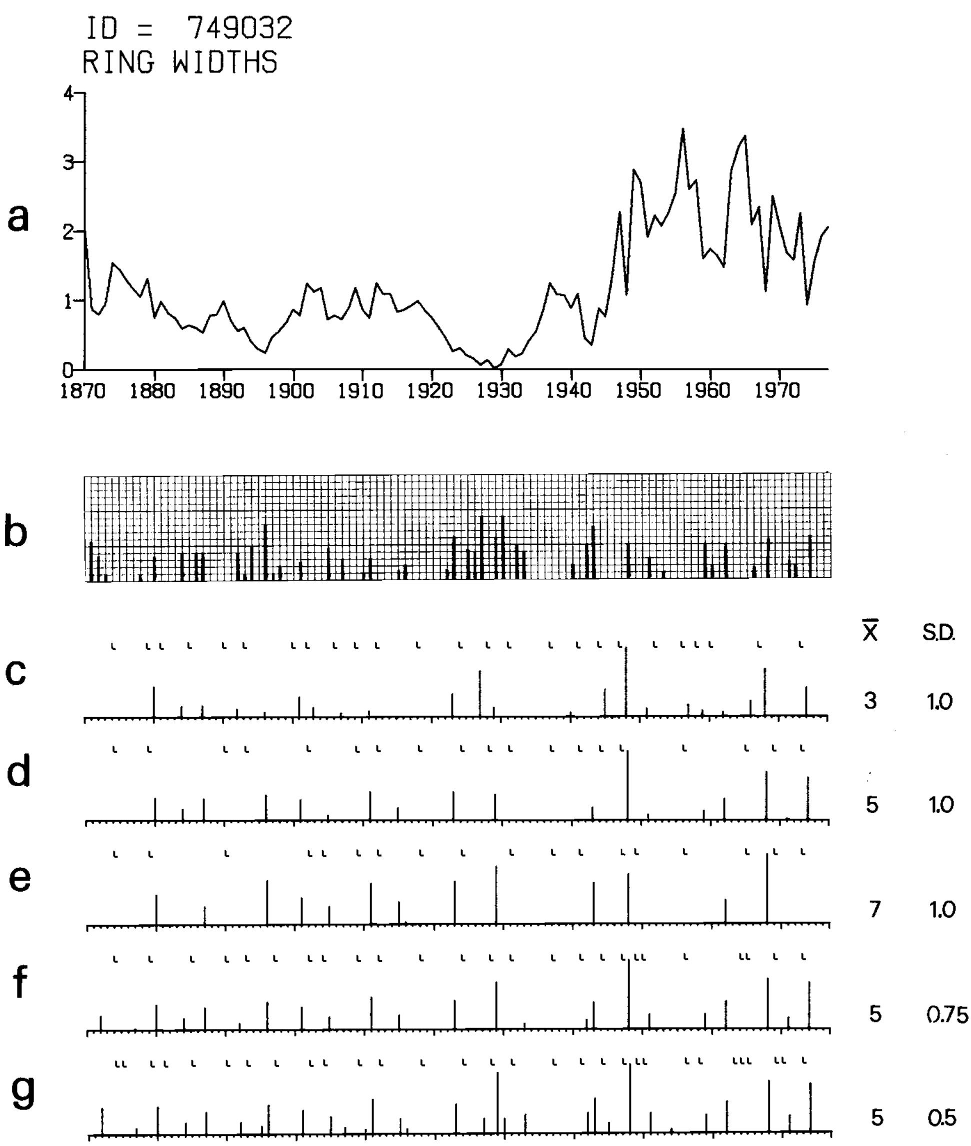


Figure 3. Series 749032. A complacent (nonsensitive) series of Western larch (*Larix occidentalis*) from British Columbia, Canada. (a) - (g) same as Figure 1.

RESULTS

Figure 1 is an example of a core from Labrador, Canada (ID = 478041). Dating the site was straightforward since there were no missing or double rings, and the mean sensitivity of the core was .224 (Duvick 1978). The top plot (a) is a graphic representation of the ring widths. Below that (b) is the skeleton plot derived manually by T. P. Harlan. Mr. Harlan is a highly experienced dendrochronologist at the Laboratory of Tree-Ring Research who specializes in crossdating tree-ring specimens. His manual skeleton plots are used as the control against which the computerized plots should be compared. The next five skeleton plots (c to g) were derived by the objective method described above, and differences between them are due to varying the number of rings considered in the running mean and varying the critical level. Plots (c), (d), and (e) all use a critical level of running mean width minus one standard deviation. The number of rings considered in the running mean is changed from three in (c) to seven in (e). In the final two plots (f and g) the critical level is varied to 0.75 and 0.5 standard deviations from the running mean of five rings in both cases. Using plots (a) and (b) as controls, definite differences can be seen between plots (c), (d), and (e). Basically the same rings are selected as being significantly smaller (or larger "L"); however, there are differences. Plot (g) would be chosen as the most similar to that developed manually: for the 107-year period it contains similar numbers of marks (36 compared to (b)'s 30 marks) of which 21 are in agreement (77.6% agreement).

Figures 2 and 3 show the results of using the same program on a sensitive series (ID = 479122) from Nevada, U.S.A., and a complacent series (ID = 749032) from British Columbia, Canada. Using the combination of a running mean of five years and a critical level of 0.5 standard deviations from the mean, a high degree of agreement with the manually produced control was obtained in these two examples: 85% in the sensitive site (Figure 2) and 81% in the complacent site (Figure 3).

However, on the complacent site (Figure 3) with a high degree of low-frequency trend, the small rings within a period of slow growth are not plotted as being as important as those small rings in fast-growth portions of the core. The small rings in these portions of the data are still correctly identified, but the scaling scheme was biased against them. The scaling scheme uses the difference between the critical level and the actual ring size, and in a period of slow growth this difference can never be very large. In a fast-growth period the potential for larger differences exists. The method used to correct for this bias converts the widths to indices before performing the skeleton plotting. By using a 13-weight low-pass filter (LaMarche and Fritts 1972; Julian and Fritts 1968) on the data a smoothed curve is fit. An index series is obtained by dividing the original data by the resultant low-pass filter values. When skeleton plots of index data are computed, the sensitive series (479122) gives identical results to those from the unaltered series. The less sensitive index series (478041) identifies the same rings as being small, but gives very slightly different weightings to them. The complacent series (479032) also identifies essentially the same rings, but the weightings given on the plot are far superior on the indexed series. Thus, the filtering and indexing procedures have little effect on sensitive series, but are beneficial on more difficult complacent series. It should be noted that the plots in Figure 1, 2, and 3 were all produced using low-pass filter indexed data.

CONCLUSIONS

The most consistent and generally applicable scheme for performing skeleton plotting by computer was found to be: (1) indexing each series by dividing the data by a low-pass filtered curve fit to the same data; and (2) identifying small rings using a running mean of five years and a critical level of 0.5 standard deviations from the mean. The production of skeleton plots is only one step in the process of chronology development. Once the plots have been produced, the patterns of each specimen must be matched (crossdated) and calendar years assigned to them. A relatively simple computer program can be written to take the original tree-ring width data cards and repunch them into a standard format with years assigned. The series should then be standardized and averaged as described by Fritts (1976), possibly using similar programs as described by Graybill (this issue).

For those interested in experimenting with this aid, listings (Figures 4 and 5) of two subroutines are included. Both subroutines are written in ANSI standard FORTRAN to make them machine-independent and to minimize any problems of implementation. The first subroutine (SKEL1) calculates the running means and running standard deviations and identifies the "small" rings. The second subroutine (SKELET) produces the plots utilizing the output from SKEL1, and CALCOMP plotting subroutines that may not be available on all machines.

The input needed for SKEL1 is: (1) an array containing the widths; (2) the number of years to be used in the calculation of the mean; (3) the critical value expressed in fractions of standard deviations; (4) the number of years in the input vector; and (5) in which row of the output matrix to place the results.

The input needed for SKELET is: (1) the output matrix from SKEL1; (2) an array containing the number of data values in each row of the above matrix; (3) an integer variable specifying the number of rows of the input matrix to be plotted (between 1 and 4); (4) an array containing the ID's of each of the data rows being plotted; and (5) a general heading to be placed on the top of the plot.

ACKNOWLEDGEMENTS

I wish to express my appreciation to G. A. Gordon for his helpful criticisms and to Ann Marek for her editorial assistance throughout the manuscript preparation. I would like to thank H. C. Fritts for his useful suggestion on the use of a filter and also Linda Drew for her encouragement through the entire project.

The facilities of the University of Arizona Computer Center were used for the development of the programs.

REFERENCES

Baillie, M. G. L. and J. R. Pilcher
1973 A simple crossdating program for tree-ring research. *Tree-Ring Bulletin* 33: 7-14.

Douglass, A. E.
1935 Accuracy in dating — II. *Tree-Ring Bulletin* 1 (3) 19-21.

Duvick, D. N.
1978 The Border Beacon, Labrador, *Picea glauca* chronology. Technical Note No. 12. Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona. 8 pp.

Ferguson, C. W.
1970 Concepts and techniques of dendrochronology. *In* "Scientific Methods in Medieval Archaeology" (R. Berger, ed.), pp. 183-200. University of California Press, Berkeley.

Fritts, H. C.
1963 Computer programs for tree-ring research. *Tree-Ring Bulletin* 25 (3-4) 2-7.
1976 *Tree rings and climate.* Academic Press, London. 567 pp.

Fritts, H. C., T. J. Blasing, B. P. Hayden, and J. E. Kutzbach
1971 Multivariate techniques for specifying tree-growth and climate relationships and for reconstructing anomalies in paleoclimate. *J. Appl. Meteorol.* 10 (5) 845-864.
Fritts, H. C., J. E. Mosimann, and C. P. Bottorff
1969 A revised computer program for standardizing tree-ring series. *Tree-Ring Bulletin* 29 (1-2) 15-20.
Giddings, J. L., Jr.
1942 Dated sites on the Kobuk River, Alaska. *Tree-Ring Bulletin* 9 (1) 1-8.
Julian, P. R. and H. C. Fritts
1968 On the possibility of quantitatively extending climatic records by means of dendroclimatological analysis. *Proc. First Statist. Meteorol. Conf.*, Amer. Meteorol. Soc., pp. 76-82, Hartford, Connecticut.
LaMarche, V. C., Jr. and H. C. Fritts
1972 Tree rings and sunspot numbers. *Tree-Ring Bulletin* 32: 19-33.
Lyon, C. J.
1953 Vertical uniformity in three New England conifers. *Tree-Ring Bulletin* 20 (2) 10-16.
Milsom, S. and M. Hughes
1977 Evaluation of x-ray densitometry as a technique. Paper presented at the International Symposium on Dendrochronology in Northern Europe, July 11-14, 1977, Greenwich, England.
Parker, M. L.
1967 Dendrochronology of Point of Pines. M. S. Thesis. University of Arizona, Tucson, Arizona. 168 pp.
Parker, M. L., G. M. Barton, and J. H. G. Smith
1976 Annual ring contrast enhancement without affecting x-ray densitometry studies. *Tree-Ring Bulletin* 36: 29-31.
Polge, H.
1966 Etablissement des courbes de variation de la densité du bois par expllorationdensitométrique de radiographies d'échantillons prélevés à la tarière sur des arbres vivants. Application dans les domaines téchnologique et physiologique. *Ann. Sci. Forest* 23: 1-206.
Schulman, Edmund
1942 Variations between ring chronologies in and near the Colorado River drainage area. *Tree-Ring Bulletin* 8 (4) 26-32.
1944 Dendrochronology in Mexico, I. *Tree-Ring Bulletin* 10 (3) 18-24.
Stokes, M. A. and T. L. Smiley
1968 *An introduction to tree-ring dating.* University of Chicago Press, Chicago.
Wendland, W. M.
1975 An objective method to identify missing or false rings. *Tree-Ring Bulletin* 35: 41-47.

```
      SUBROUTINE SKEL1(OUT,ARRAY,ILAG,NRINGS,ICALL,CUTOFF)
COMMENTS *************************************************************
C                              ***                                   C
C                    SUBROUTINE SKEL1                                C
C                    SEPTEMBER 1979                                  C
C                    JOHN PHILIP CROPPER                             C
C                    LABORATORY OF TREE RING RESEARCH                C
C                    UNIVERSITY OF ARIZONA                           C
C                    TUCSON, ARIZONA. 85721    U.S.A.                C
C                              ***                                   C
COMMENTS *************************************************************
C    PROGRAM TO TAKE THE RUNNING MEAN AND STANDARD DEVIATIONS OF AN
C    ARRAY ("ARRAY") AND DISTINGUISH SIGNIFICANTLY SMALLER OR/AND LARGER
C    RINGS. SMALL RINGS ARE SCALED BETWEEN ZERO AND TWO WHILE LARGE RINGS
C    ARE DESIGNATED "9.9".
C
C                    CALL CARD PARAMETERS                            C
C -------------------------------------------------------------------
C                              ***                                   C
C    OUT             OUTPUT
C        A MATRIX (WITH MAXIMUM OF 4 ROWS) THAT WILL CONTAIN THE SCALED
C        RESULTS.
C                              ***                                   C
C    ARRAY            INPUT
C        THE VECTOR CONTAINING THE DATA SET TO BE USED.
C                              ***                                   C
C    ILAG             INPUT
C        THE TOTAL NUMBER OF YEARS TO BE CONSIDERED IN THE CALCULATION
C        OF EACH MEAN.
C     ** MUST BE AN ODD NUMBER ** E.G. A 7 WOULD TAKE THE MEAN OF
C        SEVEN NUMBERS -- THAT IS 3 ON EITHER SIDE OF THE CENTRAL
C        VALUE BEING CONSIDERED.
C                              ***                                   C
C    NRINGS           INPUT
C        THE NUMBER OF VALUES INPUT IN THE VECTOR "ARRAY".
C        NOTE - THE COLUMNS OF THE MATRIX "OUT" MUST BE EQUAL TO OR
C        LARGER THAN NRINGS.
C                              ***                                   C
C    ICALL            INPUT
C        THE ROW OF THE OUTPUT MATRIX "OUT" IN WHICH YOU WISH THE
C        PRESENT RESULTS OF THE VECTOR "ARRAY" TO BE PLACED.
C        MUST BE AN INTEGER VALUE BETWEEN 1 AND 4
C        IT IS SUGGESTED THAT THE CALL TO THIS SUBROUTINE BE DONE IN A
C        "DO " LOOP AND THAT "ICALL" BE INCREASED BY ONE AT EACH CALL.
C                              ***                                   C
C    CUTOFF           INPUT
C        THE MULTIPLICATION FACTOR FOR THE NUMBER OF STANDARD
C        DEVIATIONS TO BE USED AS THE SIGNIFICANCE LEVEL. USUALLY A
C        REAL NUMBER BETWEEN 1. AND 0.5
C                              ***                                   C
C -------------------------------------------------------------------
C
C """""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""
C                    VARIABLES USED                                  C
C                              ***                                   C
C    AMAX       - THE SMALLEST RING (OR THE LARGEST NEGATIVE DEVIATION FROM
C                 THE MEAN).
C    AMEAN      - VECTOR OF RUNNING MEANS.
C    IMISS      - THE NUMBER OF ELEMENTS OF "ARRAY" TO BE SKIPPED
C                 BEFORE STARTING THE CALCULATIONS.
C    ISTART     - THE FIRST ELEMENT OF "ARRAY" THAT CAN BE CONSIDERED.
C    ISTOP      - THE LAST ELEMENT OF "ARRAY" THAT CAN BE CONSIDERED.
C    KK AND KKK  THE COUNTERS THAT DELINEATE EACH GROUP OF YEARS TO BE
C                 ANALYSED AT A TIME.
C    STDEV      - VECTOR OF STANDARD DEVIATIONS OF THE ABOVE RUNNING MEANS.
C    SUM        - THE SUM OF "ILAG" ELEMENTS OF THE VECTOR "ARRAY".
C    SUMSQ      - THE SUMS OF SQUARES OF "ILAG" ELEMENTS OF VECTOR "ARRAY".
C    TEST       - THE VALUE USED TO TEST FOR SIGNIFICANTLY SMALLER RINGS.
C    TESTL      - THE VALUE USED TO TEST FOR SIGNIFICANTLY LARGE (BIG) RINGS.
C                              ***                                   C
```

