There are 3 important items I wish to convey to our readership in this inaugural issue on which I am editor.

**First,** after thoughtful deliberation, the Tree-Ring Society Executive Committee has concluded it is necessary to impose page charges for Tree-Ring Research to support the increased frequency of publication and improved quality of our journal. We feel that a combination of membership dues and author page charges will provide a fair basis for financing TRR. To this end, beginning January 1, 2003, manuscripts submitted to Tree-Ring Research that are eventually accepted will be assessed modest page charges according to the following fee scale based on the number of published “journal pages” and the Tree-Ring Society membership status of the first author:

a) $35/page ($45/page for non-members) for the first 10 pages,
b) $50/page ($60/page non-members) for pages 11–16,
c) $80/page for each page beyond 16 regardless of membership.

A partial or full waiver will be available under extenuating or hardship circumstances. After notification of acceptance, the author must document these circumstances by submitting one or more of the following to support their case: (1) a letter from the author with financial responsibility for the research project stating the financial hardship, (2) a letter from a department chair or other financial officer of the author’s institution, stating that funding is not available to support page charges, (3) a letter from an officer of the agency that funded the research stating the funding for page charges was not provided, or (4) any other documentation that the author(s) wish to submit in support of their request. The request will be subsequently evaluated before the paper is printed to determine if a full or partial waiver is merited.

**Second,** the 6th International Conference on Dendrochronology, Tree Rings and Society was hosted by Yves Bégin at the University of Laval in Quebec City, August 21–28, 2002, and attracted 190 participants from 29 countries. There were more than 150 oral and poster presentations, featuring the breadth of tree-ring research taken place around the world, and highlighting an amazing number of diverse projects taking place in Canada and Quebec. As of this printing, we do not know who will host the next meeting, but indeed some very high standards were set at Quebec.

**Finally,** I thank the outgoing Editor, Tom Swetnam, for his continued assistance with the journal after his term had ended in December 2001. He played an important role in the editorial efforts for some of the articles in this issue, and likely for articles in the next issue or two to come. His overall service to the Society via improvements implemented to Tree-Ring Research over the last 2 years is greatly appreciated.

Steven W. Leavitt
TREE-RING SOCIETY

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TRENDS IN QUERCUS MACROCARPA VESSEL AREAS AND THEIR IMPLICATIONS FOR TREE-RING PALEOFLOOD STUDIES

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ABSTRACT
Changes in mean earlywood vessel areas in mature Quercus macrocarpa were analyzed to determine possible sources of bias in paleoflood records derived from anatomical tree-ring signatures. Tree-ring cores were collected at intervals along the vertical axis of four Q. macrocarpa in a flood-prone stand near the Red River in Manitoba. The WinCELL PRO image analysis system was used to measure mean vessel areas in each annual ring. Most cores displayed a pronounced juvenile increase in mean vessel area before stabilizing between 40 and 60 years. The lowest samples from several trees contain rings with anomalously small mean vessel areas that are coincident with high-magnitude Red River floods in 1950 and 1997. The anatomical response of Q. macrocarpa appears to be conditional on the relative timing of earlywood development and flooding. Flood signatures are most strongly developed near the tree base and become less evident up the trunk. Most signatures disappear between one and three meters in height. Differences in flood response between trees are likely caused by internal differences rather than hydrological or topographic factors. Paleoflood studies based on samples obtained exclusively at breast height may miss some anatomical flood signatures and underestimate flood frequency relative to earlier intervals.

Keywords: Flood rings, Manitoba, paleoflood, Quercus macrocarpa, Red River, vessel area, WinCELL PRO.

INTRODUCTION
Under normal growing conditions, ring-porous trees develop single or multiple rows of large conductive vessels in the spring and form smaller vessels during the rest of the growing season (Panshin and de Zeeuw 1970). However, inundation of the roots and stem during the growing season can disrupt the physiological processes that control cambial growth, and lead to anomalous tissue development within the annual ring. Anatomical abnormalities caused by flooding may include irregularities in the size and distribution of earlywood and latewood vessels, narrow rings, and thin-walled fibers within the latewood (Yanosky 1983; St. George and Nielsen 2000; Yanosky and Jarrett 2002). In Quercus species, abnormalities associated with spring flooding most often take the form of anomalously small vessels in the earlywood (Astrade and Bégin 1997; St. George and Nielsen...
These anatomical signatures ('flood rings', after Yanosky 1983) may serve as excellent proxy indicators of past flood events and may be used to identify and date floods prior to instrumental and historical records, with annual resolution.

The objectives of this study were to use vessel area data obtained using an image analysis system to characterize anatomical flood signatures in mature *Quercus macrocarpa* Michx. (bur oak). The variability of mean vessel size is described within individual tree rings and over time. The study also compares a composite vessel series spanning the last 115 years to nearby discharge gauge station data to estimate the sensitivity of vessel area signatures to floods of known magnitude and duration. Lastly, we determine how anatomical signatures related to flooding vary along the tree stem and discuss possible implications for sampling strategies for paleoflood studies.

### STUDY AREA

Tree cores were collected from a stand of *Q. macrocarpa* growing near Fort Dufferin, Manitoba (49°01'50"N, 97°12'10"W; Figure 1). *Q. macrocarpa* is the only oak native to Manitoba and is often found at the prairie-forest boundary near local rivers and streams.

The stand is approximately 350 meters west of the western bank of the Red River, which flows northward into Manitoba from the United States and can produce extensive spring flooding. During its most recent severe flood in 1997, the Red River flooded nearly 2000 km² in Manitoba and caused substantial social and economic disruption (direct damages of CAN $500 million in Manitoba and US $4.5 billion in North Dakota and Minnesota; Manitoba Water Commission 1998; International Joint Commission 2000). A high water level marked in 1997 on a nearby tree (not sampled) indicated that the Red River flooded the Fort Dufferin stand to a depth of roughly 1.5 meters. In addition to the flood of 1997, other recent major floods occurred in 1996, 1979 and 1950 (Water Survey of Canada 2001). Fort Dufferin itself is a heritage site that includes several 19th century buildings constructed by the British North American Boundary Commission in 1872–1873. The buildings served subsequently as a North-West Mounted Police supply base and a Canadian immigration station prior to their abandonment in the early 1880s (P. Badertscher, personal communication 2001).

### METHODS

Increment borers were used to collect several single-radius cores along the vertical axes of four
oaks (sample designations F0001–F0004) between ground level and six meters up the stem. Samples above 1.5 meters were collected with the assistance of a mobile elevated work platform. Cores were air-dried, mounted and sanded following Stokes and Smiley (1968). A high-power air hose was used to remove sawdust and other foreign material trapped inside the earlywood vessels. Chalk was rubbed into the vessels to increase contrast with the surrounding wood fiber.

The surface of each core was scanned using a Polaroid digital microscope camera coupled with a Nikon dissecting microscope. Color pictures were captured and transferred as TIFF images with a resolution of 1,600 × 1,200 pixels. Working at a magnification of 30× usually captured rings in groups of three or four. Each ring was then separated into individual images. WinCELL PRO Version 5.6c (Régent Instruments 2001) was used to identify earlywood vessels and to measure their transverse areas in each annual ring. Previous studies have shown that this parameter in Q. macrocarpa and Fraxinus pennsylvanica Marsh. growing under normal (i.e. non-flood) conditions to be influenced by drought stress (Woodcock 1989; Shumway et al. 1991). The threshold for vessel detection was set to exclude objects with areas below 1,200 µm² to prevent non-vessel elements and latewood vessels from being detected. Some vessels needed to be highlighted manually to correct errors in the automatic detection process. Vessels whose boundaries were obscured by cracks in the cores were not measured. When cracking disrupted most of the vessels in an individual ring, the ring was omitted from further analysis.

Error analysis: During analysis of the first two cores (F0002a and 2b), every earlywood vessel was measured in each ring, with the number of vessels ranging between 9 and 70 per ring. Some rings, particularly those near the pith, had relatively few vessels. To determine the minimum number of vessels necessary to obtain a good estimate of mean vessel size within a given ring, we plotted the standard error of the mean as a function of number of vessels measured. For example, standard errors were calculated from the first pair of vessels measured in each ring. These values were then averaged over all rings to estimate the standard error of the mean obtained by measuring only two vessels. Subsequent vessel measurements were added in sequence to determine the improvement in the precision of the mean with increasing sample depth. As the number of measurements increased from 2 to 10 vessels per ring, the standard error of the mean improved from 23 percent (of the mean) to 13.5 percent (Figure 2). Doubling the number of measurements from 10 to 20 caused the standard error to drop to 11.4. Increasing the number of measurements per ring to 50 provided essentially no improvement. Based on these results, we limited the number of measurements made for subsequent samples to the first 20 earlywood vessels in each ring, starting from the top of the image. Any remaining earlywood vessels were manually eliminated. However, the results from the entire dataset (Figure 2) suggest that roughly 10 vessel measurements would provide similar quality information.

Data analysis: To emphasize interannual changes in mean vessel size and rings containing locally unusual vessels, we developed a filtered series that combined vessel areas from the bottom cores of all four trees. Vessel area series were converted to differences as:

\[
DIFF_i = \frac{\left( \bar{A}_i - \bar{A}_{i+1} \right) + \left( \bar{A}_i - \bar{A}_{i-1} \right)}{2}
\]

where DIFF, is the difference value (µm²) for ring i, \( \bar{A}_i \) is the mean vessel area for ring i, and \( \bar{A}_{i-1} \) and \( \bar{A}_{i+1} \) are the mean vessel areas for the preceding and following rings, respectively. This function is equivalent to a first-difference filter applied in both directions and reduces the magnitude of
spurious positive anomalies for rings that immediately precede those containing flood signatures.

RESULTS

Temporal Trends for Individual Cores

Most cores displayed a pronounced juvenile trend in mean vessel area, as vessels increased with distance away from the pith, stabilizing between 40 and 60 years (Figure 3). Phelps and Workman (1994) observed similar, but more rapid, juvenile increases in percentage earlywood vessel area within the innermost 10 rings of *Quercus alba*. Since 1950, vessel sizes have rarely shown any departures from the long-term average lasting more than two to three years. Vessel areas within each ring are quite variable, especially when compared to the total variance along each core.

Vessel Composite Record

The samples taken from the lowest portion of the stem contained rings with anomalously small mean vessel areas, most prominently for rings formed in 1950 and 1997. However, the relative strength of individual flood signatures does vary from tree-to-tree. For example, tree F0002 contains a basal flood signature for 1997 but not 1950, while the opposite is true for tree F0004.

The differenced vessel area series from the basal cores were converted to deviates and then averaged together to produce the composite series (Figure 4). Four years have negative vessel area deviates greater than one SD: 1901, 1950, 1972, and 1997. Years that show as large positive anomalies usually precede or follow strong negative departures (e.g., 1949, 1951, and 1998), and do not themselves contain abnormally large vessels. The two largest deviates, 1950 and 1997, coincide with high-magnitude Red River floods (Figure 4). The Red River did not flood significantly in 1979, which implies that smaller decreases in annual vessel size are caused by factors other than flooding. However, the 1979 flood, which had a peak discharge roughly equal to 1950, did not produce any reduction in mean vessel sizes. Flood hydrographs indicate that the Fort Dufferin stand was under water for 24 days in 1979 (from April 23 to May 16). These trees were flooded for a longer period in 1997 and 1950, with flooding occurring between April 21 and May 20 in 1997 (30 days) and between April 24 and June 2 in 1950 (40 days). Vessels formed in 1950 were smaller than those of 1997 despite the greater flow of the later flood, suggesting that the duration of flooding has a greater influence on earlywood vessel size than does peak flood stage.

Floods in 1979 and 1997 have very similar timing, with inundation caused by the 1997 flood lasting only six more days. Daily temperature data from Emerson indicate that the timing of floods relative to the beginning of spring growth may be a critical factor determining *Q. macrocarpa*’s anatomical response. Spring thaw occurred in early April during 1979, with minimum temperatures above freezing for nearly three weeks prior to the onset of flooding. In contrast, the Fort Dufferin stand was already under water for seventeen days in 1950 before minimum temperatures rose above 0°C Celsius¹. The spring warmth in 1979 may have stimulated early bud break in *Q. macrocarpa* and allowed earlywood vessels to form completely before trees were affected by flooding. The differences in anatomical development during these major floods suggest that the response of *Q. macrocarpa* to prolonged flooding is conditional on the relative timing of earlywood development and flooding. Severe floods that occur several weeks after the spring thaw will not likely create discernible anatomical signatures in riparian oaks.

Vertical Trends in Vessel Area

In general, trees did not exhibit substantial vertical changes in mean earlywood vessel areas from core-to-core along the sampled intervals. However, vessel areas for rings formed in 1950 and 1997 are unusually small near the tree base and generally become larger as they progress up the tree trunk (Figure 5). Above three meters, most signatures disappear and some that are strongly developed near the tree base are absent at breast height. The 1950 signature in tree F0001 is visible at 0.45 meters but vessel areas at 1.1 meters are close to average. Trees F0003 and

¹ Daily climate data is not available at Emerson during the period of the 1997 flood.
Figure 3. Mean vessel area series for *Q. macrocarpa* cores collected at Fort Dufferin, Manitoba. Elevations indicate coring height above the base of the tree, while the gray confidence limits represent twice the standard error of the mean. While tree age decreases with increasing height up the stem, the number of rings analyzed does not. This inconsistency is due to lower-height cores missing the pith or containing broken segments near the pith that are too short to determine ring dates with confidence.

