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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 Caesalpiniaceae 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, Caesalpiniaceae, Mimosacae, 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-

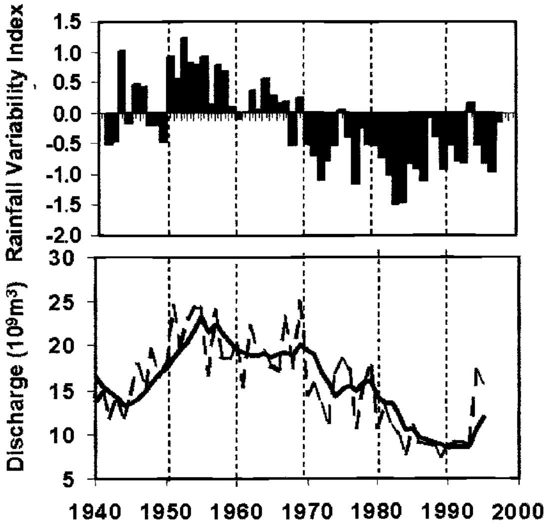

Figure 1. (a) Pronounced rainfall decline in West Africa, updated from the index of rainfall variability developed by Lamb (1985). The index is obtained by (i) expressing each station rainfall as a standardized departure (*i.e.* departure from the mean over the entire period of record, divided by the 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).

flow discharge (Figure 1) that began in the late 1960s throughout the region; progressive decline of the levels of Lake Chad (currently measured at a mere one-fifth of its size in 1963; Coe and Foley 2001) and a southward shift in the location of rainfall isohyets (Todorov 1985; Breman and Kessler 1995; Le Barbé and Lebel 1997; Tarhule and Tarhule-Lips 2001). Since the onset of these changes, concerted research efforts have revealed the broad processes involved but the specific causes—*i.e.* the dynamic interrelationships among the many possible causal factors—remain poorly understood. 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 multidecadal 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. Johnathan *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 $\delta^{13}C$ 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