Figure 4. FORTRAN program listing of subroutine SKEL1 that determines wide and narrow rings.

```
C """"""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""
C
      DIMENSION OUT(4,500), ARRAY(1), AMEAN(500), STDEV(500)
      DO 100 I = 1 , NRINGS
C
C     INITIALISE ARRAYS TO ZERO BEFORE STARTING COMPUTATION.
C
      AMEAN(I) = 0.
      STDEV(I) = 0.
  100 CONTINUE
C
C     CALCULATE START, STOP, AND INTERVAL PARAMETERS.
C
      AMAX = 0.
      ISTART = ( (ILAG - 1) / 2) + 1
      ISTOP = NRINGS - ( (ILAG - 1) / 2)
      IMISS = (ILAG - 1) / 2
         DO 200 I = ISTART,ISTOP
C
C        CALCULATE THE MEAN AND STDEV OF THE PERIOD AROUND THE RING.
C
      SUM = 0.
      SUMSQ = 0.
      KK = I - IMISS
      KKK= I + IMISS
              DO 300 J = KK,KKK
              SUM = SUM + ARRAY(J)
  300         SUMSQ = SUMSQ + (ARRAY(J)*ARRAY(J))
         AMEAN(I) = SUM / FLOAT(ILAG)
      STDEV(I) = SQRT((SUMSQ -(SUM*SUM)/FLOAT(ILAG))/FLOAT(ILAG))
  200    CONTINUE
      DO 400 I = ISTART,ISTOP
C
C     IDENTIFY THE RINGS THAT ARE MORE THAN ONE STDEV. SMALLER THAN THE MEAN
C     PUT ZERO"S IN "NORMAL" SIZED RING LOCATIONS OF THE ARRAY "OUT" AND
C     PUT THE DEPARTURE GREATER THAN THE STANDARD DEVIATION INTO THE
C     SMALL RING LOCATIONS OF THE "OUT" ARRAY.
C
      TEST = AMEAN(I) -(STDEV(I) * CUTOFF)
      TESTL = AMEAN(I) +(STDEV(I) * CUTOFF)
C     TEST FOR EXTRA LARGE RINGS AND PLACE AN IDENTIFING 9.9 IN THE
C     OUTPUT ARRAY "OUT".
      IF(ARRAY(I).LT.TESTL) GO TO 250
      OUT(ICALL,I) = 9.9
      GO TO 400
  250 IF(ARRAY(I).LE.TEST) GO TO 350
      OUT(ICALL,I) = 0.
      GO TO 400
  350   OUT(ICALL,I)  = TEST - ARRAY(I)
      IF(OUT(ICALL,I).GT.AMAX) AMAX = OUT(ICALL,I)
  400 CONTINUE
C
C    SET THE LAST NEW RINGS THAT CANNOT BE USED IN THE CALCULATIONS TO
C     ZERO BEFORE SCALEING THE REST OF THE SIGNIFICANTLY SMALLER RINGS.
C
            DO 450 I = ISTOP,NRINGS
  450       OUT(ICALL,I) = 0.0
      DO 500 I = 1,NRINGS
C     SCALE THE VECTOR IN THE RANGE ZERO TO POSITIVE TWO.
      OUT(ICALL,I) = OUT(ICALL,I) * (2.0 / AMAX )
  500 CONTINUE
      RETURN
      END
```

Figure 4, continued

```
      SUBROUTINE SKELET(OUT,NRINGS,FIRST,ISHRT,RID,HDG1)
C                                   ***                                 C
COMMENTS ***************************************************************
C                                                                       C
C                    SUBROUTINE SKELET                                  C
C                    SEPTEMBER 1979                                     C
C                    JOHN PHILIP CROPPER                                C
C                    LABORATORY OF TREE RING RESEARCH                   C
C                    TUCSON, ARIZONA. 85721  U.S.A.                     C
C                                                                       C
COMMENTS ***************************************************************
C                                   ***                                 C
C     SUBROUTINE FOR PRODUCING SKELETON PLOTS ON A "CALCOMP" PLOTTER. THIS
C     USES THE DATA MATRIX OUTPUT FROM THE SUBROUTINE SKEL1.
C                                   ***                                 C
C                    CALL CARD PARAMETERS
C                                   ***                                 C
C     OUT            INPUT
C              A MATRIX (MAXIMUM OF 4 ROWS) OF SCALED RESULTS AS
C              PRODUCED BY "SKEL1".
C                                   ***                                 C
C     NRINGS         INPUT
C              A VECTOR OF UP TO 4 ELEMENTS CONTAINING THE NUMBER OF DATA
C              VALUES IN EACH ROW OF MATRIX "OUT".
C                                   ***                                 C
C     FIRST          INPUT
C              A VECTOR OF UP TO 4 ELEMENTS CONTAINING THE FIRST YEAR
C              ASSIGNED TO THE FIRST ELEMENT OF EACH ROW OF "OUT".
C              IT IS NOT USED IN THE SUBROUTINE AT THE MOMENT BUT CAN
C              BE USED WHEN PLOTTING ALREADY DATED MATERIAL.
C                                   ***                                 C
C     ISHRT          INPUT
C              AN INTEGER VARIABLE SPECIFYING THE NUMBER OF ROWS IN "OUT"
C              THAT CONTAIN DATA. THIS CAN BE FROM 1 TO 4.
C                                   ***                                 C
C     RID            INPUT
C              A VECTOR CONTAINING THE ID (6 CHARACTERS) OF EACH OF THE
C              DATA ROWS BEING PLOTTED.
C                                   ***                                 C
C     HDG1           INPUT
C              A GENERAL HEADING (30 CHARACTERS) TO BE PLACED AT THE TOP
C              OF THE PLOT.
C                                   ***                                 C
C                                   ***                                 C
C                    VARIABLES USED.
C                                      ***                              C
C     AI       - THE DECADE TO BE WRITTEN (NUMBER NEEDS A "REAL"
C                VARIABLE IN THE CALL STATEMENT)
C                                      ***                              C
C     HT       - IS THE HEIGHT OF THE CHARACTERS WRITTEN IN CALLS TO
C                "SYMBOL" AND "NUMBER".
C                                      ***                              C
C     IBACK    - A BACK-SPACING COUNTER SO THAT THE DECADE LABELS ARE CENTERE
C                                      ***                              C
C     ITEST    - AN ALTERNATING COUNTER SO THAT NUMBERS ARE WRITTEN ONLY
C                ON ALTERNATE DECADES MARKS.
C                                      ***                              C
C     MXRNG    - IS THE STORAGE SPACE FOR THE MAXIMUM LENGTH OF ANY GROUP
C                FOUR PLOTS, SO THAT IT CAN BE USED FOR THE LENGTH OF THE
C                BASE LINE.
C                                      ***                              C
C     NC AND NCM  COUNTERS FOR ANNUAL AND DECADE MARKS.
C                                      ***                              C
C     NSTOP    - THE LENGTH OF THE SERIES THAT IS BEING PLOTTED.
C                                      ***                              C
C     TML      - THE LENGTH OF THE DECADE TICK MARKS.
C                                      ***                              C
```

Figure 5. FORTRAN program listing of subroutine SKELET that uses CALCOMP plotting routines to produce skeleton plots (in groups of four).

```
C -----------------------------------------------------------------------
       DIMENSION OUT(4,500), NRINGS(1), FIRST(1), RID(1), HDG1(1)
C     CALL THE INITIALIZATION PLOTTING ROUTINE.
       CALL INITIAL(0,99,0.4,0)
C     IF "ISHRT" IS LESS THAN FOUR THEN THIS WILL ALTER THE OUTPUT FORMAT
       IF(ISHRT.GT.4) ISHRT = 4
       MXRNG = 0
       HT = 0.35
       TML  = -0.15
C     CONVERSION OF THE PLOTTING FROM INCHES TO CENTIMETERS.
       CALL FACTOR( 1.0/2.54)
C     SAVE PAPER BY MOVING BACK FROM THE COMPUTER SET ORIGIN, MOVE TO THE
C     TOP OF PAPER READY TO WRITE OUT THE HEADING -THIS IS THE NEW ORIGIN.
       CALL PLOT(-15.0,21.0,-3)
C     WRITE THE GENERAL HEADING THAT WAS ON THE CONTROL CARD, 30 CHARACTERS
       CALL SYMBOL(0.0,0.0,HT,HDG1,0.0,30)
C
C     DO THE PLOTS IN GROUPS OF FOUR.
       DO 145 I=1,ISHRT
C     WRITE THE CORE ID AT THE TOP LEFT HAND CORNER OF THE PLOT.
       CALL SYMBOL(D.0,-1.75,HT,RID(I),0.0,10)
C     "Y" IS THE SPACING FACTOR BETWEEN THE ID AND THE PLOT.
       Y = -4.0
C     SET "X" FOR THE BEGINNING OF A NEW PLOT.
C     I.E. GO TO THE LEFT HAND EDGE OF THE PAPER.
       X = 0.0
C
C     SET NEW ORIGIN  "Y" UNITS BELOW THE PRINTED ID.
       CALL PLOT(0.0,Y,-3)
C     WRITE THE FIRST TICK MARK.
C     DRAW A DECADE SIZED TICK MARK.
       CALL PLOT(0.0,TML,2)
C     TEST FOR THE LARGEST SERIES OF THIS BATCH BEING PLOTTED.
       IF(NRINGS(I).GT.MXRNG) MXRNG = NRINGS(I)
       NC = 0
       NCM = 10
       NSTOP = NRINGS(I)
C     PLOT THE ANNUAL AND DECADE TICK MARKS IN THE Y AXIS ONLY.
          DO 140 J=1,NSTOP
C     IF   J.EQ.1  PLOT THE FIRST VALUE AS THE TICK MARK IS ALREADY DRAWN.
          IF(J.GT.1) GO TO 130
          GO TO 131
  130     NC = NC + 1
C     INCREMENT YEAR COUNTER AND DISTANCE MOVED ALONG "X" AXIS.
          X = X + 0.2
C     TEST FOR A DECADE OR THE LAST RING OF THE SERIES.
          IF(NC.EQ.NCM.OR.J.EQ.NRINGS(I))  GO TO 132
C
C     MOVES THE PEN OFF THE PAPER TO THE NEXT POSITION ON THE X AXIS.
C     PUT A SMALL MARK FOR EACH ANNUAL VALUE.
C     MOVE PEN TO BELOW "X" AXIS WITH PEN OFF THE PAPER.
  131 CALL PLOT(X,-0.05,3)
C     DRAW THE ANNUAL MARK.
       CALL PLOT(X,0.0,2)
C     LIFT PEN OFF PAPER.
          CALL PLOT(X,0.0,3)
          GO TO  135
C     INCREMENT DECADE COUNTER.
  132     NCM = NCM + 10
C     DRAW IN THE TICK FOR EACH DECADE AS YOU GET TO IT.
C     MOVE PEN BELOW "X" AXIS READY FOR PLOTTING DECADE MARK.
          CALL PLOT(X,TML,3)
C     PLOT MARK.
       CALL PLOT(X,0.0,2)
C     LIFT PEN OFF THE PAPER.
        CALL PLOT(X,0.0,3)
C     TEST FOR BIG RINGS.
  135 IF(OUT(I,J).LT.9.) GO TO 136
C     PLOT A LETTER "L" FOR BIG RINGS.
       CALL SYMBOL(X,2.0,0.15,1HL,0.0,1)
       GO TO 140
```