F0004 were sampled in less detail near ground level but rings formed in 1950 contain similar overall patterns. At 3.5 meters, the 1950 vessel areas in tree F0003 are very close to normal; the 1949 ring actually has the smallest vessels at this height (Figure 3). Although some flood signatures persist several meters up the stem (particularly within the 1997 ring from tree F0003), the most detailed record of severe flooding is provided by cores extracted near the tree base.
Figure 4. Vessel area composite for the Fort Dufferin stand compared to the Red River discharge record at Emerson, Manitoba (data from the Water Survey of Canada). The bottom vessel area series (shown in Figure 3) were filtered to emphasis annual departures from the mean and combined. Dates are shown for years with values greater than ± one standard deviation.

DISCUSSION

These results indicate that true 'flood signature' rings contain anatomical features that are clearly different from those of adjacent rings. Although rings with mean vessel areas roughly two SD or more below the mean for the entire tree are coincident with major spring floods, deviations on the order of one SD appear to be related to alternate causes. Since vessel areas appear to be relatively insensitive to the influence of less severe spring floods, this approach is probably most useful for paleoflood studies that are interested only in high-magnitude, low-frequency events.

However, the mechanism causing the anatomical response of mature Quercus to spring flooding is not known, especially since flood tolerance experiments with this species have used seedlings exclusively (Tang and Kozlowski 1982). Aloni (1991) suggested that flooding disrupts normal vessel induction in trees, causing vessels formed below the water surface to be much smaller than normal. As flood signatures in the Fort Dufferin oaks are most strongly developed near the tree base, our results may indicate that the water surface acts as a physical barrier to auxin flow that impedes vessel differentiation in the submerged portion of the stem. However, other potential mechanisms that could also affect vessel development, such as prolonged root flooding, might alter the basipetal transport of auxin regardless of the total depth of inundation. It also seems likely that differences in inter-tree mean vessel size coincident with flooding are caused by internal differences rather than hydrological or topographic

Figure 5. Vertical trends in vessel size for rings coincident with Red River floods in 1950 and 1997. Error bars represent twice the standard error of the mean.
Quercus Vessel Area and Paleofloods

factors. Because the Fort Dufferin trees are located on a flat prairie surface with little local relief, it is unlikely that their duration or depth of inundation would vary during extreme floods.

Changes in anatomical response to flooding along the tree stem have the potential to introduce biases into paleoflood records that are derived from flood rings, depending on the number and origin of tree-ring samples. Samples derived from logs entrained in river alluvium are often cut just above the root ball to maximize the number of rings in the cross-section. Therefore, most alluvial logs should contain the most complete flood signature record available in their parent tree. The original vertical position of cross-sections obtained from historical buildings is usually less obvious, as any indications of location on the trunk are removed on hewn timbers. Although samples derived from the middle or upper portion of the tree may not contain some flood signatures that are present near the base, the original height of samples from historical buildings should be essentially random and should not bias any derived paleoflood record, given large numbers of samples. In contrast, samples collected from live trees are usually obtained at breast height (~1.5 m), which may cause some flood signatures present in the lower portion of the stem to be missed. If living trees dominate the composite tree-ring record for an extended interval (such as the 20th century), more recent flood signatures may appear less often than during earlier intervals. Although other factors, particularly the development of regional flood protection structures, can also reduce the impact of extreme floods on riparian trees, samples derived from live trees could be taken too high to obtain a complete, recent flood record.

CONCLUSION

Mean vessel area series derived from tree rings can provide a proxy record of high-magnitude floods that permits researchers to identify and date paleofloods with better temporal resolution than any other non-calendrical technique available. The duration and timing of inundation during large spring floods appears to be the critical factors controlling the formation of these signatures. However, vessel signatures produced by extreme floods appear to be highly variable within the same stand, which emphasizes the need to develop paleoflood records from multiple trees. Our results also demonstrate that the strength of vessel area signatures related to extreme flooding may vary considerably over relatively short distances along the tree stem. These changes, which can occur over less than one meter in height, have important implications for paleoflood studies based on anatomical tree-ring signatures and future attempts using anatomical signatures as proxy flood records should focus sampling at the base of flooded trees, if possible.

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RECONSTRUCTION OF SEVERE HAILSTORM OCCURRENCE WITH TREE RINGS: A CASE STUDY IN CENTRAL SWITZERLAND

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ABSTRACT

Dendrochronological methods were used to date hail injuries in tree rings of six mountain pines (Pinus mugo var. uncinata) at a site in central Switzerland. Annually dated injuries (1939–1996) were in 89% of the cases attributable to years with severe regional hailstorm occurrence (1957–1996). Days with severe hailstorms were successfully dated in either the earlywood and/or latewood portions of a tree ring in a given year. Tree rings provide an alternative proxy to existing data for reconstructing past severe hailstorm occurrence.

INTRODUCTION

Information on past hailstorm activity is of interest for climate research purposes, and considerable efforts have been undertaken to reconstruct spatial and temporal frequencies and intensities of such events. Generally, hailstorm frequencies and intensities are not directly measured at weather stations but are reconstructed from a wide range of indirectly recorded data. Historical hailstorm reports (e.g. Pfister 1998) give an account of individual severe hailstorms, but storms are reported locally and coincidentally and lack consistency. In the last ten years, hailstorm damage has been monitored increasingly by satellites (e.g. Klimowski et al. 1998) and weather radar (e.g. Schiesser 1990, 1997), which permit precise analyses of storm tracks and spatial variability of hailfall. Longer hailfall climatologies have been constructed from hail damage claim data provided by crop-insurers (e.g. Paul 1991; Dessens 1995; Smith et al. 1997; Changnon and Changnon 1997). These data permit analyses of trends in hailstorm occurrence over periods as long as 100 years (e.g. Schiesser et al. 1997). However, the use of hail damage claim data for reconstruction of past hailstorm activity has

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limitations, including spatial and temporal variations in crop susceptibility, changing cropping patterns and insurance participation.

The objective of this study is to investigate the possibility that annual growth rings of hail-damaged trees record signals that could be used to reconstruct regional histories of severe hailstorms. Tree-ring samples from hail-damaged mountain pines (Pinus mugo var. uncinata) are analyzed to develop a chronology of severe hail for a site in central Switzerland. Dendrochronologically dated injuries in hail-damaged wood could be used (1) to lengthen existing hail climatologies, (2) to establish time series of most severe hailstorms (tree injuries only result from large hailstones), (3) to reconstruct hail histories for specific sites where alternative data on hailfalls are missing, and (4) to achieve a finer spatial resolution of hailfall patterns and variability.

Severe hailstorms are known to cause important damage to forest stands with both short-term and long-term effects (e.g. Cremer 1984), but hail damage to tree rings has received minor attention in forestry literature. Most studies focused on the immediate impact of a severe hailstorm on a tree stand (e.g. Dobbs and McMinn 1973; Gillis et al. 1990), recovery chances of various tree species (e.g. Riley 1953; Pechmann 1958; Linzon 1962; Evans 1978), harvest strategies in hail-damaged stands and resulting economical consequences (e.g. Badoux 1917; Cremer 1984). Impacts of large hailstones on trees cause primary injury (stem lesions, broken branches or defoliation) resulting in severe cases in secondary injury (crown dieback, reduced height increment, cankers, staining, bruises, fungal infection, or stemrot). Hail-damaged trees show several main characteristics. (1) Lesions occur only on the windward side of stems and branches (e.g. Gillis et al. 1990) whereas leeward sides are mostly without any sign of injury (Linzon 1962). Upper branches and those on the windward side of the crowns tend to shield those below and on the sheltered side. Dobbs and McMinn (1973) revealed that hailstones of 25–38 mm in diameter induced most severe wounding to the bark and sapwood and Gillis et al. (1990) reported that hailstones up to 20 mm in diameter caused lacerations to stems and branches. Doll (1988) found that the severity of hail injuries depends largely on the thickness of the bark layer protecting the underlying cambium. (2) Hail lesions and bruising effects occur on a large number of trees of various species within a stand, a distinction that is shared only with other physiological impacts such as fire and frost damage (Riley 1953). Several observers (e.g. Frei 1961; Schwerdtfeger 1991; Gillis et al. 1990) suggested that broad-leaved tree species are generally less vulnerable to hailfall than coniferous species. Dobbs and McMinn (1973) showed that stem lesions resulting from hail are more common in older trees, whose stems and branches are relatively inflexible, than in younger trees. The etiology of hail injuries is similar to wounds induced by other mechanical agents (e.g. rockfall) and injuries from insects (e.g. pith flecks from cambial miners), but the cause of damage becomes clear if viewed on the scale of the forest stand. (3) In hail-damaged forest stands, an increase in damage severity occurs with increasing exposure to the hailstorm (e.g. in dominant trees on the windward edge of a stand). (4) Beside hailfall, severe thunderstorms produce strong wind gusts (downbursts) that uproot trees, break crowns and bend stems. These large-scale effects remain visible even years after the passage of a severe hailstorm.

The impact of large hailstones (diameters >20mm) produces injuries that show typical wood-anatomical morphologies of mechanical injuries described in Mullick (1977), Shigo (1984) and Larson (1994). Three types of hail injuries can be distinguished. First, hail may damage the outer bark only, causing no cambial damage and hence producing no tree-ring signal. Second, a hailstone may penetrate the outer bark and crush the cambium, resulting in a covered cavity oriented parallel to the tree ring, here called a corrasion. Third, the cambium as well as the underlying sapwood are penetrated by a hailstone and leave an open wound, here called a scar. Healing after injury varies with the tree species, the growth rate and stand factors, as well as the type and extent of the injury. Recovery from corrasion injury is rapid and normal wood cell growth resumes at the latest in the growth ring following the injury (Schweingruber 1988). On the other hand, scar healing and
Hailstorm Occurrence and Tree Rings

Figure 1. Overview of Switzerland with main geographical regions outlined, the location of the ETH Radar (cross) with a detection range of 100 km (circle) and the location of the study area in central Switzerland (box). The enlargement shows individual communities of central Switzerland with the sampling site on the southwest exposed slope of Mt. Rossberg (Mt. Ro, altitude of 1580 m a.s.l.) and the communities of Arth (ART) and Steinerberg (STB). Well known mountains and major cities are labeled: Mt. Rigi (Mt. Ri, altitude 1798 m a.s.l.), Lucerne (LU), and Zug (ZU).

wound closure can continue for years until the open wound is overgrown by wood and bark tissues from opposing flanks (Bangeter 1984). In the case of perennial cankers, caused by fungi, Linzon (1962) observed that hail wounds seldom heal over, but either extend their area of injury until the stem is girdled, or maintain a balance with annual callus growth. Pechmann (1949) and Riley (1953) analyzed hail-damaged wood and noticed a considerable reduction of tree ring growth in the year following severe hail injury. Following the healing process, hail injuries remain distinctive in the growth rings as corrasions or scars and can be dated with dendrochronological and wood-anatomical methods.

STUDY AREA AND METHODS

The sampling site lies at the northern border of the prealpine region of central Switzerland where severe hailstorms are frequently observed (e.g. Houze et al. 1993; Huntrieser et al. 1997; Schiesser et al. 1997), on the west flank of Mt. Rossberg in the community of Arth (Figure 1). On the upper part of Mt. Rossberg, vegetation can be described as Rhododendro hirsuti-Pinetum montanae (Keller et al. 1998) and is dominated by a scattered population of individual shrub-like mountain pines (Pinus mugo var. uncinata) that grow on a conglomeratic bedrock (Figure 2). The mountain pines on Mt. Rossberg appear to be ideal to establish a hail injury time series, because of (1) slow growing trees with thin bark layers, (2) comparable growth rates and age distribution of the trees over the slope, (3) isolated and unprotected stand conditions, and (4) trees are ideally exposed to the main track direction of hailstorms from southwest to northeast.

For the present study, six equally sized and exposed mountain pines were chosen over the slope...
at an altitude of 1,100 m a.s.l. From each tree, the stem and an equal number of similarly exposed branches were systematically cut into 20-mm thick cross-sections providing a mean number of 120 samples per tree. Mechanically polished, all samples containing at least one hail injury were visually inspected. The mean diameter, the bark thickness in the sector of the injury, the distance from the pith to the injury and the type of injury (scar or corrasion) were recorded. A few samples were prepared for microscopic studies, sectioning the wood samples with a microtome and staining with safranin (Schweingruber 1978). A hail-damaged growth ring was dendrochronologically dated to identify the year of injury, and the position of the injury within either the earlywood or the latewood formation of the tree ring was determined. Based on experience from comparable sites in Switzerland, the annual growth cycle of the present trees has been assumed to last from late-May to mid-September. The transition between the earlywood and latewood cell rows occurs around mid-July, since earlywood formation has already been completed and latewood growth was just about to start in the last tree ring of all trees when they were sampled on July 15, 1997.