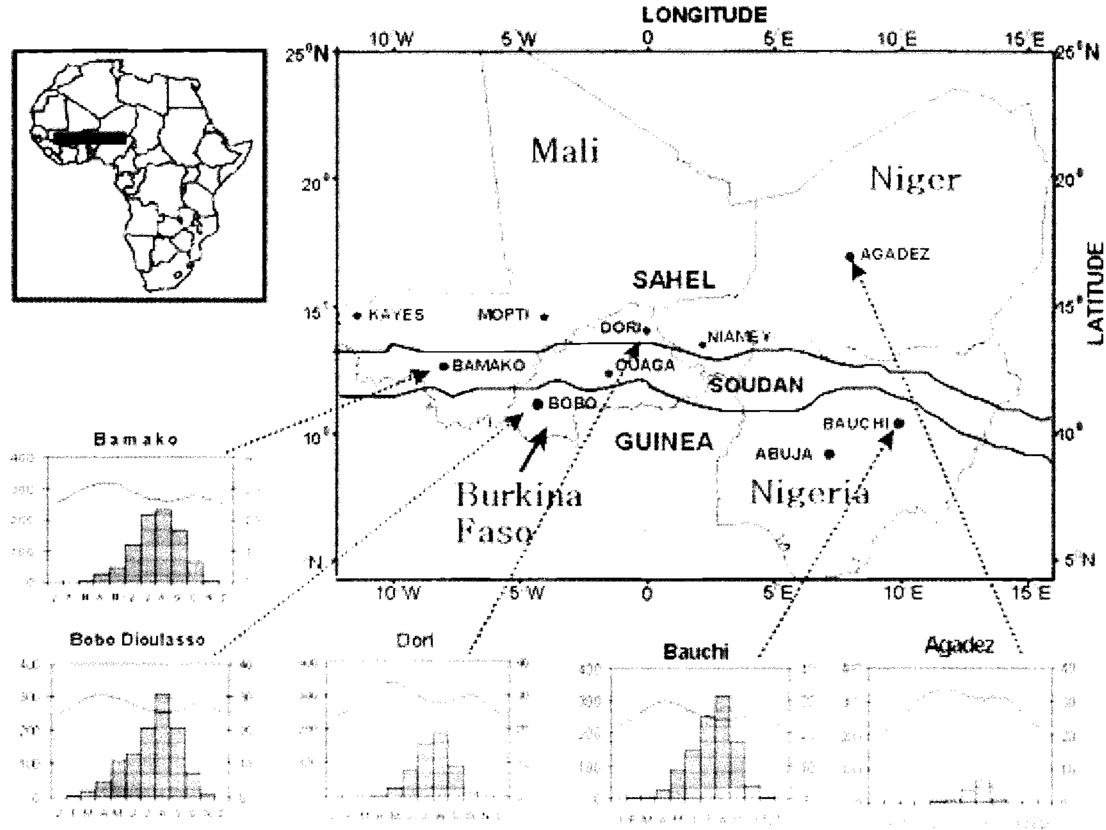

Figure 2. The study area showing bioclimatic zones and climographs for representative stations in each zone. The primary y-axis shows monthly rainfall (bars) in mm. Temperature (line) in °C is on the secondary y-axis.

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 *Isorbelinia* 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.

Family	Genera	Species	1999	2000
		Potentially Useful		
Caesalpiniaceae	*Cassia*	*sieberiana*	3	16
	Cordyla	*pinnata*	2	5
	Daniella	*oliveri*	16	55
	Isoberlinia	*doka*	12	79
	Tamarindus	*indica*	3	39
Mimosaceae	*Acacia*	*seyal*	2	16
Verbenaceae	*Gmelina*	*arborea*	7	—
		Problematic		
Caesalpiniaceae	*Afzelia*	*africana*	3	3
	Burkea	*africana*	7	11
	Detarium	*microcarpum*	13	4
Mimosaceae	*Acacia*	*polyuacantha*	5	3
		senegal	2	4
	Boscia	*senegalenses*	1	2
	Prosopis	*africana*	10	2
Papilionaceae	*Afromosia*	*laxiflora*	7	3
		Poor		
Anacardiaceae	*Lannea*	*acida*	5	3
		microcarpa	3	
		velutina	2	
	Sclerocarya	*birrea*	3	
Apocynaceae	*Landolphia*	*senegalensis*	1	
Bombacaceae	*Bombax*	*costatum*	15	2
Caesalpiniaceae	*Bauhinia*	*rufescens*	8	
		reticulata	3	
	Isoberlinia	*tomentosa*	9	
Combretaceae	*Anogeissus*	*leicarpus*	15	
	Combretum	*gazalensi*	2	
		glutinosum	3	
		hypopinum	3	
		micranthum	1	
		nigricans	7	
		paniculatum	3	
	Pteleopsis	*habeensis*	1	
	Terminilia	*avicemoids*	1	
		laxiflora	2	
		macroptera	10	
Ebenaceae	*Diospyros*	*mespiliformis*	2	
Euphorbiaceae	*Hymenocardia*	*acida*	1	
Hypericaceae	*Psorospermum*	*kuritianum*	9	
Loganiaceae	*Stycnos*	*spinosa*	1	
Meliaceae	*Khaya*	*senegalensis*	10	
	Pseudocedrela	*kotschyi*	2	
	Acacia	*albida*	7	
		macrostachya	1	
		mauritanus	1	
		nilotica	8	
	Dichrostachys	*glomerata*	6	
	Parkia	*biglobosa*	9	
	Entada	*africana*	2	

Table 1. Continued.

Family	Genera	Species	1999	2000
Moraceae	*Ficus*	*ignens*	1	
		platyphylla	1	
Ochnaceae	*Lophira*	*lanceolata*	1	
Papilionaceae	*Pterocarpus*	*erinaceus*	6	
Rhamnaceae	*Ziziphus*	*jujube*	12	
Rubiaceae	*Crossopteryx*	*febrifuga*	1	
		velvetum (*vilitinum?*)	1	
	Mitragyna	*inermis*	8	
	Nauclea	*latifolia*	4	
	Gardenia	*ternifolia*	4	
Sapindaceae	*Blighia*	*sapida*	2	
Sapotaceae	*Butyrospermum* (Now *Vetellaria*)	*paradoxum* (*parkii*)	16	
	Manilkara	*multinervis*	1	
Sterculiaceae	*Sterculia*	*setigeria*	9	
Verbenaceae	*Vitex*	*doniana*	1	
Zygophyllacaeae or Balanitaceae	*Balanites*	*aegyptiaca*	11	
Local Name (*language*)				
Karya gateri			1	
Gidido (*Fulani*); Gukaka (*Hausa*)			1	
Poupartia birrea			3	
Bolenix regia				
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 crossdating 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.