Figure 5, continued

```
C     PLOT THE DATA AT EACH POINT AS YOU GET TO IT.
  136     CALL PLOT(X,OUT(I,J),2)
  140     CONTINUE
C     DRAW IN THE X-AXIS ON THE WAY BACK TO THE ORIGIN.
      CALL PLOT(X,0.0,3)
      CALL PLOT(0.0,0.0,2)
  145 CONTINUE
C
C     SET "X" FOR THE BEGINNING OF A NEW PLOT.
      X = 0.0
C     PUT IN A BASE LINE WITH ALTERNATE DECADES LABELED.
C     FORM A NEW ORIGIN.
      CALL PLOT(0.0,-1.5,-3)
      DO 150 I=1,MXRNG,10
C     PUT IN THE DECADE TICKS.
      CALL PLOT(X,TML,3)
      CALL PLOT(X,0.0,2)
C     INCREMENT "X" TO MOVE IT TEN YEAR DISTANCE AT A TIME.
  150 X = X + 2.0
C     DRAW IN THE BASE LINE ON THE WAY BACK TO THE ORIGIN.
          CALL PLOT(0.0,0.0,2)
C     FORM A NEW ORIGIN FOR THE PLOTTING OF THE NUMBERS.
      CALL PLOT(0.0,-.75,-3)
      ITEST = 0
      DO 160 I = 1,MXRNG,10
C     TO CENTRE UP THE DACADE NUMBERS THE FOLLOWING IF STATEMENTS ARE USED.
      IF(I.LE.9) IBACK = 2
      IF(I.GE.10.AND.I.LE.99)  IBACK = 2
      IF(I.GE.100.AND.I.LE.999)  IBACK = 3
      IF(I.GE.1000)  IBACK = 4
      II = I -IBACK
      X = 0.2 * FLOAT(II)
      AI = FLOAT(I-1)
C     PLACE THE NUMBERS BELOW THE BASE LINE.
C     TEST SO THAT ONLY ALTERNATE DECADES ARE LABELED.
      IF(ITEST.EQ.0) CALL NUMBER(X,0.0,HT,AI,0.0,-1)
      IF(ITEST.EQ.0) GO TO 155
      ITEST = 0
      GO TO 160
  155 ITEST = 1
  160 CONTINUE

C     TERMINATE THIS CALL TO THE PLOTTER.
      CALL ENDPLT
      RETURN
      END
```

Figure 5, continued

TREE-RINGS AND CLIMATE IN MOROCCO

A. L. BERGER

and

J. GUIOT

Institut d'Astronomie et de Géophysique
Université Catholique de Louvain-la-Neuve

L. MATHIEU

Laboratoire de Science du Sol
Faculté des Sciences Agronomiques, Gembloux

A. V. MUNAUT

Laboratoire de Palynologie et Phytosociologie
Université Catholique de Louvain-la-Neuve

ABSTRACT

Two sites located near Ketama in the Morocco Rif have been selected, on the basis of limiting climatic factors, in order to study the relationship between tree rings and climate. After the trend associated with biological factors related to increasing age has been removed and all variables have been standardized, some statistical parameters have been computed and a variance analysis has been performed. After the persistence has been eliminated, an original technique of multiple regression on the principal components and of selection of the most significant variables has been built. Twenty-four climatic variables have been used.

The principal aim of this paper is to describe this original statistical technique of data analysis and to illustrate its power with dendroclimatological data in Morocco.

For the temperate site located in low altitude (1280 m), among the most important variables, we have retained total monthly precipitation for August, mean temperature of January, April, and May of the current year and mean temperature of October of the previous year. For the cold site (2100 m), total monthly precipitation for September and temperatures of January and May of the current year and precipitation for October of the previous year definitely influence the growth rate of cedars.

Deux sites du Rif Marocain près de Ketama ont été sélectionnés sur base de facteurs climatiques limitants pour étudier la relation entre les cernes annuels et le climat. Après avoir éliminé la tendance dans la courbe d'évolution des cernes et avoir standardisé toutes les variables, quelques paramètres statistiques ainsi qu'une analyse de la variance ont été calculés. Après enlèvement de la persistance, une technique originale de régression multivariée sur composantes principales, avec rejet conditionné de variables, a ensuite été mise au point. Vingt-quatre variables climatiques ont été utilisées.

L'objet principal de cet article est précisément de décrire cette méthode originale d'analyse statistique et d'illustrer sa puissance à partir de données dendroclimatiques du Rif marocain.

Pour le site tempéré, situé à basse altitude (1280 m), parmi les variables les plus importantes, nous avons retenu les précipitations d'août et les températures de janvier, avril et mai de l'année de la croissance ainsi que les températures d'octobre de l'année précédente. Pour le site froid (2100 m), sont favorables tout particulièrement à une bonne croissance du cèdre, les précipitations de septembre et les températures de janvier et mai de l'année de croissance ainsi que les précipitations d'octobre de l'année précédente.

Bei Ketama im marokkanischen Rifgebirge wurden zwei Baumstandorte im Hinblick auf begrenzende Klimafaktoren ausgewählt, um die Beziehungen zwischen Jahrringbildung und Klima zu analysieren. Nachdem der Alterstrend der Jahrringfolgen eliminiert und alle Variablen standardisiert worden waren, wurden einige statistische Parameter berechnet und eine Varianzanalyse durchgeführt. Nach Ausschaltung der Erhaltungstendenz in den Jahrringfolgen wurden ein multiples Regressionsverfahren für die Hauptkomponenten und ein Verfahren zur Auswahl der signifikantesten Variablen entwickelt. Dabei wurden 24 Klimavariable benutzt.

Im vorliegenden Beitrag werden dieses statistische Verfahren beschrieben und seine Möglichkeiten anhand dendroklimatologischer Daten von Marokko dargestellt.

Für den gemäßigten Standort in 1280 m Höhe erweisen sich die Augustniederschläge sowie die Durchschnittstemperaturen im Januar, April und Mai des laufenden Jahres und im Oktober des Vorjahres als einflußreich. An dem kalten Standort in 2100 m Höhe wirken sich die Niederschläge im September und die Temperatur im Januar und Mai des laufenden Jahres sowie die Niederschläge im Oktober des Vorjahres günstig auf den Zuwachs der Zedern aus.

INTRODUCTION

Recent studies (Fritts 1976) have clearly demonstrated that multivariate analysis techniques based on annual tree-ring data are able to provide reliable information on the relationship between tree rings and climate (response function) and on the nature of the climate itself and its variations in time (transfer functions). Indeed, if the dendroclimatological network is sufficiently dense in a given region, a climatic reconstruction can be made over the lifetime of the trees. These reconstructions thus require the existence of annual tree rings, limiting climatic factors, and long-live trees.

Northern Africa seems to be a good area to do such research. From a climatological point of view, this region is situated under Atlantic, Mediterranean, and Saharian influences. It is also a region where the horizontal gradients of the climatic variables are large, due to topography. Moroccan mountains are oriented along two axes: east-west (Rif) and northeast-southwest (Middle and High Atlas) with an maximum altitude of respectively 2,448 and 4,165 m.

Preliminary studies started in 1974 have shown that of the available genera (cedar, fir, cypress, juniper, pine), cedar *(Cedrus Atlantica Men.)* is particularly sensitive to climate and thus favorable in dendroclimatology. Large cedar forests covering around 140,000 ha still exist over a range of temperature and humidity conditions and on several substratums (schist, lime, basalt, . . .). Finally, numerous stands still have cedars some centuries old; some even between 500 and 1,000 years old.

In fact, research in dendroclimatology can provide information on the climatic variability in a region where sparse rain affects any agricultural or industrial development, but it also allows climatic reconstruction over a long period of time.

SITES AND DATA

Among some 40 sites under study, two were selected from the western part of Rif near Ketama (Figure 1). Site 301 is one of the lowest cedar forests in Morocco, while site 302 is located near the top of Djebel Tidighin, the Rif culminating point (2,448 m).

1. Site 301: Tleta de Ketama (1,280 m).

Ten trees were sampled in this cedar forest located near Tleta de Ketama. The soil, slightly inclined to the south, is deep and comes from the decomposition of the schist (pH 6.5). All trees are almost the same age, their mean height is around 50 m and their circumference is frequently more than 5 m. The tree density is high, this site being undisturbed by man. The mean precipitation in Ketama (1,520 m) is 1,570 mm/year and the mean temperature is around 10.7°C.

2. Site 302: Djebel Tidighin (2,100 m)

Eleven cedars were selected on the western slope of Mont Tidighin where the slope is 30°. The substratum is schistous and a humid mountainous soil is being developed (pH 6.5). The mean height of the trees is 17 m, the mean circumference is 2 m. No meteorological data are available for the site itself, but the rainfall can be estimated to range between 1,400 and 2,000 mm/year, a large part of the humidity transported by the west maritime atmospheric currents being intercepted by Mont Tidighin. The mean annual temperature is around 4 °C.

CHRONOLOGY STATISTICS

Ring widths for all cores were plotted. After crossdating the curves, indices and statistics were computed for each core, each tree, and for the master chronology which summarizes all cores in all trees. These statistics, based upon tree-ring indices (ring width divided by trend), are the mean ring width and index, the mean sensitivity and the serial correlation coefficient, as generally used (Fritts 1976). Variance analysis has also been performed, using 10 trees and two cores per tree, usually one upslope and one downslope. All the results are summarized in Table 1.

Mean ring widths indicate that the limiting factors act more strongly in site 302 than in site 301. The annual variability defined by mean sensitivity is almost the same in both sites, although it is significantly less for the master chronology of site 302 than of site 301. From experience gained in many other dendrochronological studies, one can suggest a middle to low variability of the limiting factors. The serial correlation coefficient is very large for site 302 as compared to 301, indicating a strong persistence from one year to the other. This result was more or less expected because large serial correlation is consistently associated with low mean sensitivity. From the variance analysis, irregularity of the growth within the trees for both sites may be deduced. For the site 301, the climate has less influence than other external factors. However, as it will be shown in the following sections, both sites are suitable for establishing response functions.

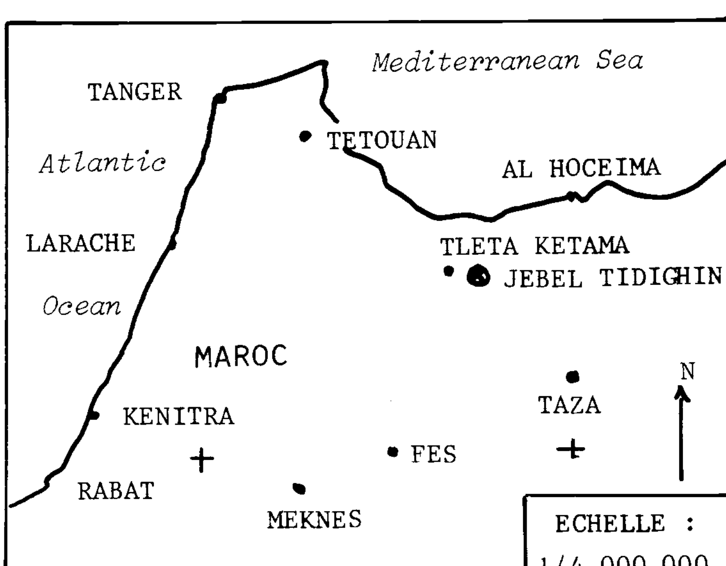


Figure 1. Location of dendrochronological sites in the Rif Mountain region near Ketama.