As branches have thinner bark layers than stems and are potentially more vulnerable to hailfall, the sample is over-represented by injuries within growth rings of the last decade. To guarantee a comparable vulnerability of stem and branch samples over all decades and to obtain a longer time series, only injuries within 0.5–3.0 mm of the pith were further analyzed. However, numbers of annually dated injuries can still be biased to a certain degree as (1) branches might still record more hail damage due to their angle of inclination towards hailfall, (2) branches can shelter the stem from hailfall and/or reduce the impact of hailstones, and (3) the exposure of the tree to the main storm direction can change over time. These biases can be neglected as the study aims to identify years with...
severe hailstorms but does not seek to develop relationships for reconstructing annual hailstorm frequency from the number of dated hail injuries.

Information on hail damage to agriculture is available from the Swiss Hail Insurance Company since the 1950s on a daily (yes/no) basis for the majority of the Swiss communities north of the alpine crest. However, precise location of hail damage within a community as well as the damage extent is not directly available. The two communities that surround the sampling site are Arth and Steinerberg (Figure 1), where annual numbers of haildays have been recorded since 1957. Additional insurance data from further surrounding communities were available for validation purposes.

Willemse (1995) analyzed dimensions of hailstorm surfaces in relation to numbers and spatial distributions of daily claimed hail damages per community and found that the larger the hail-damaged agricultural surface, the more intense the storm and the larger the maximum hailstone diameters. Schiesser et al. (1997) grouped coherent daily hail damage claims into damage cluster surfaces that represent the area of communities where hail damage was reported. Severe hailstorms typically show a damage cluster of 25 km in length with concurrent damage claims from more than 30 neighboring communities. For the present study, hailstorms that occurred over central Switzerland and produced hail damage in Arth and/or Steinerberg are grouped according to associated damage cluster surfaces into: (1) strong storms with reported damage claims from >30 communities (large damage cluster surfaces), (2) medium-intensive storms with claims from 15–30 (medium damage cluster surfaces), and (3) weak storms with <15 hail damage claims (small damage cluster surfaces). Only storms displaying medium and large damage cluster surfaces, grouped as severe storms in the following, reveal the intensity and potential to damage tree rings and are retained for comparison with hail injuries. Weak storms (small damage cluster surfaces) are less likely to produce hailstones large enough to damage the living cell layer of a tree. Because insurance data alone provide no direct information on storm severity, the time series of annual haildays cannot be compared quantitatively to the hail injury time series; e.g. strong event years in both time series do not necessarily correspond, because all injuries of a given year could be initiated by one severe hailstorm. Classifying haildays according to storm severity (damage cluster surfaces) allows comparison of insurance data to the tree-injury data on a yes/no basis; i.e. years with severe (medium and large damage cluster surfaces) and non-severe (small damage cluster surfaces) hailstorms are related to years with dated hail injuries.

In order to monitor tracks of severe hailstorms in space and time, measurements from the ETH C-Band Doppler weather radar (Figure 1) were available since 1992. Radar data display reflectivity, which is a direct function of the sizes of precipitation particles in the illuminated thunderstorm. Large hail produces a strong characteristic radar echo. In the present study, radar measurements are used (1) to verify the passage of a severe hailstorm over the sampling area, (2) to locate the maximum hailfall intensity (function of the radar reflectivity) within the area determined the damage cluster surfaces, and (3) to estimate maximum hailstone diameters from upper-level Doppler velocities, based on the close relationship between updraft velocities and maximum sizes of hailstones (Witt and Nelson 1991).

RESULTS

Eliminating dendrochronologically non-datable injuries (within wedging and narrow growth rings or discolored sapwood), 273 injuries were retained for further analyses (Table 1). Hail injuries are typically located on the windward side of stems and upper part of branches, and several samples show numerous injuries in different growth rings (Figure 3). In cases where microcut samples of hail-damaged wood have been prepared (Figure 4), the morphological characteristics of the injuries become clearly visible and dendrochronological dating is facilitated. The sample displayed in Figure 4 contains three different injuries: one corrasion in the 1987 and two scars in the 1983 and 1992 growth rings. In 1992, scar injury occurred after earlywood formation (late-May to mid-July) during the second half of the latewood cell rows (mid-July to mid-September) leaving an open wound
Table 1. Overview of samples within the defined pith-injury radii range (0.5–3.0 mm) from 6 mountain pines (Pinus mugo var. uncinata) sampled at Mt. Rossberg, central Switzerland; total of 273 injuries (1939–1996).

<table>
<thead>
<tr>
<th>Tree</th>
<th>N</th>
<th>D_{min} [mm]</th>
<th>D_{max} [mm]</th>
<th>D_{BARKmin} [mm]</th>
<th>D_{BARKmax} [mm]</th>
<th>R_{INJURYmin} [mm]</th>
<th>R_{INJURYmax} [mm]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>50</td>
<td>4.0</td>
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<tr>
<td>3</td>
<td>44</td>
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<tr>
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<tr>
<td>6</td>
<td>44</td>
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<td>52.5</td>
<td>0.5</td>
<td>4.0</td>
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<td>3.0</td>
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</tbody>
</table>

N: number of examined hail injuries.

D_{min}/D_{max}: minimum/maximum diameter of the sample containing the hail injury.

D_{BARKmin}/D_{BARKmax}: minimum/maximum bark diameter in the sector of the injury.

R_{INJURYmin}/R_{INJURYmax}: minimum/maximum pith-injury radius.

from which only one edge is visible on the micro-cut. According to the position of the traumatized cell rows that formed immediately after injury, hailfall must have occurred during the second half of August 1992 before latewood formation was completed by mid-September. From the available hail damage claim data and radar measurements it appears that a severe hailstorm passed over the study area on 21 August 1992 and caused the injuries dated in the latewood of the 1992 growth ring.

Severity of hail damage to trees depends largely on the size of individual hailstones and the thickness of the bark layer that protects the cambium from mechanical injuries (Doll 1988). In two of the present storms that initiated severe hail damage to trees, analyses of Doppler radar measurements revealed the presence of hailstones with diameters of 30 mm for the storm on August 21, 1992, and 20 mm for June 2, 1994. These findings are in agreement with the observation of Dobbs and McMinn (1973) and Gillis et al. (1990). Beside the size of hailstones, the extent of hail damage to trees can increase with the duration of hailfall and the horizontal wind component that can accelerate the stones before impact.

The time series of annually dated hail injuries (1939–1996) exhibits a general increase of annual hail injuries over time, with a minimum during the 1970s and large fluctuations thereafter (Figure 5a). Strong event years occurred in 1983 (25 injuries), 1984 (26), 1992 (29), and to a lesser extent in 1994 (21). Mean annual numbers of haildays (1957–1996) in the communities of Arth and Stierenberg (Figure 5b) show a general increase over the period of investigation with a maximum of 3.5 haildays per year in the mid-1980s and 4.5 hail-
Figure 4. Microcut on the windward side of a mountain pine (Pinus mugo var. uncinata) branch, diameter 150 mm, Mt. Rossberg, central Switzerland, enlargement 40X. The microcut displays three injuries: one corrasion (1987 tree ring) and two scars of which only one wound edge is displayed (1983 and 1992); indicated is the earlywood (EW), latewood (LW), traumatized cell rows (TC) and locations of hail injuries (arrows).
injuries were dated both in the earlywood and latewood and were most likely initiated by the severe storms on June 10 and August 1 (June 24 or July 12 and July 25). However, when several severe storms occurred during the earlywood or latewood growth period, precise assignment of hailstorms is not possible (Table 2); e.g. in 1987, three storms with medium damage cluster surfaces occurred between May and July and initiated the hail injuries that were dated in the earlywood formation of the 1987 tree ring.

**DISCUSSION**

The severity of hail damage to tree rings depends on the hailstone diameter, the wind speed that accelerates the stones before the impact and the bark diameter that protects the cambium. If reports of hailstone diameters (e.g. by the public, meteorological observers, newspaper reports) are not available as in the present study, Doppler radar measurements can be used to determine the maximum size of hailstones. As shown in other studies
Table 2. Overview of 28 days with severe hailstorm occurrence (medium and large DCS) in Arth (ART) and Steinerberg (STB) and 230 dendrochronologically dated hail injuries in tree rings of mountain pines (*Pinus mugo* var. *uncinata*); Mt. Rossberg, central Switzerland (1957–1996); 44 days with weak hailstorm occurrence and 28 dated hail injuries are not shown in the table. Note that in years when several severe storms occurred, numbers and types of hail injuries are given in the table at first storm date.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>ART</th>
<th>STB</th>
<th>DCSₘ</th>
<th>DCSₘ</th>
<th>Nₑₑₑ</th>
<th>Nₑₑₑ</th>
<th>Nₑₑₑ</th>
<th>Nₑₑₑ</th>
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<th>ERROR</th>
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</tr>
</tbody>
</table>

ART/STB: hail damage recorded within the community of Arth (ART)/Steinerberg (STB).

DCS/DCSₘ: large/medium damage cluster surface (DCS) deduced from insurance data in central Switzerland.

Nₑₑₑ/Nₑₑₑₑ: number of dated corrasions/scars.

Nₑₑₑₑ/Nₑₑₑₑₑ: number of dated hail injuries within the earlywood/latewood.

TOTAL: total number of identified hail injuries per year.

ERROR: number of attribution-errors between positions of hail injuries and the date of haildays with severe storm occurrence; a constant transition between earlywood and latewood formation has been assumed for all cases in mid-July.
(Dobbs and McMinn 1973; Gillis et al. 1990), only hailstones of diameters >20 mm have the potential to damage a tree in the way that wounds remain visible in the growth rings. Fine-scale measurements of wind velocities (e.g. from weather stations or Doppler radar velocities) and wind directions were not available for the present study but would provide information on the impact velocities and angles of hailstones on the sampled trees.

The present hailstorm climatology is based on dendrochronologically dated hail injuries from branch and stem samples of a given pith-injury radius. A time series based on branch samples alone would identify years with severe hailstorms of the last decade, whereas stem samples would show severe events of past decades only. The longest and most coherent time series of hail injuries is obtained if branch and stem samples are combined, assuming that stems and branches within a certain pith-injury radius range are equally sensitive to hailfall. The proportionally high number of annual hail injuries during the last two decades (Figure 5a) could be the result of a large number of branch samples. It would be necessary to account for such bias if hail injury were used to reconstruct annual hailstorm frequency. The objective of this study, however, was to determine whether hail injuries could be used to identify years in which at least one severe hailstorm had occurred.

The hail injury time series reveals an overall increase in hail injury from 1957–1996, which is consistent with a general trend for the Swiss Mittelland identified in (1) Schiesser et al. (1997), where a general trend towards an increase of days with hail damage claims in more than one of the Swiss communities north of the alpine crest (1920–1993) was found and (2) Willemse (1995) who revealed that annual numbers of large coherent damage clusters (>25 km) north of the alpine crest (1949–1994) increased generally over the years. The studies of Willemse (1995) and Schiesser et al. (1997) show a relatively high hailstorm activity in the entire Swiss Mittelland during the 1970s, while both the hail injury and the damage claim time series from Arth and Steinerberg, reveal a decrease during that time (Figure 5c). This discrepancy in hailstorm activity shows not only that reduced hailstorm activity in the 1970s is a local phenomenon but also that hail injury time series can be used to identify local trends in hailstorm occurrence.

Overall, the study shows that 89% of the annually dated hail injuries (Figure 5a) occurred in years when severe hailstorms were identified from damage claim data (Figure 5b) and that actual dates of severe storms fall in 93% of the cases into the appropriate dendrochronologically reconstructed periods. Possible errors in annual correspondence between the data can be from various sources. First, as haildays are based on claims from crop-insurers, it is likely that hail damage to non-insured land such as forests are not recorded and are therefore missing in the statistics. Second, a hailstorm that produced hail damage to crops in the community of Arth and/or Steinerberg, did not necessarily move over the sampling area on Mt. Rossberg and damage the sampled trees. As crops are far more sensitive to hailfall than trees and hail damage claim data do not directly reveal hailfall intensity, damage cluster surfaces (i.e. coherent surfaces of daily hail damage reports over several communities) can be used to distinguish storms according to their severity. Third, some of the errors in dendrochronological dating are due to the occurrence of severe hailstorms around the transition between earlywood and latewood growth in mid-July (e.g. 8 July, 1970, or 9 July, 1969). Dating errors can be reduced if such samples are not considered due to the temporal uncertainty of the transition between earlywood and latewood. A detailed study of the growth cycle of mountain pines in the study area itself or on a comparable site would further improve the results. Fourth, the presence of hail injuries in parts of stems and/or branches that are within the 20-mm thick samples (and were not assessed), could provide additional information on severe hailstorm occurrence. Intra-annual dating could be improved by counting individual cell rows of the earlywood and/or latewood according to the growth cycle depending on the species and area.

Although the use of dendrochronological methods is restricted to wooded areas, and only impacts of severe hailstorms that produce hailstones large
enough (> 20-mm) to damage tree rings are re-
recorded, tree rings reveal an alternative proxy to
insurance data and historical chronicles for past
hailstorm occurrence. The study has shown that
tree rings can be used to identify years during
which severe hailstorms occurred. A further step
would be to link the number of hail injuries to the
number of haildays available from crop-hail insur-
ance data and to reconstruct frequencies of hail-
days for years where relevant insurance data are
not available.