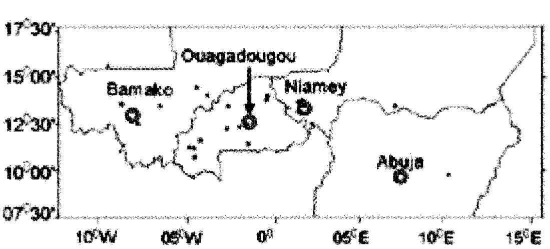

Figure 3. The location and distribution of major sampling points within the study area.

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-emphasizing 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 (Caesalpiniaceae)

The habitat of this species is the Suodan 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. Growth rings are variable, comprising both narrow and extremely wide rings (up to 20 mm). We achieved crossdating between radii, with some difficulty, in four samples (72–110 rings). The difficulty is due to the presence of "double" rings that sometimes alternate consistently with large rings (up to 23 sequences) and then fail to appear in some rings. These double rings are less distinctive, and therefore more difficult to trace from one radius to the next, especially on cores (the problem is less of a constraint on whole stem discs). Additionally, the double rings frequently merge into their large neighbors, or fade out.

These samples appear to hold great promise for dendrochronological research. Detailed phenological investigations including band dendrometer measurements and "wounding" are needed to establish whether the rings are annual (*e.g.* Worbes 1995), and to determine the relationship between flood events and ring formation.

Isoberlinia doka (Caesalpiniaceae)

This species occurs mainly in the Guinea savanna region from the Republic of Guinea to Uganda, and from Sudan to Northern Zaire. It does not occur north of about latitude 12°N, or south of the Equator. Mature trees stand at about 18 m, with trunk diameter of about 30 cm. Sapwood color is silver, tinged with red. The wood grain is usually interlocked and uneven, with coarse texture.

Isoberlinia doka performs well on all types of soils and was the most readily available tree within the Guinea savanna zone. The wood is diffuse-porous with large prolate vessels. Owing to their large size, vessel density is low (Figure 5a). Distinctive marginal parenchyma cells (4–6 cells wide) delineate ring boundaries (Figure 5b). Vessels are also associated with parenchyma cells (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 (>

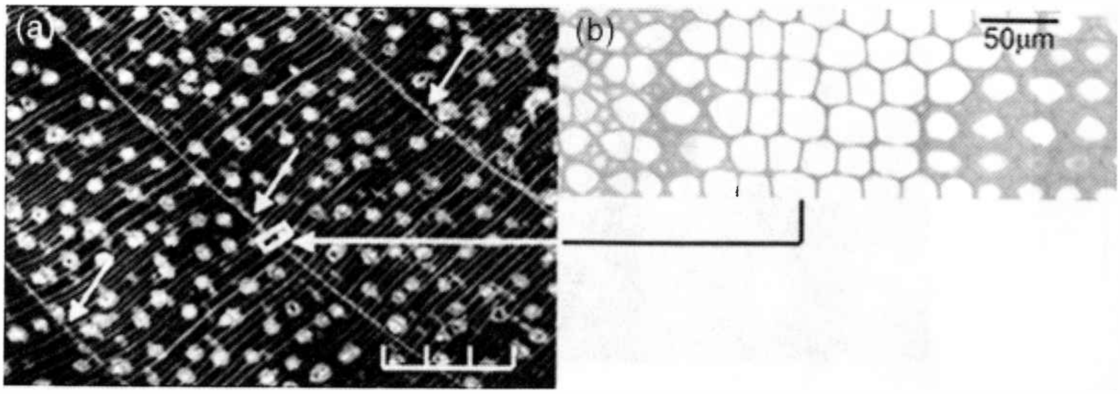

Figure 4. *Daniella oliveri* (a) micro view (b) thin section of parenchyma cells at ring boundary. The boxed area (Figure 4a) shows the approximate location (not to scale) of the view in Figure 4b. The scale with 3 subdivisions (appearing here and in Figs. 5–12 represents 3 mm.