Table 1. Statistics for the Moroccan sites.

		SITE 301	SITE 302
Total Period	interval	1790-1975	1754-1975
	number of trees	10	11
	number of cores	29	34
	missing rings	0.2%	0.33%
	mean ring	2.1 mm	1.4 mm
	mean index	0.99	0.99
	std. dev.	0.22	0.26
	serial R.	0.28	0.83
	mean sensitivity	0.18	0.15
ANOVA Period	interval	1871-1970	1901-1970
	number of trees	10	10
	number of cores	20	20
	missing rings	0%	0.64%
	mean ring	1.5 mm	1.0 mm
	mean index	0.99	1.0
Variance Analysis			
	variance components (%)		
	cores	75	47
	trees	0	1
	chronology	25	52

METEOROLOGICAL DATA

Climatological data are taken from the Tetouan Airport station and extend from 1941 to 1971. The following 24 variables have been selected on the basis of the growth season of cedar trees (around April to September): monthly mean temperature and total monthly precipitation for October of the year prior to growth till September of the current year. As compared with the classical Fritts 14-month interval (June of the previous year till July of the current year, Fritts et al. 1971), this 12-month interval has been chosen to clarify the interpretation of the model's results. On the other hand, it must also be stressed that the number of variables that can be taken into account is limited by the number of observations (30 years). More details are given in Guiot et al. (1979).

These meteorological data are represented on Figure 2 and the means and standard deviations in Table 2. The indices of site 301 and site 302 are represented on Figure 3. It can be seen that the driest months are July and August and the wettest months are December to February. For site 301, the indices of years 1963, 1969, 1970, 1971 are the largest. During these years, April and May are relatively cold. The indices of years 1945, 1949, 1953 are the smallest, which corresponds to warm April or May.

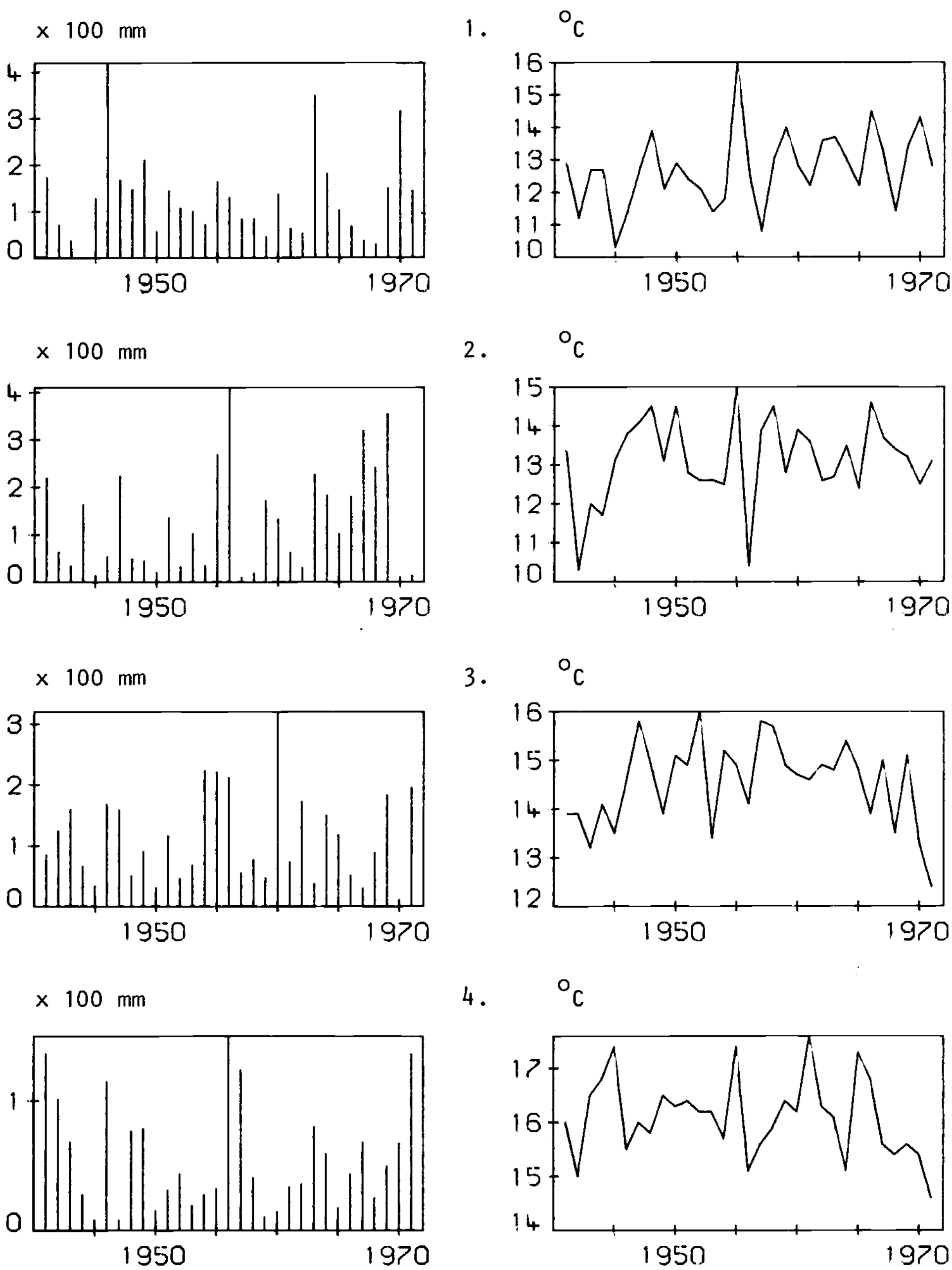


Figure 2. Meteorological data for Tetouan Airport from January (1) through December (12). Precipitation on the left, temperature on the right. Scales vary.