CONCLUSIONS

The present case study has concentrated on the
reconstruction of past severe hailstorm activity
from hail-damaged shrub-like mountain pines (Pin-
us mugo var. uncinata) sampled at Mt. Rossberg,
central Switzerland. Based on 273 dendrochrono-
logically dated hail injuries in tree rings, a regional
time series (1939–1996) was established and com-
pared with annual days of severe hailstorm occur-
rence (1957–1996) on an annual and intra-annual
basis over central Switzerland, using damage
claim data from two relevant communities. The
study showed the following key results:

1. Tree rings are most vulnerable to impacts of
large hailstones, estimated in two severe storm
cases to be around 20 mm and 30 mm in diameter.
2. Time series of annual hail injuries, haildays of
two relevant communities, and haildays with se-
vere hailstorm occurrence over central Switzerland
all show a general increase of local hailstorm ac-
tivity (1957–1996) which is consistent with a gen-
3. Years in which hail injuries were dendrochrono-
logically dated corresponded to 89% of years
with severe hailstorm occurrence. (4) Intra-annual
correspondence between dendrochronologically
reconstructed periods of severe hailfall (position of
the hail injury either in the earlywood or latewood
formation of the growth ring) and dates of hail
damage claims associated with severe storms was
93%.

The results show that dendrochronological
methods open up new possibilities to reconstruct
past local severe hailstorm activity. Hail injury
time series are ideally established from hail-sen-
sitive, isolated and slow-growing trees that typi-
cally grow on bedrocks or xeric slopes that are
exposed to the main direction of hailstorm tracks.
If hail-damaged trees from several comparable
sites are analyzed, local hail injury time series can
be combined into a regional series, and could pro-
vide new data on past hailstorm occurrence in ar-
eas where hailstorms have not been monitored or
alternative data are not available. Additional data
on frequencies of past severe hailstorms will cer-
tainly contribute to a better understanding of pres-
ent fluctuations in hailstorm activity. The present
study is only a first step in what could be contin-
ued on a larger scale by further investigations in-
volving other tree species from a variety of sam-
ping sites.

ACKNOWLEDGMENTS

We are very grateful to the Swiss Hail Insurance
Company for the damage claim data and to the
Kreisforstamt Schwyz for the permission to sam-
ple the trees on Mt. Rossberg. A particular thanks
goes to Ch. Hoffmann for statistical advice and to
local forester S. Weber for his helpful support dur-
ing the sampling. We thank M. Rebetez, R. Hae-
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TREE-RING ANALYSIS OF *TAXUS BACCATA* FROM THE WESTERN HIMALAYA, INDIA, AND ITS DENDROCLIMATIC POTENTIAL

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ABSTRACT

A 345-year (AD 1656–2000) ring-width chronology of common yew (*Taxus baccata* L.) from the western Himalaya has been prepared. This provides the first record of a well crossdated ring-width chronology of yew from the Himalayan region, India. The mean temperature of the premonsoon (March–June) season has an indirect relationship with tree growth. The yew chronology is also significantly correlated with an *Abies pindrow* chronology prepared from the same stand as well as *A. spectabilis* from the treeline zone of an adjacent site. Such a significant relationship indicates the good potential of yew for dendroclimatic studies in the Himalayan region.

Keywords: *Taxus baccata*, growth rings, dendroclimatology, western Himalaya, India.

INTRODUCTION

Rapid industrialization and large-scale deforestation to meet insatiable human demand, have led to changes in the Earth’s natural climate system (Houghton *et al*. 2001). High-resolution, long-term climate data are needed to understand natural climate variability and the magnitude of human impact on it (Bradley *et al*. 1996). The need for such data increases many fold in critical locations like the Himalaya, the climate of which is known to interact with the climate systems in other regions such as Eurasia and the Pacific and Indian Ocean region via atmospheric and oceanic teleconnections (Vernekar *et al*. 1995; Douville and Royer 1996). However, for such a climatically important Himalayan region even observational climate records are very patchy, and barely cover the last century. Tree-ring studies recently conducted in this region have shown potential to supplement these limited observational data (Hughes 1992, 2001; Borgiaonkar *et al*. 1996; Yadav *et al*. 1997, 1999; Yadav and Singh 2002).

Yew trees growing in moist shady sites in the Himalayan region of India are usually undercanopy trees with fluted stems. They are found in coniferous forests all along the Himalaya, Khasi-Jan-tia Hills, Naga Hills and Manipur between 2,300–3,400 m a.s.l. The young plants require shelter and deep shade. In the western Himalaya, yew is usually associated with *Quercus semecarpifolia* and *Abies pindrow*, sometimes with *Picea smithiana*, *Cedrus deodara* and *Q. dilatata* (Gamble 1902; Raizada and Sahni 1960; Sahni 1990).

Dendrochronological studies on yew are very limited (Parasapajouh *et al*. 1986; Biondi 1992; Tabush and White 1996; Moir 1999). This could be because of difficulties realized in crossdating due to frequent wedging of growth rings. Moir (1999) reported good crossdating in yew and prepared a 303-year (AD 1690–1992) chronology based on 12 disc samples collected from Hampton Court Palace, England. He emphasized that the longevity of yew and the availability of prehistoric yew timbers provide such potential that yew could emerge as the third major dendrochronological species in Europe after oak and Scots pine. Though yew is a very important constituent of temperate forests in the Himalaya, the dendrochronological study of this species, with the exception of one abortive attempt in the eastern Himalaya (Chaudhary *et al*. 1999), has not yet been done so far. This study presents the first published, successfully crossdat-
ed, *Taxus baccata* chronology from the Himalayan region.

**MATERIALS AND METHODS**

**Tree-Ring Materials**

During the autumn of 2000 we collected 44 tree core samples from 21 mature yew trees growing in mesic upper temperate forests at 2,910 m a.s.l. in the western Himalaya (Figure 1). The trees sampled constituted the under canopy of an *Abies pindrow* and *Quercus semecarpifolia* forest. We selected trees with cylindrical boles for sampling to minimize the problem of missing rings largely due to the wedging of growth rings in trees with fluted stems. However, in the case of old trees, if the stem was fluted we cored through the lobed portion rather than the notches. For sampling we selected healthy trees without any visible sign of injury. Usually 2–3 cores were collected from each tree. The yew wood is very hard to core and there is risk of breaking the increment borer. In our present sampling the bit of one borer got broken inside the tree trunk. The increment cores were air dried and glued onto wooden mounts in the transverse position. The transverse surfaces of the cores were cut with a sharp razor and then polished using different grades of sandpaper until the cellular details became clear under a binocular microscope.

**Climatic Data**

Meteorological stations with long, homogeneous records in the Himalayan region are few and they are usually located far from tree-ring sites. The meteorological record from any such single station cannot be assumed to be representative of regional climate and may not provide ideal data...
Dendrochronology of Yew from Western Himalaya

for calibrating tree-ring data from distant sites. Averaging of two or more meteorological station records avoids many problems associated with record inhomogeneities and differing station microclimates so that they can provide potentially more reliable data to calibrate tree-ring chronologies (Blasing et al. 1981; D’Arrigo and Jacoby 1993; Jacoby et al. 2000).

For comparing modern tree growth with climate we prepared a regional temperature series by merging two homogeneous data sets from Shimla (31°10′N, 77°17′E; 2,205 m a.s.l.) and Mukteswar (29°28′N 79°39′E; 2,311 m a.s.l.) in the western Himalaya (Figure 1). It has been found that there is large-scale coherence in temperature records unlike precipitation records, which show great variation over short distances depending on the slope, aspect and direction of the hills (Shrestha et al. 2000). For this region, only temperature records provide the ideal database to study tree growth and climate relationships even for chronologies prepared from remote highland sites lacking any recorded data adjacent to the sampling site. Our mean temperature series from Mukteswar and Shimla (1897–2000) shows that January is the coldest month with an average of 5.7°C and June the warmest with an average of 19.2°C.

We could not prepare a mean precipitation series mainly due to high spatial variability in precipitation in the Himalayan region and also large data gaps in Shimla precipitation records. However, we tested the utility of Mukteswar precipitation records in the present study by computing correlations between mean temperature series and precipitation in different seasons. The seasonal temperatures in the Himalayan region are inversely related with precipitation of the respective seasons. To test the consistency in the relationship we calculated correlations between mean temperature of the regional series and total precipitation of Mukteswar for extended winter (previous November–current February), premonsoon (March–June) and monsoon (July–October) seasons. This showed the weakest relationship in monsoon months (r = −0.36, n = 101, AD 1898–1998) and strongest for the winter (r = −0.54, n = 101, AD 1898–1998). The high spatial variability in precipitation during the monsoon season could be one of the important reasons for such relationship. Again the correlations calculated in two split sub-periods (i.e., 1898–1948 and 1949–1998) for the above three seasons were stronger in the first half sub-period (winter, r = −0.64; spring, r = −0.55; monsoon, r = −0.53) as compared to second half (winter, r = −0.48; spring, r = −0.40; monsoon, r = −0.22). We presume that this could have resulted due to change in precipitation pattern in second half of the 20th century or some inconsistency in precipitation records. Due to such inconsistent relationships in mean temperature series of the two stations and precipitation of Mukteswar we did not use precipitation data in our study. However, mean precipitation series prepared by using a nearby data network could be useful in future dendroclimatic studies in the region.

Crossdating and Ring-Width Measurements

The skeleton plot method (Stokes and Smiley 1968) was used to crossdate the tree core samples. We noticed very good cross matching both within and between the tree samples. Missing rings were noticed in a few samples. We presume that these missing rings could result from the wedging of rings rather than harsh environmental conditions. However, false rings were found frequently in the early life of the trees. We could successfully crossdate 30 core samples from 18 trees. The ring widths of crossdated samples were measured to an accuracy of 0.01 mm. The ring width measurements were used to verify the crossdating using program COFECHA (Holmes 1983) as well as by plotting together to see pattern matching (Figure 2).

Chronology Preparation

The individual ring-width measurement series were standardized to remove long-term growth trends largely attributed to increasing age and tree size (Fritts 1976; Cook et al. 1990). In order to minimize the removal of any long-term variance in the process, we used negative exponential curves or straight lines fitted to each ring-width measurement series of each individual tree core. The indices for each series were derived by taking
the ratio of the measurement to the fitted value in each year. These indices were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike criterion and combined across all series in each year using biweight robust estimation of the mean to discount the influence of outliers. A set of three chronologies was developed: a standard chronology, a residual chronology, containing only the high-frequency variations, and an ARSTAN chronology, composed of the residual chronology with the pooled autoregression reincorporated (Cook 1985). The standard chronology (AD 1656–2000) is shown in Figure 3. The statistical qualities of the tree-ring chronologies show a gradual decay due to the diminishing replication of samples back in time. The acceptable chronology confidence (0.85), based on the sub-sample signal strength (SSS, a combination of mean interseries correlation and the number of tree-core samples represented in the chronology; Wigley et al. 1984), is achieved with a minimum sample replication of 14 trees (i.e. from AD 1848 onwards). The general chronology statistics are given in Table 1.

**Tree Growth and Climate Relationships**

We used response function analysis (Fritts 1976) to identify the influence of temperature on tree growth. The residual chronology and the mean monthly temperature beginning in September of the previous growth year and ending in September of the current growth year over the period 1898–1998 were used for this purpose (Figure 4). Tem-
Table 1. General statistics of *Taxus baccata* chronology.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronology span</td>
<td>345-years (AD 1656–2000)</td>
</tr>
<tr>
<td>Number of trees (cores)</td>
<td>18 (30)</td>
</tr>
<tr>
<td>Mean sensitivity</td>
<td>0.14</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.20</td>
</tr>
<tr>
<td>Autocorrelation Order I</td>
<td>0.64</td>
</tr>
<tr>
<td>Autocorrelation Order II</td>
<td>0.12</td>
</tr>
<tr>
<td>Common interval analysis period</td>
<td>(1848–2000)</td>
</tr>
<tr>
<td>Number of trees (cores)</td>
<td>17 (24)</td>
</tr>
<tr>
<td>Mean correlations:</td>
<td></td>
</tr>
<tr>
<td>Among all radii</td>
<td>0.32</td>
</tr>
<tr>
<td>Between trees</td>
<td>0.29</td>
</tr>
<tr>
<td>Within trees</td>
<td>0.63</td>
</tr>
<tr>
<td>Signal-to-noise ratio</td>
<td>7.04</td>
</tr>
<tr>
<td>EPS</td>
<td>0.88</td>
</tr>
<tr>
<td>Variance in first eigenvector</td>
<td>34.60%</td>
</tr>
</tbody>
</table>

Figure 4. Response function of the residual chronology with mean monthly temperature (1898–1998). The vertical bars are the 95% confidence limits.

RESULTS AND DISCUSSION

We achieved the first successful crossdating of ring-width sequences in yew from the western Himalayan region. COFECHA showed a mean correlation of all 30 radii from 18 trees with the master series of 0.60. Such a high correlation and good ring width pattern matching endorse the establishment of good crossdating and strongly suggest the presence of a dominant climatic signal in the tree-ring data.

The ring-width measurements have been used to develop a 345-year (AD 1656–2000) ring-width chronology, which is the first chronology of yew from the western Himalayan region, India. The general statistics of the chronology are given in Table 1. The low mean sensitivity (0.14) and standard deviation (0.20) of the yew chronology, showing little year-to-year variation, is comparable to the mean sensitivity and standard deviation of *Abies pindrow* (0.15, 0.17, respectively) growing in the same stand, and *Abies spectabilis* (mean sensitivity 0.13, standard deviation 0.21) from a treeline site 15 km to the north. The serial correlation coefficient in the yew chronology is very large (0.64), which indicates a strong persistence from one year to the next. The common interval statistics, such as signal-to-noise ratio (7.04) and total variance explained in the first eigenvector (34.60%), suggest suitability of the yew chronology for climatic studies (Table 1).

The response function analysis between ring widths and mean monthly temperature series shows that tree growth has a negative relationship with the temperature of premonsoon (March–June) season. The significant months (April–June) correspond with the onset of tree growth, bud break and the formation of earlywood. Warm spring months cause intense evapotranspiration, which drastically reduces the soil moisture budget thus limiting tree growth. The mean March–June temperature has shown significant correlation with the chronology \( r = -0.31, n = 101, \ AD 1898–1998 \). However, this correlation is slightly higher for the first half sub-period \( r = -0.40, n = 51, \ AD 1898–1948 \) in comparison to the second half \( r = -0.22, n = 50, \ AD 1949–1998 \). More site chronologies of yew are needed to test the validity of such relationships in the two sub-periods.

The yew chronology is significantly correlated with the *Abies pindrow* ring-width chronology prepared from the same stand \( r = 0.38, 1840–2000 \) and an *Abies spectabilis* chronology prepared from a treeline community \( r = 0.20, 1840–2000 \) in the same region. Such interspecies relationships perature data during months prior to the growing season were included in the response function study because growing season ring widths can integrate climate over a longer period (Fritts 1976).
indicate that the yew chronology could become an important constituent of the multispecies chronology network needed to reconstruct Himalayan climatic variation over the past few centuries.

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TREE-RING RESEARCH IN SEMI-ARID WEST AFRICA: NEED AND POTENTIAL

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ABSTRACT

High-resolution paleoclimatic data for West Africa are needed to provide context for contemporary climatic and ecological dynamics. Six hundred trees (22 botanical families, 43 genera and over 70 species) from semi-arid West Africa were evaluated for their suitability for dendrochronological research; specifically ring development. The samples were classified as 'potentially useful', 'problematic', or 'poor' based on the presence and distinctiveness of annual rings, ability to achieve crossdating between radii using skeleton plots on at least some samples, circuit uniformity, ring wedging, and variability of ring widths. Samples were classified as potentially useful if (a) they exhibited distinctive annual rings that could be identified and counted with little uncertainty and be independently verified by a second person with little or no error, (b) crossdating between radii could be successfully achieved, at least on some samples, (c) the rings were generally consistent throughout the stem cross section, (d) ring wedging was minimal (in the relative sense) or absent, and (e) the ring widths were variable, indicating the possibility of climatic sensitivity. Seven species, including five from the Caesalpiniaaceae family (Cassia sieberiana, Cordyla pinnata, Daniella oliveri, Isoberlinia doka, Tamarindus indica), and one each from Mimosaceae (Acacia seyal) and Verbenaceae (Gmelina arborea) families, that most closely satisfied these criteria were classified as 'potentially useful'. The 'problematic' category includes those samples that satisfied some of the criteria but for which greater diligence is required to detect rings. Eight species from three families were classified in this category. Finally those samples on which ring detection appears futile given current methods and techniques were classified as 'poor'. Most of the samples classified as 'potentially useful' belong to three botanical families, Caesalpiniaaceae, Mimosaceae, and Verbenaceae. These results are consistent with the findings of other studies, and therefore support further investigation of the potential of West African trees for tree-ring analysis focusing on these families. Furthermore, inability to crossdate between trees and to explain several ring anatomical features underscores the pressing need for comprehensive field studies of cambial activity during the growing season, and for the identification of dormant seasons. This requirement, and other difficulties discussed suggest a need for increasing the local dendrochronological expertise in West Africa.

Keywords: Soudano-Sahel savanna, tree-rings, Africa west, climatic variability, drought.

INTRODUCTION

The Soudano-Sahel savanna region of West Africa is experiencing significant climatic and ecological change (Charney 1975; Hulme 1992; Eltahir and Gong 1996; Nicholson 2000). These changes manifest most vividly in pronounced and persistent decrease in annual rainfall and stream-
Figure 1. (a) Pronounced rainfall decline in West Africa, updated from the index of rainfall variability developed by Lamb (1985). The index is obtained by (i) expressing each station rainfall as a standardized departure (i.e. departure from the mean over the entire period of record, divided by the standard deviation); and (ii) calculating the regional average from the standardized station departures for all the stations used, in this case 41. (b) Discharge of River Niger at Koulikoro (Mali).

The uncertainty concerning the causes and significance of on-going changes derives at least in part from the short length of scientifically measured hydro-climatic data against which to evaluate the changes. Indeed, only for limited areas of West Africa does one find systematically measured and written records for key climatic variables, such as rainfall and temperature, that date to the first decade of the 20th Century. Only during the 1930's did synoptic stations become generally established throughout the region. The available hydroclimatic series are therefore too short to establish whether the persistence and magnitude of the present drought are unprecedented in the recent climatic history (i.e. the last several centuries) of the region. Knowledge concerning the magnitude of contemporary climatic variability relative to previous events is important for the planning and management of several activities in the region, including water resources, agriculture and ecological systems. For example, if it were demonstrated that persistent, multi-decadal droughts are part of a low frequency pattern that is integral to the climate, then the design and planning for long-lived projects such as water supply systems would need to incorporate the risk for such events during the useful life span of the project. On the other hand, establishing that the events are unprecedented could also be useful for seeking the most likely causes and explanations for the changes, as well as for developing new planning criteria that accommodate the new climatic regime. These observations point to a need for extending the available hydro-climatic time series back in time, using proxy sources.

Unfortunately, the Soudan savanna has few sources of proxy climatic information. Qualitative historical information on landscape, river discharge, droughts and famine exist in various forms including travelers’ accounts and diaries, folklore, oral history, colonial records and palace chronicles from the great empires and kingdoms (Nicholson 1978, 1979, 1996; Apeldoorn 1981; Tarhule and Woo 1997). However the authenticity—and therefore scientific utility—of this information has yet to be established. Nicholson (1996) succinctly elaborates the major limitations inherent with the archival sources, including the lack of scientific rigor, the fallibility of memory and oral tradition, the fact that the information is frequently second, or third hand, observer bias and the tendency to generalize a single observation at a point over large areas. Tarhule and Woo (1997) attempted to quantify the magnitude of rainfall deficits during historical famines and droughts by implementing a simple optimization procedure for the period when both sets of data were available (1895–1954). The authors calculated the magnitude of cumulative rainfall deficit corresponding to various
folklore droughts during the instrumented period, but provided no objective means for validating the estimates for events predating the beginning of measured data.

To date, paleolimnological investigations of the Kajemarum oasis in the Manga Grassland of northeastern Nigeria have furnished much of the information on Holocene climate for the Sahel. Street-Perrot et al. (2000) found evidence of multi-decadal to centennial-scale droughts in the 5500-year paleolimnological sequence of dust deposition in the oasis, prompting them to declare that the post-1968 Sahel drought is not unique. Jonathan et al. (1998) provided insight into variations in salinity and solute composition in the oasis, both of which reflect hydroclimatic changes in the vicinity of the lake. Salzmann (1996) and Waller and Salzmann (1999) determined that the modern Sahelian vegetation of the region became established around c. 3300 yr BP as a result of the onset of drier conditions.

Because trees are more widely distributed than lakes, tree-ring analysis could, in principle, provide historical information that is more representative for the Sahel, and reveal spatial patterns that are not otherwise detectable in limnological sequences. However, despite encouraging reports from various parts of the tropics (Mariaux 1981; Worbes 1989; Jacoby and D’Arrigo 1990; Bhattacharyya et al. 1992; Buckley et al. 1995; D’Arrigo et al. 1997) the potential for dendrochronology in the Soudano-Sahel region has not been systematically investigated. To a certain extent, this is surprising because several researchers (Hummel 1946; Lowe 1961; Mariaux 1981; DeTienne 1989; Jacoby 1989) provided evidence that annual rings formed in several tropical species in various parts of Africa. Regrettably, several factors, including difficulty in identifying and interpreting growth bands and the lack of precedents demonstrating successful crossdating, contributed to stifle further investigations of these promising results. Additionally, political instability in many of Africa’s countries as well as economic and logistical difficulties all contributed to impede dendrochronological research in Tropical Africa. The situation is further exacerbated by the fact that most practitioners of dendrochronology are from the mid-latitudes and have limited time and resources for devoting effort to evaluating tropical trees for dendrochronological research.

Nevertheless, spurred by rapid environmental change and the successful development of precisely dated chronologies in South America and South Asia, more concerted effort was brought to bear in an attempt to establish the potential of African trees for tree-ring analysis during the 1990s. Stahle et al. (1995) developed tree-ring chronologies based on Vitex keniensis and Premna maxima grown in plantations in Southeastern Mt. Kenya. Stahle et al. (1997) also developed a 200-year dated chronology for Pterocarpus angolensis at Hwange National Park, Zimbabwe. Maingi (1998) evaluated 19 species sampled from the Tana riverine forest of Kenya. He identified four species (Acacia elatoir, Acacia robusta, Tamarindus indica and Newtonia hildebrandtii) as being potentially useful for dendrochronology. In Ethiopia, research is focusing on Juniperus procera and Ekebergia capensis (Conway 1998). In South Africa, February and Stock (1998a, 1998b, 1999) demonstrated the relationship between δ13C values of wood cellulose as well as the relationship between ring-width measures and precipitation in Widdringtonia cedarbergensis and Podocarpus sp.

Here we present results from a systematic evaluation of dendrochronological potential of tree species in the Soudano-Sahelian region of West Africa. In the short term, it contributes to the growing literature and species lists of potentially useful trees for developing dated chronologies and improves understanding of the microenvironmental characteristics that favor ring formation in tropical savanna species. In the long term, it is an essential first step towards the goal of reconstructing hydroclimatic time series for West Africa.

**STUDY AREA AND METHODS**

Samples were collected between latitude 9°45’–14°30’N and longitude 7°59’W–11°33’E, which lies within the Soudan and Sahel savanna bioclimatic regions (Figure 2). Annual rainfall is markedly seasonal, controlled by the relative intensities of the opposing high pressure systems centered over the Azores in the Northern Hemisphere and
St. Helena in the Southern Hemisphere (Anyadike 1993). There are only two seasons, a dry season when no rain falls, and a rainy season with unimodal distribution (Figure 2). The duration of the dry season increases from five months (November–March) in the south (e.g., Bobo Dioulasso) to nine months in the North (September–July, e.g., Agadez). The total annual rainfall diminishes from 1100 mm in the south, which is the lower limit of rainfall in the Guinea Savanna, to about 250 mm in the north. The transition zone from the Soudan to Sahel savanna occurs at about the 600 mm/year rainfall isohyet (Breman and Kessler 1995). Temperature is high year-round, averaging from 27°C to 29°C in the southern and northern parts of the study area, respectively. As a result, pronounced water scarcity during the dry season, rather than low temperature, is the major constraint on cambial activity. Vegetation consists of grasses and an over story of deciduous trees typified by *Isorbelina* sp. and *Combretum* sp. in the Soudan, and scrub, brush and various species of *Acacia* in the Sahel.

Fieldwork was conducted over two seasons (1999 and 2000), and consisted of driving along two transects between Nigeria and Mali. We originally set out to collect samples from the Sahel savanna region. However, trees are extremely scarce north of about latitude 15°N. Indeed, around Mopti (Figure 2) and much of the Dogon country in Mali, there are no trees at this latitude. Elsewhere, isolated stands of mixed thorny species remain but the possibility of obtaining sufficient samples at one site to attempt a chronology is poor. A second problem was the relatively small diversity of species within the Sahel. Anthropogenic influences play a role in both the absolute scarcity of trees and the poor diversity of species, but the
Sahel is by definition a treeless ecological zone. Due to scanty rainfall, the “groundwater table usually lies below the reach of tree roots . . . [and] . . . the soil is not wetted deep enough for roots of woody plants to successfully compete with annual species” (Breman and Kessler 1995, p. 29). Moreover, decreasing annual rainfall during recent years has led to a high mortality of trees, as rainwater no longer infiltrates sufficiently deeply. This phenomenon is easily observed around Dori (Burkina Faso), where the landscape is virtually a wood graveyard. As a result, attention was focused on the relatively humid Soudan and Guinea savanna zones.