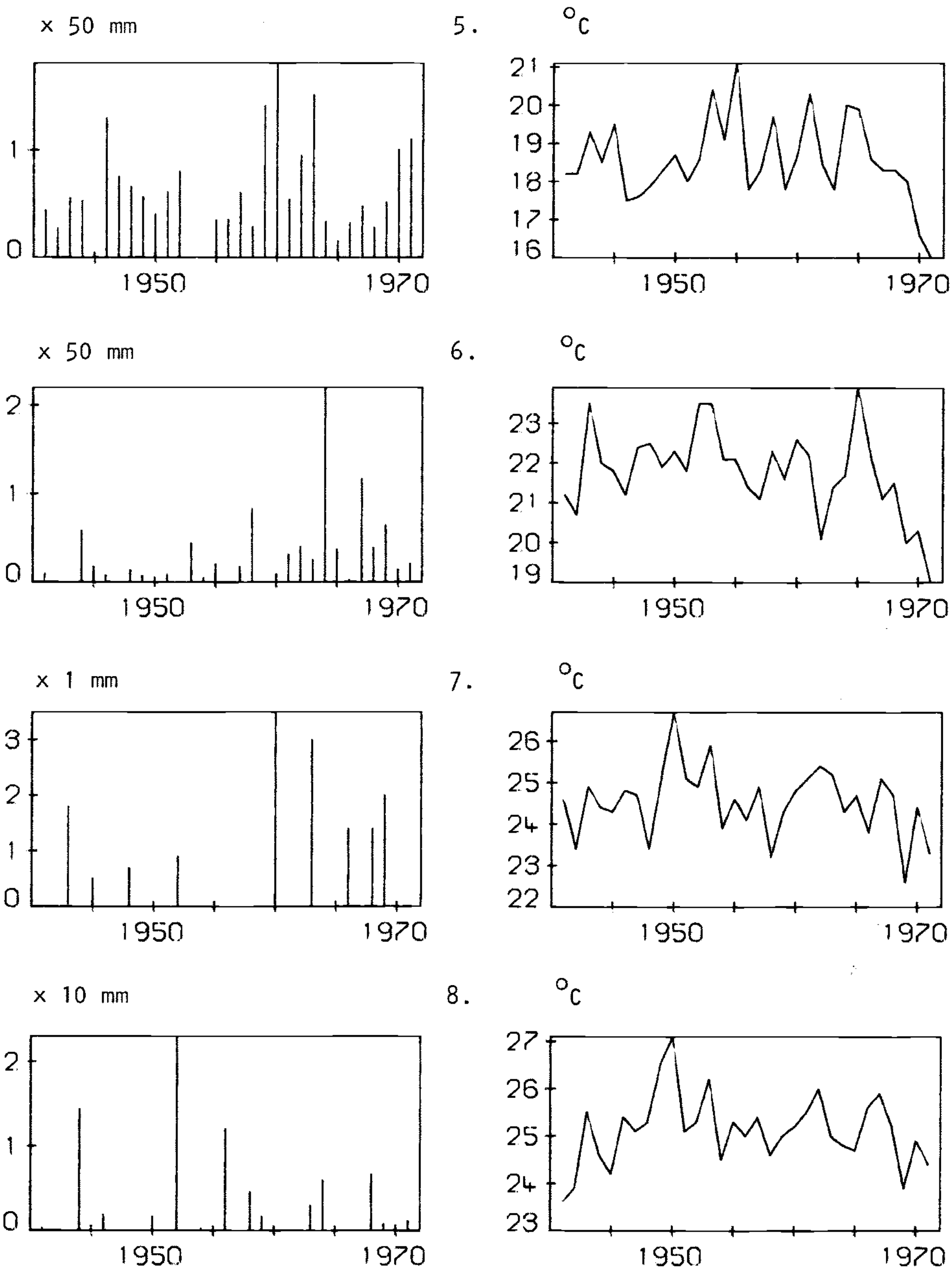


Figure 2, continued

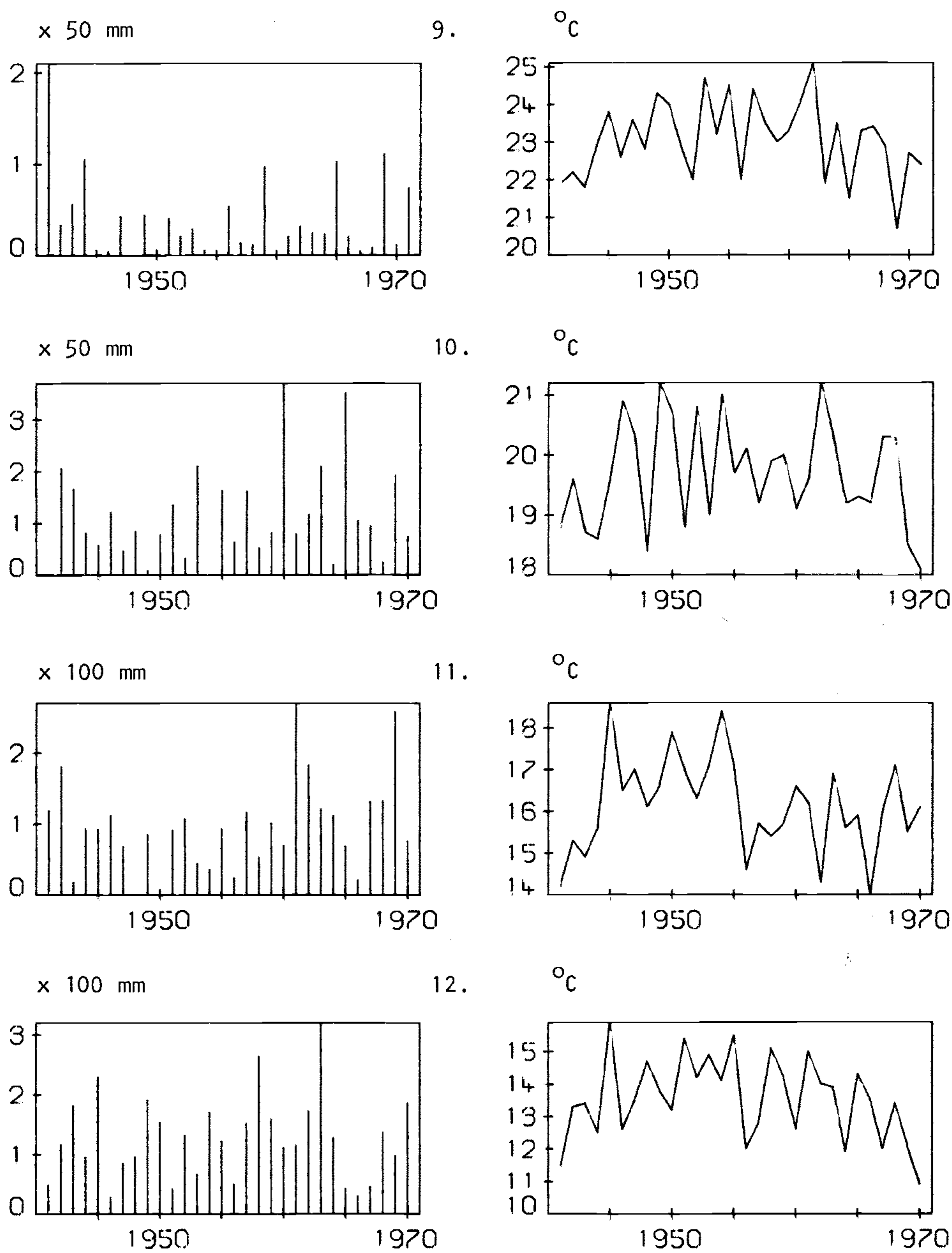


Figure 2, continued

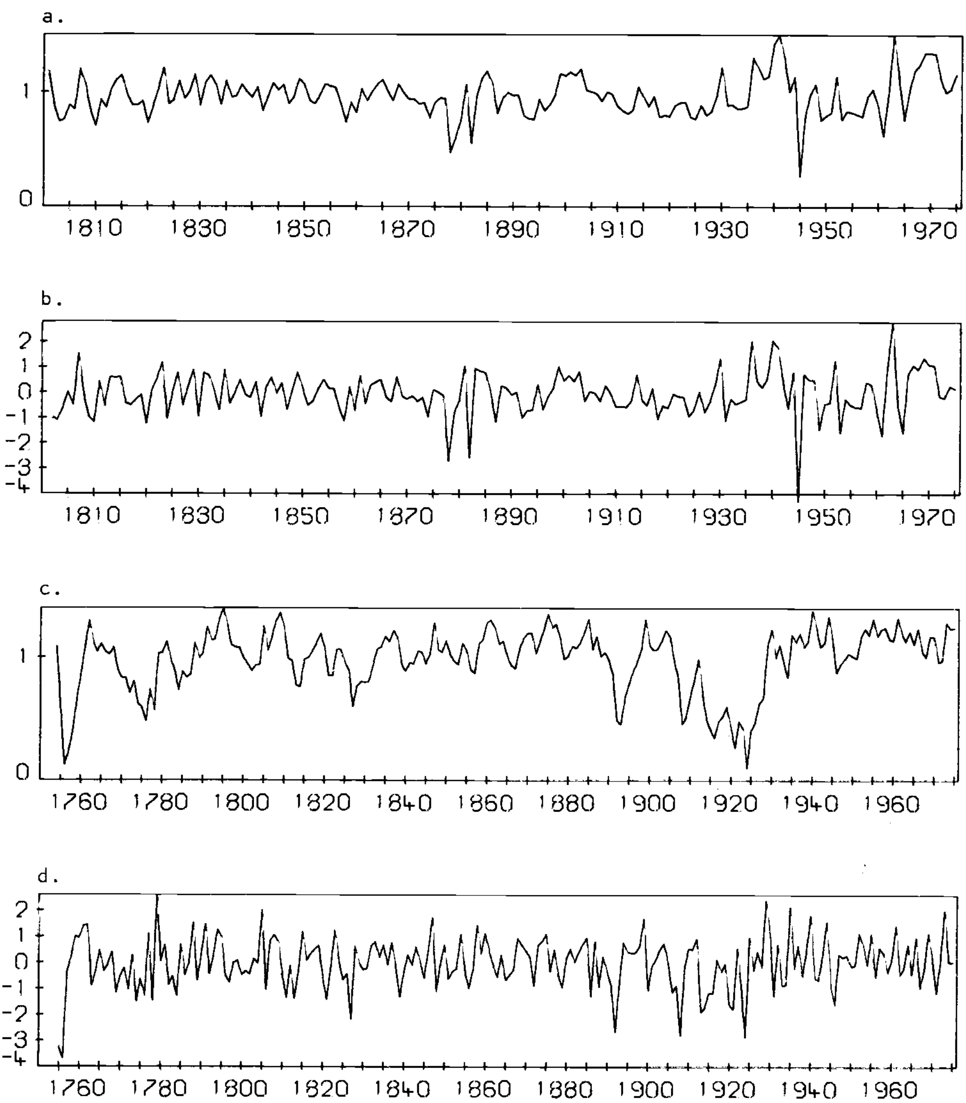


Figure 3. Moroccan chronologies: *a,* site 301; *b,* site 301 with persistence removed; *c,* site 302; *d,* site 302 with persistence removed.

Table 2. Statistics of climate for Tetouan Arport, A.D. 1942-1971.

	Variable	mean	standard deviation
Precipitation (mm)	January	129.0	97.1
	February	125.1	114.3
	March	112.8	75.4
	April	55.2	40.7
	May	31.9	23.5
	June	15.5	23.1
	July	0.5	1.0
	August	2.6	5.3
	September	17.3	17.4
	October	57.4	46.6
	November	98.2	65.7
	December	127.7	71.7
Temperature (°C)	January	12.7	1.2
	February	13.1	1.1
	March	14.5	0.9
	April	16.1	0.8
	May	18.6	1.1
	June	21.8	1.1
	July	24.5	0.8
	August	25.2	0.7
	September	23.1	1.0
	October	19.7	0.9
	November	16.1	1.1
	December	13.5	1.3

For site 302, it is remarkable that the curve of May temperature follows quite well the curve of indices.

RESPONSE FUNCTIONS

This section will provide a relationship between standardized tree-ring indices (^tC) and standardized climatic variables (X_j). It is based upon statistical data analysis techniques which differ from the usual Fritts et al. (1971) method in the following way.

1) The persistence in the tree-ring chronology (i.e. the autocorrelation at lag 1 or more in the series) is extracted before starting to compute the response functions (The procedure is even different from the procedure in Munaut et al. 1978). This leads to a chronology directly related to the climate. For the response function and for the reconstruction of the climate (the next step), tree rings of the previous years are no longer entered. 2) The regression is performed after extracting the principal components, but the principal components are introduced with a probabilistic criteria.

Table 3. Serial correlation and significance of chronologies before (t_C) and after t_C*) removal of persistence.

		Site 301	Site 302
t_C	serial correlation	0.452	0.819
	significant level	0.9999	0.9999
t_C*	serial correlation	-0.005	0.048
	significant level	0.51	0.78

3) The variables that are less important for tree growth are rejected in a stepwise fashion and, finally, only a very limited number of climatological parameters are selected.

Elimination of the persistence in the index series

A chronology of 222 years for the site 302 (1754-1975) and a chronology of 175 years for the site 301 (1800-1974) are available. These series are detrended, because they are autocorrelated (Table 3). Their serial correlation coefficient at lag 1 is significant at the 95% level for both sites. Thus a regression has to be performed between ${}^{t}C$ and ${}^{t-1}C$. At the following steps, the serial correlation of the residuals are computed. As they are not significant at the 95% level (Table 3), it will not be necessary to introduce indices ${}^{t-2}C$, ${}^{t-3}C$ . . . in the regression (this test on serial correlation is explained in Sneyers 1978).

A regression is thus performed between ${}^{t}C$ and ${}^{t-1}C$ only. This leads to uncorrelated residuals which are considered as indices ${}^{t}C^{x}$ where persistence is left out, the regression equations being:

site 301: ${}^{t}C^{*} = {}^{t}C - 0.447\,{}^{t-1}C - 0.553$

site 302: ${}^{t}C^{*} = {}^{t}C - 0.820\,{}^{t-1}C - 0.179$

This 1-year persistence explains 20% of the total variance in the series from site 301 and 67% from site 302. This is closely related to the comments already made about some values given in Table 1.

Regression after extracting the principal components

The predictor variables of this regression are the 24 climatic parameters, monthly precipitation and temperature for October of the year prior to growth till September of the current year. They are standardized. These variables being not independent, principal components must be extracted to provide 24 orthogonal variables (Table 4). Because the least important components (those that account for a portion of the data variance not significantly different from zero) will contribute to the inaccuracy of the regression coefficients (Richard 1977), only the most important eigenvectors are retained. Table 4 shows that the eigenvalues product becomes clearly less than one after the 18th eigenvalue. This eigenvalues product is in fact the determinant of the correlation matrix of the climatic data and if we keep all the principal components, this determinant appears to be much less than one. As a determinant of a correlation matrix of orthogonal variables is equal to one, only around 18 principal components

Table 4. Results of principal component analysis (* indicates components used in regression).

principal component	variance explained (%)	eigenvalues product	weight on 301 coeff.	weight on 301 signif.	weight on 302 coeff.	weight on 302 signif.
1	17.9	4.292	0.21	0.98*	-0.18	0.91*
2	12.4	12.773	0.25	0.98*	-0.04	0.24
3	9.8	30.029	0.02	0.18	-0.28	0.95*
4	7.7	55.824	-0.09	0.57*	-0.08	0.39
5	7.2	96.018	-0.04	0.25	-0.07	0.35
6	6.0	137.882	-0.34	0.98*	-0.19	0.72*
7	5.8	191.518	-0.03	0.21	0.17	0.67*
8	5.5	254.144	0.22	0.89*	-0.00	0.01
9	4.9	298.366	-0.19	0.80*	-0.15	0.56*
10	4.5	320.743	-0.03	0.18	0.02	0.06
11	3.5	268.782	-0.05	0.23	-0.04	0.15
12	3.2	208.844	-0.28	0.88*	-0.04	0.14
13	2.2	110.479	0.17	0.56*	0.15	0.39
14	2.0	52.146	-0.13	0.44	-0.07	0.18
15	1.9	24.456	-0.05	0.20	0.15	0.38
16	1.5	8.682	-0.01	0.02	-0.34	0.67*
17	1.3	2.804	-0.02	0.06	-0.00	0.01
18	1.0	0.701	-0.07	0.19	0.38	0.64*
19	0.7	0.112				
20	0.04	0.010				
21	0.03	7.10^{-4}				
22	0.02	2.10^{-5}				
23	0.01	6.10^{-7}				
24	0.00	3.10^{-9}				

are allowed to be kept to provide a resulting determinant nearly equal to one. It must be noticed that each of the first 18 principal components explain more than 1% of the data variance (Table 4). Moreover, applying the test of Lawley (Kshirsagar 1972), it can be seen that the last six principal components are not significantly different from zero. These three remarks amply justify our selection.

However, some components in this selection have a zero weight on the dependent variables in such a way that we are also going to reject such components that have a zero weight on ${}^tC^*$ with a probability greater than 0.50. This level was chosen after several experiments. When the number of observations is small as in our case (30), this level is more justified than higher one like 0.90 or even 0.95. Comparison between all these procedures are described in Guiot et al. (1979).

Thus eight principal components for the site 301 and seven for the site 302 have finally been kept.

Then a multiple regression analysis has been performed between tree-ring indices from which persistence (lag 1) has been eliminated, ${}^tC^*$, and the amplitudes of the selected components (principal components in the observation-space, Guiot et al. 1978). This leads respectively to two sets of eight and seven regression coefficients. These coefficients are then converted into a new set of coefficients, T_i $(1 < i < 24)$, expressing the same relationship but in terms of the 24 original amplitudes (Figure 4):

$$ {}^{t}C^{*} = \sum_{i=1}^{24} T_i \quad X_i $$

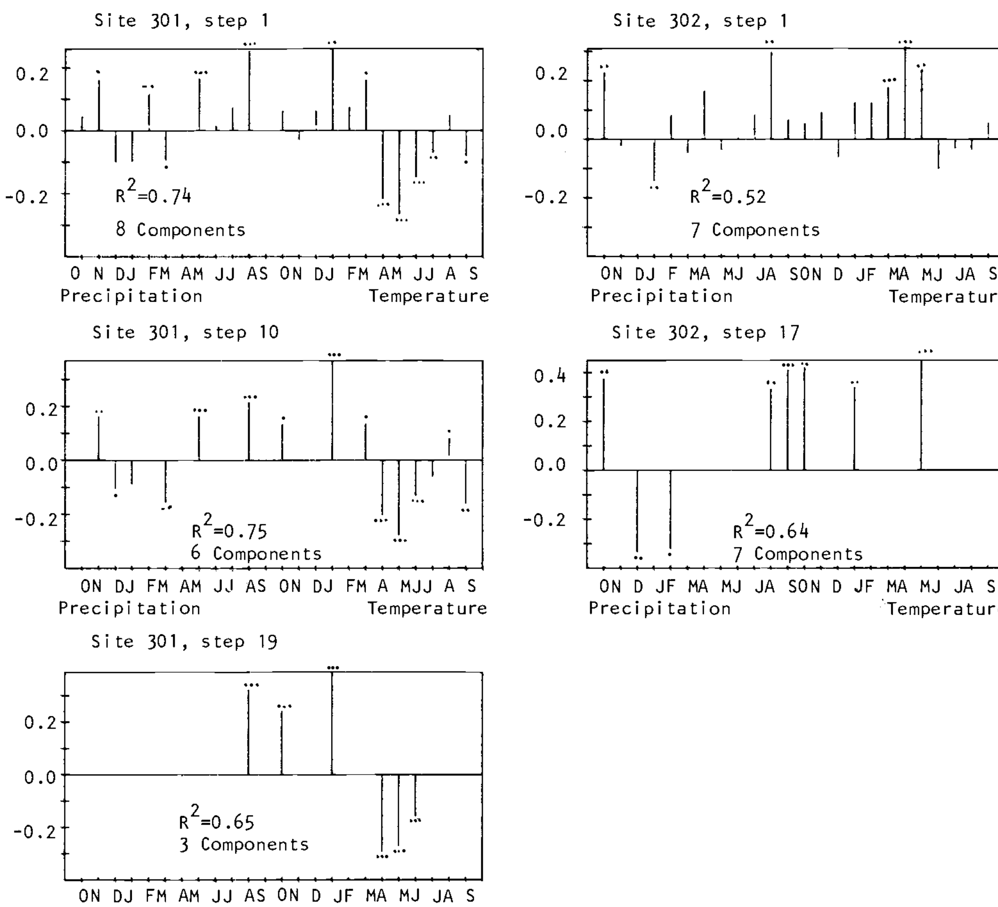


Figure 4. Response functions. Vertical bars represent the regression coefficients of the 24 standardized variables. One, two, or three dots mark significance of 90, 95, and 99% respectively. Using all principal components, R^2 of site 301 is .95 and of site 302 is .88.