To sample the trees, we employed the strategies suggested by Stahle (1999) to search for tree species with discernible growth bands. Specifically, we sought species belonging to botanical families that have proved promising elsewhere in the tropics, including those identified by Détienne (1989), Jacoby (1989), Stahle et al. (1995, 1997), Maingi (1998), and Stahle (1999). However, because part of our goal was to produce a comprehensive list of species that exhibit discernible annual rings, a large number of other representative or highly visible species were also collected. Trees were sampled from both stressful and complacent sites such as floodplains, to determine the role of micro-environmental variables. During the first year (1999), 419 samples comprising twenty-one (21) families and about 70 species weighing approximately one half ton were collected (Table 1). Samples were collected with the assistance of local foresters, who knew the locations of the trees. In any event, prior written permission from the forestry services or overseeing agency was critical because the scarcity of trees increases their relative value. Additionally, the countries of the region are fighting a losing battle against illegal tree harvesting for sale as fuel wood in the urban centers. As a result, armed guards patrol important forests and problem areas.

Figure 3 shows the distribution of major sampling sites. To minimize uncertainty associated with ring identification, complete stem discs, rather than cores were collected from stumps, and fallen or dead trees. This criterion imposed an unavoidable limitation on sampling procedure in the sense that samples could not always be obtained at the most desirable locations. Consequently, a few cores were also taken from live trees, using 5-mm borers. The samples were air freighted to the Laboratory of Tree-Ring Research at the University of Arizona, Tucson. Sample preparation involved polishing the surfaces with progressively finer sanding paper grit (up to 400 or 600) to expose micro-anatomical features.

Some of the problems more frequently encountered in using tropical trees as chronometers were used as the criteria for classifying the samples into three categories, namely; potentially useful, problematic and poor. The criteria used include distinctiveness of ring boundaries, ability to achieve crossdating between radii using skeleton plots on at least some samples, circuit uniformity, ring wedging, and variability of ring widths. For example, a sample was classified as ‘potentially useful’ if (a) rings could be identified with little uncertainty, ring counts could be independently verified by a second person with little or no error (distinctive ring boundary); and crossdating between radii could be successfully achieved at least on some samples, (b) the rings are generally consistent throughout the stem cross section (circuit uniformity), (c) ring wedging is minimal (in the relative sense) or absent, and (d) the ring widths are variable, indicating possible climatic sensitivity. The ‘problematic’ category includes those samples for which some combination of the desirable characteristics is observed, but these require greater diligence to detect and involve a higher probability for error. Finally, those samples on which ring detection appears futile given current methods and techniques were classified as poor.

Based on these criteria, 7 species (3 families) were classified as ‘potentially useful’, and 10 species (3 families) as ‘problematic’. However, limited sample size constrained further exploration of the potential of these samples. A second field survey was therefore conducted from October to November of 2000 during which the species identified as potentially useful were sought from diverse micro-environmental conditions throughout the study area. On this occasion, there was little alternative to coring because stumps and dead material of the desired species were not always available.
Table 1. List of samples collected, classified according to their potential for dendrochronology. Species included under the heading "unknown" are those for which botanical names could not be verified. The local language from which the names given are derived are italicized in parentheses.

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Local Name (language)

Karya gateri 1
Gidido (Fulani); Gukaka (Hausa) 1
Posoparia birrea 3
Bolenix regia 4
Wogoro wagara iri (Dioulla) 4
Kokebe (Songhai) 3
Sisn (Songhai) 1
Gole (Bambara) 5
Bulanga (Zarma) 1
Dulubakwobai (Zarma) or Farikaihanga (Hausa) 1

Killing live trees was, of course, out of the question. Between two to four cores were taken from each sampled tree. Again, sample preparation and analysis, including ring identification and cross-dating between radii on skeleton plots, were conducted at the Laboratory of Tree Ring Research at the University of Arizona, Tucson. Finally, thin sections were produced for some species to examine the anatomical features of the rings—particularly at the ring boundary—at the cellular scale.

RESULTS AND DISCUSSION

Table 1 presents the species collected, classified according to the criteria described above. The table shows that the 7 species classified as potentially useful belong to 3 families; 5 are from the Caesalpiniaceae family, and one each from the Mimosaceae and Verbenaceae families. Other studies in the tropics (e.g. Maingi 1998; Maria et al. 2002), have also noted the dendrochronological potential of Caesalpiniaceae trees. Following the suggestion by Stahle (1999), further work may do well to focus on this family without de-emphasiz-
ing the search for additional species that may prove to be useful. *Gmelina* sp., in the Verbenaceae family, is exotic to West Africa and was not evaluated further. It is planted primarily in plantations because of its fast growth. The following section describes the specific anatomical characteristics of the rings from these samples. The reader is invited to read an appropriate text for phenological and physiological information related to these samples (e.g. Adams 1967; Booth and Wilkinson 1988; Hall and McAllan 1993; Rosa 1993; Breman and Kessler 1995; Arbonnier 2001).

**Daniella oliveri (Caesalpinaceae)**

The habitat of this species is the Sudanic and Guinea Savanna on all types of soils but it grows only in the open. It often occurs in clusters, irregularly distributed from Senegal to Cameroon, and parts of Congo and Angola. Most samples of *Daniella oliveri* were collected from the floodplain of the Nazinon River (a tributary of the White Volta), in Burkina Faso. Drift wood and other debris as well as river stage records indicated that the site is periodically inundated, perhaps by as much as 1 m of flood water. *Daniella oliveri* is a big tree; several trees at the site exceeded 50 m in height, measuring 200–300 cm around the trunk. The wood is diffuse porous with a moderate density of nearly circular vessels, that are distinguishable by size into small and large vessels (Figure 4a). However, both types occur evenly throughout the ring. Growth bands are very distinctive at the microscopic level and are indicated by thick marginal parenchyma bands. Figure 4b reveals that the parenchyma bands are about 5 to 6 cells wide, but the limited number of sections produced precluded further exploration of the feasibility of improving ring identification based on cell characteristics. Parenchyma cells are also associated with large vessels, so that they are more properly described as aliform paratracheal parenchyma. Ring-width variability is good, and we achieved independently verified ring counts and crossdating between radii on several samples containing between 56 to 93 rings. However, we have not been able to crossdate between trees.

There are two major problems with this species. First, growth bands become incoherent, we suspect, during stressful years such as drought periods when growth is suppressed. The rings become extremely narrow and merge or split in no discernible pattern. These rings are a challenge to trace around the circuit even on whole stem discs; the possibility of resolving them on cores is extremely limited. In nearly all the samples we examined (>...
Dendrochronology Prospects in West Africa

Figure 4. Daniella oliveri (a) micro view (b) thin section of parenchyma cells at ring boundary. The boxed area (Figure 4a) shows the approximate location (not to scale) of the view in Figure 4b. The scale with 3 subdivisions (appearing here and in Figs. 5–12 represents 3 mm.

Figure 5. Isoberlinia doka (a) micro view (b) thin section of parenchyma cells at ring boundary. The boxed area (Figure 5a) shows the approximate location (not to scale) of the view in Figure 5b.

60), this anastomosis occurs towards the perimeter of the stems, suggesting that it could be related to senescent growth. Note, however, that drought has persisted in West Africa since the mid 1960s, hence the ring behavior may in fact reflect sensitivity to diminished rainfall conditions. In any case, it appears that a mixture of trees of various ages may facilitate crossdating assuming that younger trees, with more vigorous growth are less susceptible to ring anastomosis.

Second, partial rings are common, more so than in any of the other species classified as 'potentially useful'. These are rings that appear on some radii, but not on others. Yet, where they occur, partial rings may be quite wide and distinctive, further emphasizing the need for whole stem samples. Field observations and isotopic analysis may provide insight about the cause(s) and significance of these partial rings. A variation of the partial ring problem is that some distinctive rings terminate quite abruptly, without fading out gradually or merging into neighboring rings; they simply terminate for no apparent reason.

These problems complicate efforts to crossdate on this species, although correlations between annual rainfall and ring width (r = 0.42, n = 62, p < 0.001) and δ13C (r = −0.64, n = 18, p < 0.001) suggest that the rings are probably annual. Ultimately, however, there is little alternative to detailed fieldwork designed to provide information on cambial activity during the growing season.

In addition to problems described above, durability and wood preservation is a concern for the long-term potential of Isoberlinia doka for den-
Figure 6. *Tamarindus indica.*

dendrochronology. The timber is susceptible to termite, marine borer, and pinhole borer attack. Even if a chronology is successfully developed from this species, obtaining old specimens to extend the length of the chronology could prove to be problematic.

*Tamarindus indica* (Caesalpiniaceae)

*Tamarindus* is a slow growing but long-lived tree that commonly remains productive for 150 years or longer (Rosa 1993). Under favorable conditions, it may attain a height of 24–30 m. The tree is native to Africa and thrives in both semi-arid and humid climates. It also tolerates a great diversity of soil types, from deep alluvial soils to rocky land and porous, oolithic limestone.

The wood is light brown to yellowish, extremely dense and hard, making it very difficult to core. *Tamarindus* was responsible for 4 of 10 cores broken during the field survey of 2000. The heartwood is occasionally stained black. Paradoxically, this made ring identification easier in some cases, but more difficult in others, depending on the specific combination of wood and heartwood color. Marginal parenchyma cells delineate growth bands. Vessels are diffuse porous, but occasionally appear to be less dense close to the parenchyma bands (Figure 6). Vessel density is moderate and vessels do not appear to change in size or frequency across the ring. Unlike the samples examined by Maingi (1998), our samples exhibited consistent rings that permitted crossdating between radii. However, we recommend using whole stem discs wherever possible because the absence of indicator rings makes crossdating between radii difficult. Rings are quite variable in width, indicating possible climatic sensitivity.

On occasion, the wood also contains a rotten core, an unpleasant trap for the incautious corer. If one must core, it is important to select samples with care; twisted or seriously scarred trunks, especially with the bark missing, may spell trouble.

*Cassia sieberiana* (Caesalpiniaceae)

The habitat for this species is the Soudan and Northern Guinea savanna zones. It occurs in clusters on all soil types from Senegal to the Republic of Sudan and parts of the Democratic Republic of Congo. In the field, we found samples mainly adjacent to the beds of dry washes and only rarely on the interfluves. The wood is white, very dense and extremely difficult to core. It accounted for as many broken borers (4) as *Tamarindus indica* during the fieldwork of 2000. The rings are distinctive, visible to the naked eye and generally concentric (Figure 7). Vessel density is moderate. Ring width variability is good. However, due to great density, thin sections are difficult to obtain, even after soaking in water and glycerine for several days.

*Cordyla pinnata* (Caesalpiniaceae)

*Cordyla pinnata* occurs on rocky or stony outcrops in parts of Mali and Burkina Faso. It is irregularly distributed within its habitat (Soudan sa-
vanna), but is reported to be locally fairly common (Arbonnier 2001). However, only five samples were collected in 2000. The wood is dense, heavy and very rarely attacked by termites. As a result, C. pinnata is popular with local furniture makers, who have harvested it into rarity. From the perspective of dendrochronological research, both its durability and widespread use in furniture works will be beneficial if a chronology could be developed. However, polishing with fine paper is required to improve ring visibility (Figure 8). Even so, the rings are sometimes obscured by the elongated vessels or ‘lost’ in the copper brown to dusty white color of the wood fabric. On the samples we examined, however, ring wedging was minimal.

The forestry service in Mali, where it is most common presently protect surviving trees with jealousy and refused to permit destructive sampling.

**Acacia seyal (Mimosaceae)**

This is a small tree that matures to only 9–10 m in height. Its range extends from Senegal to Western Somalia and from Egypt to Southern Zambia. Acacia seyal exhibits distinctive growth bands marked by marginal parenchyma cells (Figure 9). Ring width variability is less pronounced relative to the other samples classified as ‘potentially useful’. Vessels are prolate in shape with low density. Prominent large rays and co-joined vessels give the wood a whitish appearance that obliterates ring boundaries. This is the most serious constraint to using this species. Ring appearance was not improved by staining with various dyes. Even so, verifiable ring counts were successfully achieved on several samples.

Durability and preservation are of concern.
Over 40 species of insects are reported associated with *A. seyal*, including *Sinoxylon senegalense*, a bostrychid that infests freshly cut wood. As a result, even if successful crossdating is achieved, finding old samples to extend chronologies beyond the life span of living trees could prove a serious problem.

### 'PROBLEMATIC' SPECIES DESERVING MENTION

The following species were classified as 'problematic' but it is possible that under suitable conditions, they could exhibit sufficient desirable characteristics to qualify as 'potentially useful'.

*Khaya senegalensis* (Meliaceae)

Also known as African mahogany, *Khaya senegalensis* matures to a height of about 30 m and up to one meter in diameter. The sapwood is pinkish tan and the heartwood is dark brown. Samples obtained from Nigeria showed no discernible rings, but those from Burkina Faso had distinctive rings that are clearly visible to the naked eye (Figure 10). However, ring boundaries frequently display eccentricity, fade out and or merge with other rings. Despite much work, ring count was prone to considerable error but the promise is sufficiently tantalizing to merit investigations at other sites, perhaps closer to the limit of its range.
**Detarium macrocarpum** *(Caesalpiniaceae)*

This is a relatively small tree; matured members reach only about 12 m tall, with trunk diameter of between 24 and 30 cm. The wood is pink or copper brown. Ring boundaries are delineated by marginal parenchyma of 2–3 cells wide. The most distinctive characteristic of this species is the prevalence of resin ducts that occur either in conjunction with axial parenchyma or apart from it (Figure 11). The resin ducts are the main impediments to ring identification because they obscure the parenchyma cells where the two occur together, but are themselves neither exclusive nor sufficiently consistent to mark ring boundaries. Removing the resin could significantly improve the potential of this species.