Table 5. Serial correlation of chronologies for total length and for period of instrumented climate.

	Site 301	**Site 302**
whole period	0.452	0.819
30-year period	0.439	0.281

Selection of the most significant variables

The regression coefficients (T_i) of the response functions for both sites are given in Figure 4, where it can be seen that some of them are not significantly different from zero at the 95% level. As a consequence, the T_i with the smallest value of the Student's *t*-statistic is deleted and the whole procedure is started again in a stepwise fashion. However, some of the variables could never be rejected. Indeed, it is possible that, when dealing with a large number of variables, some of them become significant only after other competitive variables have been eliminated. Thus other criteria for the selection have to be defined. At the same time as the procedure of rejecting the less significant variables, we select, in the set of climatic variables, the variables which individually explain a part significant at more than 95% of the variance of ${}^tC^*$. This gives a final selection of variables which may not be deleted, and the final selection will at least contain these variables and, as a consequence, in the stepwise fashion, the least significant climatic parameters are deleted one by one beyond this minimal selection. The program provides these different steps till the minimal selection remains. So we can extract from these different steps, the step which explains the maximum of ${}^tC^*$ variation but where the coefficients are "sufficiently" significant. More details on this method and comparisons with others are given in Guiot (1979).

In this study, for the site 301, 15 climatic parameters have been selected and their influence on the indices ${}^tC^*$ have been represented by six principal components ($R^2 = 0.75$). The coefficients, except one, are significant at the 90% level. For the site 302, we have selected eight climatic parameters which the influence on the indices ${}^tC^*$ may be represented by seven principal components ($R^2 = 0.64$). All the coefficients are significant at the 90% level. Figure 4 provides, for both sites, the response function related to the variables remaining in the final regression equations.

Study of the 30-year period

These response functions are established for the indices from which persistence has been taken out on the basis of the whole chronology (222 years for the site 302 and 175 years for the site 301). These functions are mainly useful for the reconstruction of the climate; but if we want to study the relationship of cedar to climate, we have to eliminate the persistence on the 30-year period basis only (1942-1971). For the site 302, the serial correlation appears to be larger over the whole chronology ($\rho = 0.82$) than over the partial chronology ($\rho = 0.28$) (Table 5), which means that persistence was more important in the first part of the tree's life than now. However, for the site 301 persistence has not changed.

Considering only this 30-year period, the relations between the tree-rings and the most important climatic parameters for both sites can now be written as:

site 301

$$ {}^{t}C = 0.448\,{}^{t-1}C + {}^{t}C^{*} $$

$$ {}^{t}C^{*} = 0.283\,P_{Aug} + 0.192\,{}^{t-1}T_{Oct} + 0.438\,{}^{t}T_{Jan} - 0.336\,{}^{t}T_{Ap} - 0.353\,T_{May} + \in $$

$$ R^2 = 0.660 $$

site 302

$$ {}^{t}C = 0.420\,{}^{t-1}C + {}^{t}C^{*} $$

$$ {}^{t}C^{*} = 0.388\,P_{Oct} + 0.317\,{}^{t}P_{Sept} + 0.247\,{}^{t}T_{Jan} {}^{\wedge} 0.471\,{}^{t}T_{May} + \in $$

$$ R^2 = 0.516 $$

where all the variables are standardized. As these relations are computed only over the 30-year period, they describe the real behavior of the tree during this period.

INTERPRETATION

Site 301

Using 24 or 15 variables, it appears that the monthly precipitation of November, May, and August has a positive effect on growth. On the other hand, winter and early spring precipitation seems to be unfavorable. This effect is explainable in a mediterranean cold climate when it is snowing during winter. An accumulation of snow in the forest can delay the tree growth by maintaining a cold microclimate. This unfavorable effect of cold winter and spring is clearly illustrated by the positive effect of the temperature during the same period. On the other hand, at middle altitude, high temperature during April, May, June, and July, are the cause of an intense evapotranspiration which reduces drastically the water resource in the soil and the subsequent growth. The five variables still giving a high R^2 summarize obviously this interpretation emphasizing the positive effect of high precipitation in summer and high temperatures during fall and winter, while high spring temperature, lengthening the summer dryness, reduces the yearly growth.

Site 302

Compared with the response function of site 301, this one shows some interesting analogies but also dissimilarities. The positive effect of precipitation during fall and summer and the negative one in winter may be explained in the same way as for site 301. It is especially obvious that in a fairly wet environment (maybe more than 1 m/year) *Cedrus* takes advantage of summer rains. Concerning the temperature, warm

October and January are also favorable, but this effect is the same for February, March, April, and May. Indeed at high altitude, during springtime, the water supply is still sufficient, but if the temperature is too low the growth is reduced.

CONCLUSION

In conclusion, this preliminary study shows that the dendrochronological analysis of two adjacent forests of *Cedrus atlantica* located at the upper and at the lower limits of this species in the Rif mountains, gives two response functions of the same type. In fairly wet and cold mediterranean climate, precipitation is of great influence on the yearly growth, except in winter when a snowy cover delays the spring growth. Temperature acts favorably at both sites during winter, and also during spring at high elevation where there is no fear of strong evapotranspiration.

ACKNOWLEDGEMENTS

Thanks are due to the Fonds de la Recherche Fondamentale Collective de la Belgique which kindly grants our dendrochronological studies and to the Institut pour l'Encouragement de la Recherche Scientifique dans l'Industrie et l'Agriculture for financial help provided to one of the authors. Our gratitude is also expressed to Monsieur S. Zaki, Directeur Général de l'Administration des Eaux et Forêts et de la Conservation des Sols du Maroc, Monsieur Tamri, Directeur de la Station de Recherches Forestière de Rabat, and Monsieur O. M'Hirit, Professeur à l'Ecole Nationale Forestière d'Ingénieurs à Salé whose help has been greatly appreciated for the field work. Meteorological data have been kindly provided by Monsieur S. Benarafa, Chef de la Division de Climatologie de CASA/ANFA.

INDXA program has been kindly provided by Prof. H. Fritts, Laboratory of Tree-Ring Research, University of Arizona and adapted to IBM computer facilities at the Institute of Astronomy and Geophysics, UCLLN.

REFERENCES

Fritts, H. C.
1976 *Tree rings and climate.* Academic Press, New York and London.

Fritts, H. C., T. J. Blasing, B. P. Hayden, and J. E. Kutzbach
1971 Multivariate techniques for specifying tree-growth and climate relationships and for reconstructing anomalies in paleoclimate. *Journal of Applied Meteorology* 10 (5) 845-864.

Guiot, J., A. Berger, and A. Munaut
1979 Response function in dendroclimatology; comparison of different methods and recommendations. Workshop on Dendroclimatology, Norwich.

Guiot, J., A. Berger, and A. Munaut
1978 Response function in dendroclimatology. *Institute of Astronomy and Geophysics; Catholic University of Louvain, Scientific Report* 1978/1 (in French).

Kshirsagar, A. M.
1972 *Multivariate analysis.* Marcel Dekker, Inc., New York.

Munaut, A., A. Berger, J. Guiot, and L. Mathieu
1978 Dendroclimatological studies on cedars in Morocco. In "Evolution of planetary atmospheres and climatology of the earth," pp. 373-379. CNES, Nice.

Richard, J. F.
1977 Colinéarité et structures particulières des régresseurs. In "Analyses de régression," Délincé and Mouchart, editors. *Biométrie-Praximétrie* XVII: 74-77.

Sneyers, R.
1978 Homogénéité et stabilité des éléments météorologiques à Uccle (Belgique). In "Evolution of planatary atmospheres and climatology of the earth," pp. 419-426. CNES, Nice.

REVISED COMPUTER PROGRAMS FOR TREE-RING RESEARCH

DONALD A. GRAYBILL

Laboratory of Tree-Ring Research
The University of Arizona

ABSTRACT

Three computer programs that are basic to the processing and development of tree-ring chronologies are now available. They were designed to refine and replace older programs that were previously furnished by the laboratory. Program RWLIST replaces program RWLST and is used for data inspection. Programs INDEX and SUMAC replace INDXA. INDEX is used for curve fitting procedures while SUMAC does summaries of series of indices, analysis of variance and cross-correlation. The new programs represent an increase in efficiency and flexibility in use. They are written in current ANSI Fortran IV and will be readily adaptable to most computing environments.

Trois programmes pour ordinateur qui constituent la base du traitement des données et de l'élaboration de séries dendrochronologiques sont disponibles. Ils ont été travaillés pour affiner et remplacer des programmes plus anciens, autrefois fournis par le Laboratoire de Tucson. Le programme RWLIST remplace le programme RWLST, utilisé pour vérifier les données. Les programmes INDEX et SUMAC remplacent INDXA. INDEX est utilisé pour la recherche des courbes de lissage, tandis que SUMAC fait les résumés de séries d'indice, analyse de la variance et les calculs des corrélations. Ces nouveaux programmes sont plus efficaces et plus souples à l'usage. Ecrits en ANSI Fortran IV normal, ils sont facilement adaptables à la plupart des ordinateurs.

Für die Bearbeitung und Entwicklung von Jahrringchronologien stehen jetzt drei Computerprogramme zur Verfügung. Sie sollen die älteren Programme, die bisher vom Laboratory of Tree-Ring Research angeboten wurden, verbessern und ersetzen. Das Programm RWLIST ersetzt das Programm RWLST und dient der Datensichtung. Die Programme INDEX und SUMAC ersetzen das Programm INDXA. Mit dem Programm INDEX werden Ausgleichslinien an die Jahrringkurven angepaßt, das Programm SUMAC summiert Indexreihen und führt Varianzanalysen und Kreuzkorrelationen durch. Die neuen Programme haben ene höhere Effizienz und Flexibilität zur Folge. Sie sind in ANSI Fortran IV geschrieben und können an die meisten Computer-systeme angepaßt werden.

One of the continuing goals of the Laboratory of Tree-Ring Research is to maintain or develop computer software that is current by international scientific standards and to make this available to the scientific community in order that replicable research efforts are possible. Most recently this has resulted in new or revised programs that are basic to the development of tree-ring chronologies and to the understanding of their statistical characteristics. The main features of each of these programs is described in the following sections.

PROGRAM RWLIST

The purpose of this program is to provide output of raw ring-width measurements and to plot their 20 year means. This permits examination of the data for the purpose of proofreading and for decision making about the type of curve fitting procedure that might be used in the subsequent development of indices. The primary differences in this program and the older RWLST concern the upgraded Fortran and a new series of error checking procedures. RWLIST will detect a variety of maladies that are notoriously common to the batch-oriented user. These involve decadal sequences that are reversed, missing, or duplicated and decadal sequences from two or more series that have been mixed. Input to the program may be from any standard peripheral device. A sample of the output is shown in Figure 1.

PROGRAM INDEX

Program Index uses curve fitting procedures to transform ring-width measurements into indices that have a mean value per series of about 1.0. The curve fitting options are the same as those found in the older INDXA program. They include a negative exponential curve, a straight line with positive, negative or zero slope, and a least squares polynomial. The computational formulae for the indices and the several statistics that describe each series are given by Fritts (1976). Figure 2 illustrates the printed output from the program operations.