**Boscia senegalensis** *(Mimosaceae)*

Only one sample was collected at one site in Niger. Rings are distinctive and visible to the naked eye (Figure 12). Vessel density is moderate and the growth following ring boundaries appears to be free of vessels. Because of the limited sample size, the full potential of this species could not be evaluated.

**CONCLUSIONS**

Reconstructing paleoclimatic events that predate instrumental records is possible only by utilizing proxy sources, such as tree rings. This study attempted a systematic evaluation of the suitability of tree species for dendrochronological research in
the Guinea, Soudan, and Sahelian ecological regions of West Africa. The major findings that emerged could be summarized as follows.

1. There is a general scarcity of suitable sampling sites within the Sahel region. This arises from the sparse distribution of trees and relatively small diversity of species composition. As a result, the time, effort and cost required for carrying out a systematic search for ring-forming species proved prohibitive. It is critical that some local dendrochronological expertise be developed, or at the very least, affiliations with local forestry agencies, universities and research institutions should be encouraged. These local agencies are the best placed to collect samples from remote or inaccessible locations. The need for such local expertise is further highlighted by the huge freight cost involved in sending samples to Europe or North America for analysis. With some basic facilities, preliminary analysis could eliminate obviously poor or useless samples, reducing shipping weight and cost.

2. The relatively humid Soudan and Guinea savanna zones provide greater choice of sampling sites and species. Three families, Caesalpiniaeae, Mimosaceae, and Verbenaceae, contained all the species that satisfied basic requirements for dendrochronology. Following the strategies recommended by Stahle (1999), further work might do well to focus on these families although it is important to continue the search for as yet unidentified families and species.

3. The study identified 6 endemic species that appear to have the best potential for tree-ring analysis. A further 8 species are identified as deserving more study. The dendrochronological potential of some of these 14 species (e.g. Tamarindus indica), has been previously investigated elsewhere in the tropics (e.g. Maingi 1998). However, the study identified several new species whose potential had neither been investigated nor reported.

4. All the species classified as potentially useful are ring porous, which might reflect genetic traits of the families to which they belong. Furthermore, the presence of a marginal parenchyma band is the most diagnostic and reliable feature of ring boundary. In the samples we examined, no other anatomical feature at the cell or macro view provided the same consistency and distinctiveness in growth zonation.

5. The ability to crossdate radii drawn on a complete stem disc is not a guarantee that cores collected from various radii could be crossdated. This observation echoes previous emphasis on whole stem samples, rather than cores.

We agree with Stahle (1999, p. 250) that “even with annual banding, we are still quite far from the development of centuries-long chronologies that provide sensitive records of the paleoclimate”. However, identifying the trees that form distinctive growth bands is an essential first step towards developing any chronology. By examining a large number of species in West Africa, this study has narrowed the search field, providing a basis for expansion as well as valuable insight for subsequent stages of the process, i.e. determining that the bands are annual and sensitive to instrumental records.

ACKNOWLEDGMENTS

This study was funded by Grant #ATM-9906386 from the U.S. National Science Foundation Paleoclimate Program. We thank the numerous people that assisted with fieldwork and sample preparation, especially Mark Kaib, Daniel Dabi, Moctar Sanogo, Zie Sanongo and Djimadoum Madibaye. Rex Adams supervised sample preparation and verified ring counts and crossdating between radii. We thank Drs. Martin Muuro for the micro images and Irina Panyushkina for making the thin sections. We acknowledge with gratitude the assistance rendered by the Yankari Tourism Cooperation (Nigeria), The Ministry of the Environment and Rural Resources (Niger), The Department of Forestry in Ouagadougou and Bobo Diollasso (Burkina Faso) and Bamako (Mali). We thank the two reviewers for significant improvement to the manuscript.
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TECHNICAL NOTE

STANDARDIZING THE REPORTING OF ABRASIVE PAPERS USED TO SURFACE TREE-RING SAMPLES

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ABSTRACT

Dendrochronologists traditionally report the grit size on abrasive papers used to prepare surfaces for tree-ring analysis, but significant differences exist in the measured particle size ranges defined by the different systems (e.g. FEPA, ANSI, ISO, JIS, etc.) used worldwide. The systems themselves are also subject to change and discontinuation. We propose that dendrochronologists report (1) the standard used to manufacture the grit (e.g. ANSI in the U.S.), (2) the grade within the standard (e.g. 400-grit), and (3) the SI equivalent measurements of mean or included-range grit-size dimensions (e.g. 20.6–23.6 µm). For example, rather than reporting our use of 60-grit or 400-grit, we would instead report ANSI 60-grit (250–297 µm) and ANSI 400-grit (20.6–23.6 µm) sandpaper. Adopting SI equivalents will help standardize our methods by providing concise, replicable information about surface preparation, considered by many the most crucial step for helping to define clear ring boundaries and to ensure successful crossdating.

Keywords: Abrasive paper, sanding methods, SI standard.

INTRODUCTION

Although selection of abrasives seems fairly straightforward to most dendrochronologists, this may not always be the case. Suppose, for example, that an American is collaborating with Japanese colleagues on comparing the ring-forming characteristics of the Asian and North American species of a particular genus of tree. At some point in their association one of the Japanese colleagues comments that they are puzzled by the methods reported in the American’s papers. His methods involve finishing sections with 400-grit sandpaper, but when the Japanese colleagues reach 400-grit the surface is still unacceptable. On the other hand, the sections sent to them by the American have excellent surfaces. The discrepancy is resolved when further investigation reveals that 400-grit paper in Japan is considerably coarser than 400-grit paper in the U.S.!

Dendrochronologists sand or otherwise surface their samples until they can clearly view micro-anatomical features such as cell walls. Deciding when one has reached that point is inherently subjective, however, so preparation methods reported in the literature typically refer to the grade of sandpaper used to achieve the final surface. As a means of communicating one’s methods this is a very reasonable practice, because normal methods of measuring the smoothness of the surface itself do not work for a microporous material like sectioned wood. For example, engineers and manufacturers specify polished metal finishes and other finishes in surface metrology not by the size of grit used to achieve a finish, but by the smoothness of the resulting surface (e.g. $R_a$ or “roughness average,” the integral of the absolute values of the roughness profile across the surface in relation to the mean). Because the roughness profile of sectioned wood includes the interior spaces of the cells and vessels that the investigator plans to examine, measurements like $R_a$ have little practical meaning. Reporting the grit size makes practical sense (see “Grit versus Finish,” below).
Table 1. Effective size ranges in micrometers for abrasive grit sizes in several current systems. The way standards are defined varies between systems and by analytic technique. These numbers are sufficient for reporting in dendrochronology.

<table>
<thead>
<tr>
<th>International</th>
<th>U.S.A.</th>
<th>Europe*</th>
<th>Japan</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO(86) µm</td>
<td>ANSI(74) µm</td>
<td>FEPA(93) µm (mean)</td>
<td>JIS(87) µm</td>
<td>GB2478(96) µm</td>
</tr>
<tr>
<td>P22</td>
<td>850–1000</td>
<td>P20 1000</td>
<td>22</td>
<td>850–1000</td>
</tr>
<tr>
<td>P24</td>
<td>710–850</td>
<td>P24 764</td>
<td>24</td>
<td>710–850</td>
</tr>
<tr>
<td>P30</td>
<td>600–710</td>
<td>P30 642</td>
<td>30</td>
<td>600–710</td>
</tr>
<tr>
<td>P36</td>
<td>500–600</td>
<td>P36 538</td>
<td>36</td>
<td>500–600</td>
</tr>
<tr>
<td>P40</td>
<td>425–500</td>
<td>P40 425</td>
<td>40</td>
<td>425–500</td>
</tr>
<tr>
<td>P54</td>
<td>300–355</td>
<td>P50 336</td>
<td>54</td>
<td>300–355</td>
</tr>
<tr>
<td>P60</td>
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<td>P60 269</td>
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<td>P70</td>
<td>212–250</td>
<td>P70 212–250</td>
<td>70</td>
<td>212–250</td>
</tr>
<tr>
<td>P80</td>
<td>180–212</td>
<td>P80 201</td>
<td>80</td>
<td>180–212</td>
</tr>
<tr>
<td>P90</td>
<td>150–180</td>
<td>P90 150–180</td>
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<td>100</td>
<td>125–150</td>
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<td>P120</td>
<td>106–125</td>
<td>P120 125</td>
<td>120</td>
<td>106–125</td>
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<td>P150</td>
<td>75–106</td>
<td>P150 100</td>
<td>150</td>
<td>75–106</td>
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<tr>
<td>P180</td>
<td>63–90</td>
<td>P180 82</td>
<td>180</td>
<td>63–90</td>
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<tr>
<td>P220</td>
<td>53–75</td>
<td>P220 68</td>
<td>220</td>
<td>53–75</td>
</tr>
</tbody>
</table>

ISO(77) µm | ANSI(77) µm | FEPA(93) µm | JIS(83) µm | GB2477(83) µm |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P240</td>
<td>56.5–60.5</td>
<td>P240 56.5–60.5</td>
<td>240</td>
<td>56.0–64.0</td>
</tr>
<tr>
<td>P280</td>
<td>50.2–54.2</td>
<td>P280 50.2–54.2</td>
<td>280</td>
<td>49.0–55.0</td>
</tr>
<tr>
<td>P320</td>
<td>44.7–47.7</td>
<td>P320 44.7–47.7</td>
<td>320</td>
<td>43.5–48.5</td>
</tr>
<tr>
<td>P360</td>
<td>39.0–42.0</td>
<td>P360 39.0–42.0</td>
<td>360</td>
<td>38.0–42.0</td>
</tr>
<tr>
<td>P400</td>
<td>33.5–36.5</td>
<td>P400 33.5–36.5</td>
<td>400</td>
<td>32.0–36.0</td>
</tr>
<tr>
<td>P500</td>
<td>28.7–31.7</td>
<td>P500 28.7–31.7</td>
<td>500</td>
<td>26.0–30.0</td>
</tr>
<tr>
<td>P600</td>
<td>24.8–26.8</td>
<td>P600 24.8–26.8</td>
<td>600</td>
<td>22.5–25.5</td>
</tr>
<tr>
<td>P800</td>
<td>20.8–22.8</td>
<td>P800 20.8–22.8</td>
<td>700</td>
<td>19.7–22.3</td>
</tr>
<tr>
<td>P1000</td>
<td>17.3–19.3</td>
<td>P1000 17.3–19.3</td>
<td>800</td>
<td>17.0–19.0</td>
</tr>
<tr>
<td>P1200</td>
<td>14.3–16.3</td>
<td>P1200 14.3–16.3</td>
<td>1000</td>
<td>14.5–16.5</td>
</tr>
<tr>
<td>P1500</td>
<td>9.5–11.1</td>
<td>P1500 11.6–13.6</td>
<td>1200</td>
<td>12.0–14.0</td>
</tr>
<tr>
<td>P2000</td>
<td>8.5–10.5</td>
<td>P2000 9.5–11.1</td>
<td>1500</td>
<td>9.5–11.5</td>
</tr>
<tr>
<td>P2500</td>
<td>7.9–9.1</td>
<td>P2500 7.9–8.9</td>
<td>2000</td>
<td>7.8–9.2</td>
</tr>
</tbody>
</table>

*The respective standards associations of India, the Russian Federation, the Union of South Africa, and Turkey are also corresponding members of FEPA.

Doing so, however, is only useful if your grit size numbers are meaningful to others. As the USA-Japan example illustrates, such meaning may be elusive. In fact, “400-grit” in the U.S. is about the same as “800-grit” in Europe, whereas in Japan you would use “600-grit” to achieve the same finish (Table 1). Grit designations also change over time. In the U.S., sanding papers were once graded with numbers like “00” and “000” in the finishing grades, or solely with verbal descriptions such as “very fine” and “extra fine” (Table 2). A single international standard may be adopted in the future (e.g. ISO 86, Table 1), but for that to happen many of today’s standards will necessarily be replaced and their meanings will fade from memory.

We have three primary goals in writing this report. First, we wish to make the dendrochronological community more aware of the differences in abrasive paper grading systems. Second, we wish to provide the information researchers need to un-
Table 2. Approximate equivalents for customary U.S. terms (accepted usage in the industry, not vernacular usage) and historic sandpaper grades. Historic grades were less standardized than today's. Grades such as 2/0 and 3/0 are also written 00, 000 or may be spelled out as two-aught, three-aught.