RUN TITLE CHETRO KETL (ARCHAEOLOGICAL BEAM)
DATE 10/08/79

IDENT. 101201

TREE-RING WIDTHS

20 YR. MEAN	YEAR	0	1	2	3	4	5	6	7	8	9
0.000	646							2.020	4.700	4.080	5.480
3.741	650	4.600	3.560	3.720	4.610	3.210	3.950	3.560	4.070	3.080	1.730
2.640	660	.850	.980	1.750	1.320	.890	2.090	2.130	2.390	2.350	1.960
1.600	670	2.440	2.080	1.620	1.270	1.880	1.140	1.340	.890	1.320	1.310
1.473	680	1.050	1.350	1.710	1.200	1.750	1.420	1.140	1.520	1.610	1.420
1.210	690	.960	.870	1.030	.990	.940	1.400	.900	1.100	.850	.980
.844	700	.340	1.250	.820	1.200	.080	.860	.360	.510	.980	.460
.672	710	.990	.610	.500	.830	.550	.760	1.010	.200	.300	.830
.586	720	.770	.450	.420	.190	.080	.510	.800	.480	.700	.740
.829	730	.970	1.160	1.340	1.610	1.290	.980	2.100	1.220	.240	.540
.993	740	1.010	.360	.370	.810	.770	1.080	1.250	1.320	.390	1.060
.694	750	.470	.270	.240	.860	.520	.480	.660	.080	1.020	.860
.764	760	.760	1.080	1.070	1.140	.430	.980	1.080	.680	1.420	1.180
.959	770	.680	.880	1.390	1.020	.570	1.130	1.390	1.200	.850	.250
.945	780	1.070	.960	.380	.720	1.010	.960	.760	1.600	.960	1.130
.915	790	1.500	.620	1.160	.800	1.090	.700	.630	0.000	1.130	1.130
.965	800	1.350	1.320	1.530	1.230	.950	1.260	1.460	.740	.490	.220
.970	810	.830	.900	1.050	1.230	1.220	1.500	1.020	.320	.010	.770
1.163	820	1.310	1.350	2.040	1.590	1.080	.940	1.560	1.330	1.660	1.550
1.387	830	1.070	1.800	1.830	1.760	2.080	1.800	.860	.380	1.110	.640
1.234	840	.340	1.150	1.160	1.500	1.710	1.310	.970	.990	1.350	.870
1.052	850	.940	.580	1.030	1.170	1.060	.520	1.080	.830	1.410	1.070
.851	860	.880	.850	1.070	.780	.840	.500	.700	.200	.680	.830
.652	870	.480	.600	.740	.660	.780	.490	.820	.620	.080	.440
.545	880	.380	.650	.550	.320	.210	.940	.510	.690	.350	.600
.719	890	.700	.740	.640	.950	.500	.630	1.020	.890	1.410	1.710
.656	900	1.120	.460	.610	.160	.090	.570	0.000	.010	.580	.330
.514	910	.630	.580	.780	.600	.750	.340	.280	.810	.650	.940
.684	920	.970	.680	.240	.270	.050	1.200	1.180	.440	1.140	1.160
.738	930	.450	1.000	1.140	1.010	.820	.270	1.020	.240	.830	.650
.753	940	.910	.830	.600	.290	.630	.470	.790	1.050	.870	1.190
.795	950	1.140	.370	1.330	.930	.520					

LISTING FOR SPECIMEN 101201 FROM 646 TO 954. 309 YEARS. MEAN RING WIDTH 1.044 STANDARD DEVIATION .766
MEAN SENSITIVITY .477 FIRST ORDER AUTOCORRELATION .800

RUN TITLE CHETRO KETL (ARCHAEOLOGICAL BEAM)
DATE 10/08/79

PLOT OF 20 YEAR MEANS OF RING WIDTHS BY DECADE FOR SPECIMEN 101201

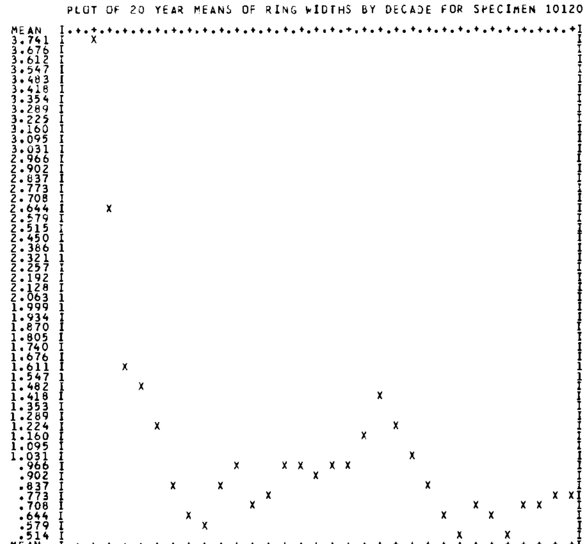


Figure 1. Output from program RWLIST.

```
RUN TITLE      HIDDEN FOREST, NEV. (BRISTLECONE PINE)
DATE           10/08/79

 IDENT.                         T R E E - R I N G   I N D I C E S
737321
```

EXPEC. GROWTH	YEAR	0	1	2	3	4	5	6	7	8	9
1.382	1550	.716	1.115	.867	1.170	1.104	1.413	1.311	.893	.569	.612
1.280	1560	.797	.708	.872	.512	.709	.844	.458	.898	1.129	1.121
1.186	1570	.851	1.121	1.575	.966	.947	1.112	.812	1.102	.744	1.047
1.099	1580	.982	1.301	1.154	.986	.244	.274	1.075	1.093	1.005	1.460
1.020	1590	.765	.682	.916	1.033	1.041	1.079	1.252	1.116	.989	1.081
.946	1600	.761	.895	1.266	.638	1.688	1.942	1.128	1.292	1.391	1.616
.878	1610	1.731	.906	1.052	.699	1.243	1.962	1.512	1.715	2.090	1.814
.816	1620	1.496	1.507	1.282	1.291	.202	1.005	.410	.917	.858	1.179
.758	1630	.409	.572	.241	.742	.965	.862	2.206	1.152	1.105	1.113
.705	1640	1.490	.772	1.468	.928	.920	1.118	1.363	1.134	.421	1.378
.656	1650	.854	1.367	.634	.249	.063	.806	1.098	1.202	1.082	.732
.611	1660	.950	.957	.947	.736	1.028	.390	1.025	.826	.260	.524
.569	1670	.035	1.381	.856	1.239	1.428	.564	1.081	1.790	1.710	1.198
.531	1680	1.621	1.480	1.300	1.693	.562	1.015	.039	1.484	1.295	1.123
.495	1690	1.434	1.179	1.187	1.216	1.079	1.379	1.031	1.292	.448	.966
.463	1700	1.405	1.567	1.753	.529	1.443	2.124	1.215	.340	.251	.758
.433	1710	1.063	.931	1.476	.424	1.353	.932	.144	.848	1.341	.932
.405	1720	1.507	1.044	.075	1.133	1.166	1.123	1.413	1.086	.885	.210
.379	1730	.422	.637	.721	.296	.730	.109	.384	.662	.832	.056
.356	1740	.731	.877	.057	1.604	.548	.348	1.022	.910	.887	1.100
.334	1750	1.017	.452	.061	.701	.982	.154	.870	.062	1.132	.759
.314	1760	1.178	.673	.741	.292	.652	.230	1.551	.996	.100	1.479
.296	1770	.845	.782	.958	1.308	1.212	1.776	1.542	.846	1.489	1.498
.279	1780	1.112	.794	.073	1.168	1.175	.074	.409	.785	.338	1.096
.263	1790	.076	.650	.884	.889	.894	.274	.511	.554	.557	.600
.249	1800	.442	.849	.732	1.267	.740	.455	1.164	.794	.168	.465
.235	1810	1.444	.641	1.202	.086	.912	1.178	.834	1.103	.576	.847
.223	1820	.941	1.171	.362	.592	.412	.322	.740	.511	.607	.704
.212	1830	.850	1.139	1.812	1.438	.096	1.356	.097	2.201	.688	.988
.201	1840	.894	1.397	1.153	1.915	1.266	.712	.971	.206	1.084	1.089
.192	1850	1.095	1.205	1.158	1.428	1.222	1.388	.644	.108	1.787	.816
.183	1860	1.202	.769	1.213	.111	.390	.168	.899	.734	.567	.911
.175	1870	.286	.862	.115	.580	1.164	1.053	1.116	1.062	.770	.536
.167	1880	.120	.480	.543	.121	.973	1.160	.674	1.847	2.040	1.056
.160	1890	1.372	1.941	1.006	.821	.887	1.846	.639	1.540	1.610	1.552
.154	1900	.649	.652	.393	.986	.132	1.457	.798	1.869	1.072	1.480
.148	1910	1.215	1.830	1.361	1.639	2.879	2.339	1.381	2.079	1.670	2.025
.143	1920	2.032	2.814	1.906	1.346	1.422	1.427	2.005	1.150	2.524	.362
.138	1930	1.816	1.968	2.267	.954	.147	2.438	.593	2.529	.896	2.022
.133	1940	1.653	2.036	1.815	2.049	1.523	1.146	1.609	1.691	1.465	1.780
.129	1950	.155	.311	1.797	.157	1.258	1.262	.158	1.587	1.114	.160
.125	1960	2.001	1.686	1.530	.404	1.458	1.381	1.059	.490	1.475	1.726
.121	1970	.989	1.653	.829	1.330	.584	2.090				

* * * S T A T I S T I C S   F O R   I N D I C E S * * *

NUMBER OF YEARS	426	MEAN RING WIDTH	.444
FIRST ORDER AUTOCORRELATION	.258	MEAN INDEX VALUE	1.021
STANDARD DEVIATION	.532	SUM OF INDICES	435.098
MEAN SENSITIVITY	.585	SUM OF SQ. OF INDICES	564.870
NUMBER OF ABSENT RINGS	0	PERCENT OF ABSENT RINGS	0.0

```
CURVE FIT OPTION  0
NEGATIVE EXPONENTIAL CURVE      (Y = AEXP(-BX)+D)
 16 ITERATIONS WERE REQUIRED
COEFFICIENTS OF THE EQUATION ARE - -
A =   1.314
B =    .008
D =    .079
```

Figure 2. Output from program INDEX.

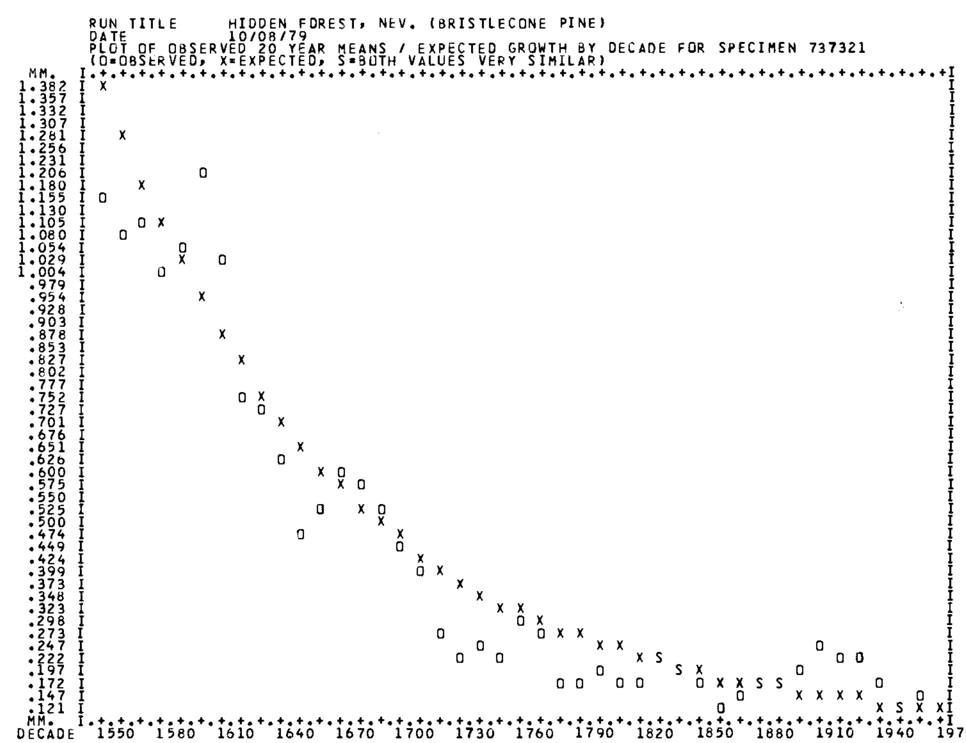


Figure 3. Printer plot from program INDEX.

In addition to the updated Fortran and the revised output print format, program INDEX differs from INDXA in several ways. Extensive error checking procedures have been added that are similar to those described for program RWLIST. When errors in the input stream or in other facets of processing are encountered, messages that attempt to specify the problem are printed on the output file before the program is stopped. Also included now is an option that permits a line printer plot of 20 year means of the expected and observed values of the indices for each series. An example of this is shown in Figure 3.

Program INDEX may be used as a single unit or in sequential job processing with program SUMAC described below. The input stream is basically composed of control records and measurement records. The user has extensive control over the devices used for data origination and destination. The output stream is minimally composed of printed output. Indices may also be punched or stored on peripheral devices.