<table>
<thead>
<tr>
<th>Term</th>
<th>One or More Grades Within the Range (µm)</th>
<th>Pre-CAMI U.S. Grade</th>
<th>Typical Mean Size (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra Coarse</td>
<td>1000–2000</td>
<td>3</td>
<td>715</td>
</tr>
<tr>
<td>Very Coarse</td>
<td>500–1000</td>
<td>2</td>
<td>535</td>
</tr>
<tr>
<td>Coarse</td>
<td>250–500</td>
<td>1</td>
<td>351</td>
</tr>
<tr>
<td>Medium</td>
<td>125–250</td>
<td>0</td>
<td>192</td>
</tr>
<tr>
<td>Fine</td>
<td>63–125</td>
<td>2/0</td>
<td>141</td>
</tr>
<tr>
<td>Very Fine</td>
<td>40–63</td>
<td>3/0</td>
<td>116</td>
</tr>
<tr>
<td>Extra Fine</td>
<td>25–40</td>
<td>4/0</td>
<td>93</td>
</tr>
<tr>
<td>Super Fine</td>
<td>10–25</td>
<td>5/0</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>6/0</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7/0</td>
<td>53.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8/0</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9/0</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10/0</td>
<td>23.6</td>
<td></td>
</tr>
</tbody>
</table>

ambiguously record their methods and to translate between systems that are in common use. Finally, we wish to encourage researchers to publish SI equivalent units with their sample preparation methods (SI refers to “Système International” units, the modern version of the metric system and the standard for scientific writing).

REFERENCE YOUR STANDARD—AND ANNOTATE WITH SI UNITS

For the dendrochronological community, the question is what needs to be communicated when we report our sample-finishing methods. If the goal is to allow other researchers, especially inexperienced ones, to understand and replicate our techniques, we are falling short of the mark, because for example finishing a surface with European “400-grit” sandpaper may still leave grooves in the wood that could mask the ring boundaries or important ring features that aid in visual cross-dating. The fineness of the finish on samples is an important aspect of replication, determining how well one can discern cellular structure and the architecture of the wood under the microscope. In today’s international scientific world, it makes little sense to describe one’s methods in terms that are place- and time-specific.

Fortunately, the problem is easily addressed and the intended goal easily achieved. We suggest that when discussing their sanding methods, authors (and editors) in dendrochronology at the very least state (and request that authors state) what standard of grit measurements their numbers reflect. We also urge them to include (and request) SI equivalents. Doing so is good science—a basic tenet of scientific reporting is that you should include all necessary information to allow someone else to replicate your methods in another lab, or at a later time—even centuries later.

The different grit grading systems all have precise meanings—they are based on explicitly defined standards set by the respective regulating bodies. For example, in the United States the Coated Abrasives Manufacturers Institute (CAMI, now merged into UAMA, the Unified Abrasives Manufacturers’ Association) originally defined the U.S. Standard Scale later adopted by the American National Standards Institute (ANSI), while the present pan-European system is regulated by the Federation of European Producers of Abrasives (FEPA). Standards differ in important ways other than the mean particle sizes we report in Tables 1 and 2. For example, there may be differences in the permissible range of particle sizes within a grade, or in the permissible degree of variability of particle sizes around the nominal size.

Correctly stated, a grit size reference should include three parts: (1) the standard used to manufacture the grit (e.g. ANSI in the U.S.); (2) the grade within the standard (e.g. 400-grit); and (3) the SI equivalent measurements of mean or included-range grit size dimensions (e.g. 20.6–23.6 µm). For example, “We sanded our sections beginning with ANSI 60-grit (250–297 µm) sandpaper, and used progressively finer sizes, ultimately finishing with ANSI 400-grit (20.6–23.6 µm).” Ideally, researchers will eventually be able to adopt a uniform standard. We recommend using abrasive paper manufactured to the ISO standard when a choice exists, as that standard is likely over time to grow in use among manufacturers.

Mentioning the beginning grit size used in the sanding process is important information for new initiatives in dendrochronology. Cross sections with deep chain saw cuts will often require ANSI 24-
grit (707–841 µm) or ANSI 36-grit (500–595 µm) sandpaper to remove the grooves if no band saw or electric planer is available to create a flat initial surface. Increment cores from pines and other conifers can often be sanded initially with ANSI 100-grit (125–149 µm) or ANSI 120-grit (105–125 µm) sandpaper, while cores from hardwoods may require an initial surfacing with ANSI 80-grit (177–210 µm) sandpaper.

GRIT VERSUS FINISH

The difference between appropriate grits for hardwoods and softwoods reflects the fact that the actual finish you achieve using a particular sandpaper grade also depends on factors other than grit size. It is for this reason that the finishes of machined and cast solid materials are defined by measuring their surface roughness, as discussed above. While it’s not practical to do that in sectioned wood, we believe that given a particular type of wood and a particular grade of sandpaper, different experienced workers will tend to achieve very similar finishes when hand-sanding or when using similar equipment. We acknowledge, however, that this is not guaranteed, and there are other factors involved.

First, the amount of abrasion depends on the hardness of the wood—the harder the wood, the smaller the scratches and grooves made by the grit. The second factor concerns the amount of pressure applied to the surface, which often depends on the person doing the sanding. Greater pressure produces deeper abrasions. Third, the finish also depends on how well-used the sandpaper is. Most sanding belts (and sanding sheets and finishing films) are not inexpensive, necessitating their extended use and occasional cleaning with commercially available belt cleaners (typically large sticks of gummy rubber). As sandpaper is used, the grit both dulls and fractures, the rate depending partly on the grit material (aluminum oxide, garnet, etc.) and its original sharpness, so that over time it produces shallower abrasions and a smoother surface.

SUMMARY

Communicating the sizes of abrasives we use, in such a way that anyone else can immediately understand our methods and replicate them at will, is an easily achieved and important aspect of scientific rigor. Hopefully, the information in this report puts that practice easily within our capabilities.

USEFUL WEB RESOURCES REGARDING ABRASIVES STANDARDS

National Resource for Global Standards: http://www.nssn.org
American National Standards Institute: http://www.ansi.org
International Organization for Standardization: http://www.iso.ch
Federation of European Producers of Abrasives: http://www.fepa-abrasives.org

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ADDENDUM

At press time we received new information from the Association of Producers of Abrasives (APA) of the Russian Federation that elucidates the situation in the former USSR. In recent decades sandpaper has been manufactured with grit size classes defined according to the GOST 3647-80 standard (Table 3), but a new Russian standard will be implemented in 2003 that will march the ISO(86) and ISO(77) standards.

<table>
<thead>
<tr>
<th>Grit size (µm)</th>
<th>Grit size (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>800-1000</td>
</tr>
<tr>
<td>63</td>
<td>630-800</td>
</tr>
<tr>
<td>50</td>
<td>500-630</td>
</tr>
<tr>
<td>40</td>
<td>400-500</td>
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<tr>
<td>32</td>
<td>315-400</td>
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<td>25</td>
<td>250-315</td>
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<td>20</td>
<td>200-250</td>
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<td>160-200</td>
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<td>12</td>
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<tr>
<td>4</td>
<td>40-50</td>
</tr>
<tr>
<td>3</td>
<td>28-40</td>
</tr>
</tbody>
</table>
SOFTWARE REVIEW

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In my last software review (Tree-Ring Research, volume 57, number 2), I introduced the 2-CD set Woody Plants of North America, which contained detailed dendrological and environmental information on 470 species of woody plants found in North America. I consider this software indispensable for my research and for teaching students the most efficient means for identifying and describing trees commonly used in dendrochronology. To round out a comprehensive suite of software that covers the majority of species information useful to dendrochronologists, I recently bought The Wood Explorer, a CD that provides what could be the most comprehensive package of technical information on most tree species worldwide.

The Wood Explorer is exactly as its title suggests. The software emphasizes the technical details of wood properties of over 1,650 timber species from over 225 countries (searchable by country and even by multiple countries). The Windows-based software installs easily but requires time (ca. 10 minutes on my Pentium® laptop) to download the over 3,000 pictures of wood to your hard disk (100 Mb minimum free space required). Unlike the Woody Plants CD, this software runs directly from your hard disk—having the CD loaded in the CD tray is not required. The included serial number is required for the initial run of the software, but save the serial number as you’ll need it to access all wood information on their companion web site! It’s nice to know that, in case you don’t have access to your laptop or personal computer, all information is available from their web site.

The vast amount of information available to you is dizzying. As an example, let’s explore information for longleaf pine (Pinus palustris Mill.). To begin, select the “Search” function and type in “palustris” under the “Scientific Name” option. From the search return box, click on “Pinus palustris” (of the three species returned) and the software returns all general, numerical, physical, and woodworking information for that species. This includes: family, scientific, trade, and common names; regions and countries of distribution; common uses; environmental profile; and distribution overview (i.e., topoedaphic requirements). Then comes technical information on: heartwood and sapwood color; grain; texture; odor; types of growth defects; durability; weathering; resin content; and tree size and bole identification information. Additional technical woodworking information is provided on: kiln drying schedule; planing; mortising; carving; nailing; staining; varnishing; sanding; cutting resistance; resistance to splitting; and many more properties too numerous to mention. Horizontal bars to the left of each property highlight the most common attributes for each. For example, the dominant heartwood color for longleaf pine is either brown or red, while the dominant sapwood color is either yellow, golden-yellow, or orange. Shorter bars indicate less frequent attributes (e.g., sapwood color that is pink or pale red). Searching can be conducted using any of the names, locations, general, physical, numerical, or woodworking criteria.

To the right of the panel that opened for longleaf pine is another panel containing images of longleaf pine wood. Clicking on each enlarges the image for greater detail, but note, however, that not all
species have microphotographs available for details on cellular structure. Selecting "Photo Guide" from the Main Menu brings up color swatches for wood (e.g., the "Whites," "Yellow-Browns," and "Lighter Browns"). Clicking on any swatch brings up a new window that contains swatches for all species represented by that color. Click on any swatch to see the species information described above. The photographs are perhaps one of the most useful and educational guides in this software, and key specifically on gross features of the wood only (i.e., grain, color, resin) rather than micro-features. If you’re looking for macro- and microphotographs of wood in all three sectional views—transverse, tangential, and radial—you won’t find that level of detail in this software, nor on their web site.

Needless to say, users may require information for a set number of species, and these can be kept permanently by adding the species to and later selecting "My List." Properties for each species in "My List" can then be "Custom Compared" (e.g., comparing the texture or sanding properties) or compared to other popular species not included in "My List." If the user is not sure about some of the terms used, the software comes with a comprehensive glossary—if more than one definition is available, it will be provided (three for "sapwood" alone). A very comprehensive reference section is also provided for each individual species at the end of the information section. The PC-based software is complemented by the web version, where you will find a new twist: information submitted by subscribed members to complement the "system" information. Users can also contribute microphotographs and images of the actual trees. Also found only on their web site are the actual geographic range maps for most species—I tried to find a species that did not have a range map, but was unsuccessful, even trying some of the more obscure African wood species. In all, this software and its companion web site are impressive, a very worthwhile investment, and a great learning tool for the dendrochronologist.
TREE-RING RESEARCH
EDITORIAL POLICY AND INSTRUCTION FOR AUTHORS

*Tree-Ring Research* is devoted to papers dealing with the growth rings of trees and the applications of tree-ring research in a wide variety of fields, including but not limited to archaeology, geology, ecology, hydrology, climatology, forestry, and botany. Papers involving research results, new techniques of data acquisition or analysis, and regional or subject-oriented reviews or syntheses are considered for publication.

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*Articles, Reports, and Reviews* are published only in English. Abstracts of the *Articles* or *Reports* may be printed in other languages if supplied by the author(s) with English translations.

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Follow the style and format of recent issues as guides to organization, units of measurement, abbreviations, and literature citation. Manuscripts must be typewritten double-spaced throughout (including the abstract, tables, captions, footnotes and references) on one side of approximately 22 × 28 cm paper, with margins of at least 2.5 cm. A separate title page should include the title, author(s) affiliations(s) and mailing address(es). Include telephone numbers in the letter of transmittal. The abstract should appear on a separate page preceding the text. Number tables consecutively using Arabic numerals; do not prepare tables with lines or boxes. Type tables (including titles) and figure captions separately and place them at the end of the manuscript. Explanatory notes in tables should be numbered and referenced in table titles or footnotes. All illustrations, whether line drawings or photographs, are considered figures to be denoted by Arabic numerals and cited consecutively in the text. Supply one copy (not exceeding 22 × 28 cm) of each illustration in a form suitable for photo-reproduction. Lettering should be large enough to allow 50% reduction. Original line drawings, black-line positives on acetate, and glossy prints are acceptable. Authors are responsible for reading proofs carefully and noting all errors. Except for corrections, alterations or additions must be kept to an absolute minimum. Additional detailed instructions to authors are accessible online at: [http://www.treeringsociety.org/TRS_journal.html](http://www.treeringsociety.org/TRS_journal.html)
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Specific goals of the Tree-Ring Society are:
- To promote tree-ring research to the global scientific community
- To facilitate organization of symposia, conferences, and workshops on all aspects of tree-ring research
- To publish results of tree-ring studies in a peer-reviewed journal
- To disseminate knowledge of tree-ring research to other disciplines and to the public

The Society's journal *Tree-Ring Research* (formerly *Tree-Ring Bulletin*) has been published since 1934 as a principal outlet for dendrochronological and tree-ring-related studies. Submissions on all aspects of tree-ring research are encouraged.

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