PROGRAM SUMAC

SUMAC is a program designed to accomplish three different procedures: (1) develop summaries of series of indices, (2) do analysis of variance of series of indices, and (3) do cross-correlation of series of indices. All three types of analysis may be performed in any particular job execution or each may be done separately depending

RUN TITLE SATAN PASS, N.M. (DOUGLAS FIR)
DATE 10/09/79

IDENT. 161540

S U M M A R Y O F T R E E - R I N G I N D I C E S

SEQUENCE NUMBERS INCLUDED ARE 31 32

YEAR	INDICES 0	1	2	3	4	5	6	7	8	9
1381		4.348	1.664	3.118	2.850	1.786	2.099	2.159	1.558	.994
1390	.410	.606	.998	.509	.725	.805	.629	.275	.256	.118
1400	.355	.356	.435	.436	.674	.437	.358	.152	.244	1.084
1410	1.595	1.628	2.961	.838	2.143	1.061	1.942	2.382	1.031	.392
1420	1.189	.556	.987	.627	.955	1.104	1.689	2.158	2.552	1.180
1430	1.035	2.329	2.163	2.419	1.675	1.172	.565	.740	.320	.687
1440	.757	1.010	.464	.620	.472	.241	.180	.744	.273	.393
1450	.189	.782	.888	1.038	.517	.042	.741	.113	1.295	.833
1460	.606	.486	.569	.073	.191	.119	.720	1.046	.840	1.013
1470	.943	.319	.390	.487	.129	.377	.449	.656	.164	.104
1480	.147	.481	.489	.556	.833	.935	.509	.289	.817	1.107
1490	.842	1.757	1.261	.907	.824	.067	.281	.592	1.134	1.085
1500	.216	.335	.493	.649	.608	.895	.211	.760	.321	.690
1510	.510	1.330	1.384	1.331	1.937	1.777	.985	.191	1.054	1.491
1520	1.721	.870	.421	.641	.473	.571	.961	.787	.945	.887
1530	1.346	1.525	1.087	.890	.682	.853	.764	1.297	.310	1.035
1540	1.351	1.169	.182	1.320	.535	1.141	.588	.807	.560	1.222
1550	1.287	.454	.580	.981	.384	.852	1.279	1.646	1.150	.872
1560	.564	.315	.344	.517	.701	1.148	.881	.798	1.036	1.657
1570	1.460	.936	.967	.398	.581	.593	.434	1.010	.584	.409
1580	.194	.566	.574	.209	.198	.263	.680	.746	1.405	.919
1590	.415	1.362	.345	.278	1.776	1.547	1.367	1.340	.755	1.131
1600	.533	.632	.510	.640	1.002	1.614	1.454	1.907	1.957	2.365
1610	3.689	3.399	2.456	2.616	1.230	2.054	2.023	2.177	2.727	1.663
1620	2.680	2.969	1.030	.780	.432	.603	.336	1.355	1.247	2.233
1630	1.868	.997	.753	1.644	1.929	1.252	1.100	.587	.825	1.549
1640	2.081	1.149	1.457	1.654	1.285	.930	1.905	1.588	1.082	1.283
1650	.932	1.648	1.452	1.442	.879	1.237	1.452	.698	.950	.367
1660	1.058	.755	.671	.775	.339	1.787	.893	.570	.281	.490
1670	.172	1.058	.353	1.061	.329	1.077	.337	.890	.793	.511
1680	1.506	1.381	1.630	1.792	.369	.087	1.217	1.078	.900	1.302
1690	1.813	1.317	1.754	1.735	1.133	1.240	.456	.288	.679	1.307
1700	.900	1.955	1.047	1.094	.716	.686	1.168	1.194	.917	.601
1710	1.781	1.417	1.662	1.248	1.031	.939	.164	1.020	.765	.938
1720	1.929	1.391	.552	1.393	.274	.855	1.296	1.399	.120	.040
1730	.682	1.017	1.312	.450	.843	.109	.850	.613	.311	.735
1740	.642	.645	.226	1.173	.352	1.414	1.859	2.736	.120	2.029
1750	.899	.867	.298	.644	1.269	.632	.665	.612	1.224	1.849
1760	1.298	.322	1.647	.240	1.301	.476	1.532	.854	1.758	1.619
1770	1.355	1.532	1.225	.190	.886	.669	.967	.256	.816	.583
1780	.330	.922	.216	1.424	1.756	1.221	.686	1.441	.451	1.084
1790	.920	1.361	1.620	1.873	.975	1.757	.745	.880	1.005	.703
1800	.404	.637	1.076	.560	1.190	.957	.129	1.415	.869	.811
1810	.456	.434	.558	.510	.899	.919	2.095	1.910	.255	.137
1820	.806	1.263	.007	.273	.625	.822	.351	.282	1.147	.323
1830	1.007	.852	1.111	1.470	1.769	1.722	1.194	1.770	2.099	2.480
1840	2.412	1.824	.848	.840	1.450	.641	.972	.015	1.446	1.371
1850	1.163	.554	1.495	.892	.378	1.957	2.025	.656	1.293	.971
1860	.855	.134	1.403	.634	.510	.861	1.002	1.640	1.303	2.098
1870	1.032	1.212	.207	1.160	1.613	.515	.596	1.870	.738	1.048
1880	.130	.429	1.287	1.217	1.604	1.336	.807	.853	1.638	1.171
1890	.937	1.466	1.081	.577	.296	1.228	.580	1.024	.702	.348
1900	.590	.679	.345	1.104	.040	1.604	.989	1.259	2.044	.438
1910	1.255	1.077	1.387	.584	1.321	1.821	1.574	1.470	.425	1.493
1920	2.032	.501	1.019	.775	1.722	.261	1.376	.782	1.301	.758
1930	.747	1.185	1.472	.698	.528	2.117	1.242	1.645	1.162	1.128
1940	.433	2.191	1.354	.607	1.119	1.111	.526	.880	1.508	1.043
1950	.312	.127	1.138	.399	.270	.136	.334	.332	.929	.383
1960	1.043	.664	.816	.840	.727	1.336	1.111	.196	1.659	1.314
1970	1.433	.342	1.017							

YEAR	NUMBER OF CORES 0	1	2	3	4	5	6	7	8	9
1381		1.	1.	1.	1.	1.	1.	1.	1.	1.
1390	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
1400	1.	1.	1.	1.	1.	1.	1.	2.	2.	2.
1410	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1420	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1430	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1440	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1450	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1460	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1470	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1480	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1490	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1500	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1510	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1520	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1530	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1540	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1550	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1560	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
1570	2.	2.	2.	3.	3.	3.	3.	3.	3.	3.
1580	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
1590	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.
1600	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.
1610	4.	4.	5.	5.	5.	5.	5.	5.	5.	5.
1620	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.
1630	7.	7.	7.	7.	7.	8.	8.	8.	8.	8.
1640	9.	9.	9.	9.	9.	9.	10.	10.	10.	10.
1650	13.	13.	14.	14.	14.	14.	14.	14.	14.	14.
1660	14.	14.	14.	14.	14.	14.	14.	14.	14.	14.
1670	14.	14.	14.	14.	14.	14.	14.	15.	15.	15.
1680	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.
1690	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.
1700	18.	18.	18.	18.	18.	18.	19.	19.	19.	19.
1710	19.	19.	20.	20.	20.	20.	20.	20.	20.	20.
1720	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1730	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1740	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1750	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1760	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1770	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1780	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1790	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1800	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1810	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1820	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1830	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1840	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1850	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1860	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1870	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1880	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1890	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1900	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1910	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1920	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1930	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1940	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1950	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1960	20.	20.	20.	20.	20.	20.	20.	20.	20.	20.
1970	20.	20.	20.							

* * * S T A T I S T I C S F O R S U M M A R Y * * *

TIME RANGE IS	1381-1972	NUMBER OF YEARS	592	STANOARD OEVIATION	.616
FIRST ORDER AUTOCORRELATION	.450	MEAN SENSITIVITY	.576	MEAN INDEX VALUE	.995
STANDARD ERROR	.102	SUM OF INDICES	589.147	SUM OF SQ. OF INDICES	810.409
MEAN RING WIOTH	.442	NUMBER OF ABSENT RINGS	182	PERCENT OF ABSENT RINGS	15.71675
ANOVA PERIOO IS	1820-1969	NUMBER OF YEARS	150	MEAN INDEX VALUE	1.017
R OF MEAN WITH				SUM OF SQ. OF INOICES	199.389
STANOARD ERROR	.837	(INTERCEPT)	.024	(SLOPE)	.0393
MEAN RING WIOTH	.329	NUMBER OF ABSENT RINGS	103	PERCENT OF ABSENT RINGS	34.33333

Figure 4. Summing of series output from program SUMAC.

upon the problem at hand. The rationale for these procedures, the associated statistical formulae, and examples of their usage are given by Fritts (1976).

The major differences between SUMAC and the summary processing sectors of INDXA concern increased flexibility in the types of input stream that are possible, simplification of input directives, revised output print format and increased efficiency of operation. There are three types of summary processing that SUMAC does. The first of these is one of the most common types of analysis encountered, i.e., ring-width data from one site are available that represent replicated series of two or more samples per tree. In this case program INDEX is loaded, executed, and the resulting indices are written to intermediate disk storage. Program SUMAC is then loaded and executed. It reads the indices from intermediate storage and then develops a new data file that can be directly instead of sequentially accessed in search of any series. The program then develops tree summaries, matched specimen summaries and a site summary. Data sets that contain replicated series from several sites may also be processed as long as the number of samples per tree and the number of trees per site are constant. In this case additional summaries across samples for all sites and across trees for all sites would be produced. The printed output from a final site summary is shown in Figure 4. Options are present that permit any or all summaries to be punched or stored on other devices.

The second type of summary processing in SUMAC is designed to do the same tasks as those described above but the data being input are indices that have been produced by INDEX or INDXA that have been stored as physical card images. The third summary procedure is designed to do summaries of indices for single specimens and/or multiple specimen summaries. For example, site summaries and tree summaries developed at different times may be input to produce an areal or regional chronology.

The cross-correlation procedures and output do not vary substantially from those found in INDXA. The analysis of variance procedures remain constant but the output

RUN TITLE SATAN PASS, N.M. (DOUGLAS FIR)
DATE 10/09/79

ANALYSIS OF VARIANCE

SOURCE OF VARIATION		RAW SUM OF SQUARES	CORRECTED SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	VARIANCE COMPONENT	PERCENTAGE VARIANCE COMPONENT
GROUP MEANS	(G)	ONLY ONE GROUP IS BEING USED					
CORE CLASS MEANS	(C)	3101.201	.197	1.000	.197		
TREE MEANS IN GROUPS	(T X G)	3111.260	10.257	9.000	1.140		
CORE MEANS IN GROUPS	(C X G)	ONLY ONE GROUP IS BEING USED					
CORE MEANS WITH TREES IN GROUPS	(C X T/G)	3121.044	9.587	9.000	1.065		
SUBSAMPLE	(C X T/G)	SUBSAMPLING NOT USED					
MEAN INDICES IN TOTAL CHRONOLOGY	(Y)	3987.785	886.782	149.000	5.952	.291	76.622
CHRONOLOGIES OF GROUPS	(Y X G)	ONLY ONE GROUP IS BEING USED					
CHRONOLOGIES OF TREES IN GROUPS	(Y X T/G)	4174.441	176.399	1341.000	.132	.041	10.905
CHRONOLOGIES OF CORE CLASSES	(Y X C)	3993.243	5.261	149.000	.035	-.001	-.353
CHRONOLOGIES OF CORE CLASSES WITH GROUPS	(Y X C X G)	ONLY ONE GROUP IS BEING USED					
CHRONOLOGIES OF CORES WITH TREES IN GROUPS	(Y X C X T/G)	4254.807	65.322	1341.000	.049	.049	12.826
SUBSAMPLE	(Y X C X T/G)	SUBSAMPLING NOT USED					

TOTAL SUM = 3101.00 N OF ELEMENTS = 3000.
ERROR SQ. OF Y = .0059 ERROR OF Y = .0769

Figure 5. ANOVA output from program SUMAC.

print format has been extensively revised. It follows the tabular presentation of Fritts (1976: 288). An example is shown in Figure 5.

The new programs are written in Fortran IV that conforms to ANSI standards at the present time. They have been extensively tested on a Control Data Corporation Cyber 175 using a Fortran compiler (FTN version 4.6), under the SCOPE and NOS/BE operating systems. No major difficulty should be encountered in adapting the programs for use on other computing systems.

A detailed operating manual for the programs (Graybill 1979), a tape with the Fortran source statements, test data and sample output can be ordered for a nominal processing fee. Please direct inquiries to:

Data Processing
Laboratory of Tree-Ring Research
The University of Arizona
Tucson, Arizona 85721
U.S.A.

ACKNOWLEDGEMENTS

The design and performance of the programs described here have been greatly enhanced by the suggestions of Linda G. Drew. Many other faculty and staff members at the laboratory have provided comments that were fully appreciated.

REFERENCES

Fritts, H. C.
1976 *Tree rings and climate.* Academic Press, London and New York.
Graybill, D. A.
1979 *Program operating manual for RWLIST, INDEX and SUMAC.* On file at the Laboratory of Tree-Ring Research, The University of Arizona, Tucson, Arizona.

VOL. 39 TREE-RING BULLETIN 1979

Subscription $5.00 per Volume

Manuscripts and inquiries should be directed to the Laboratory of Tree-Ring Research
The University of Arizona, Tucson, Arizona 85721

CONTENTS