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 $\delta^{13}C$ ($r = -0.64$, $n = 18$, $p < 0.001$) 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-

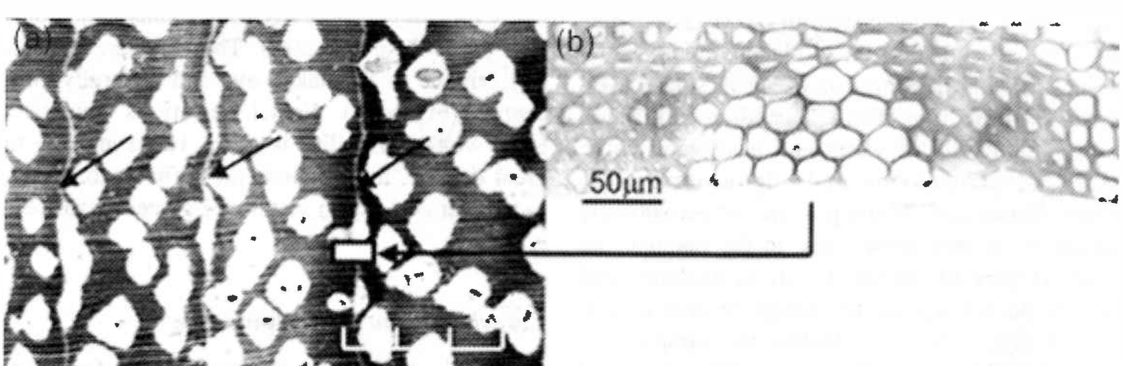

Figure 5. *Isoberlinia doka* (a) micro view (b) thin section of parenchyma cells at ring boundary. The boxed area (Figure 5a) shows the approximate location (not to scale) of the view in Figure 5b.

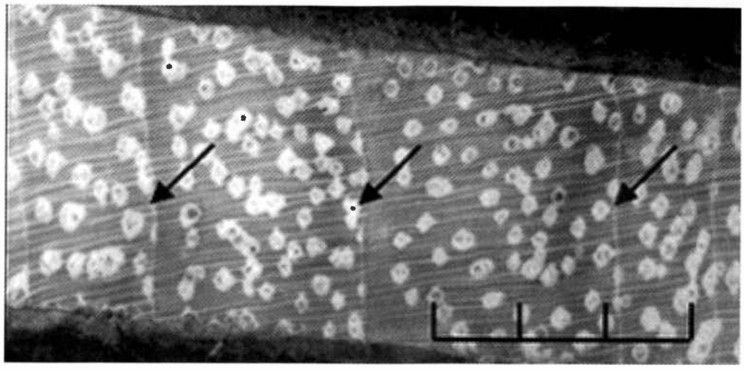

Figure 6. *Tamarindus indica.*

drochronology. 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-

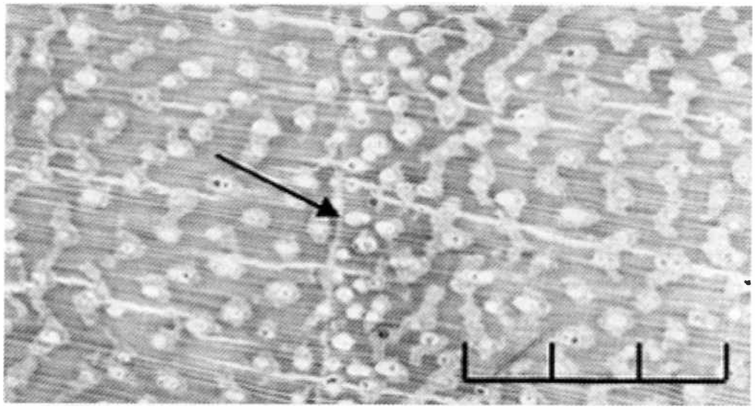

Figure 7. *Cassia sieberiana.*

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.

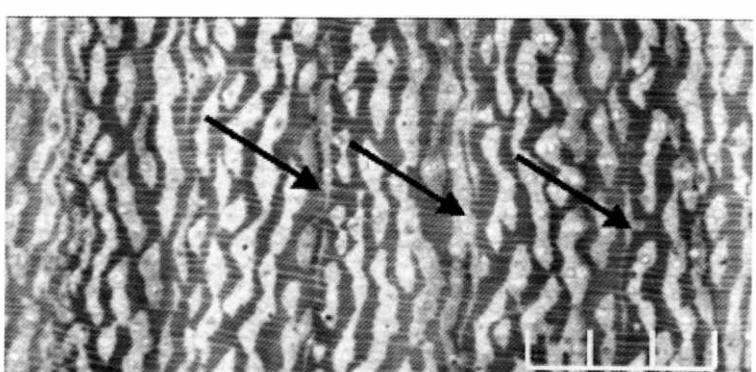

Figure 8. *Cordyla pinnata.*

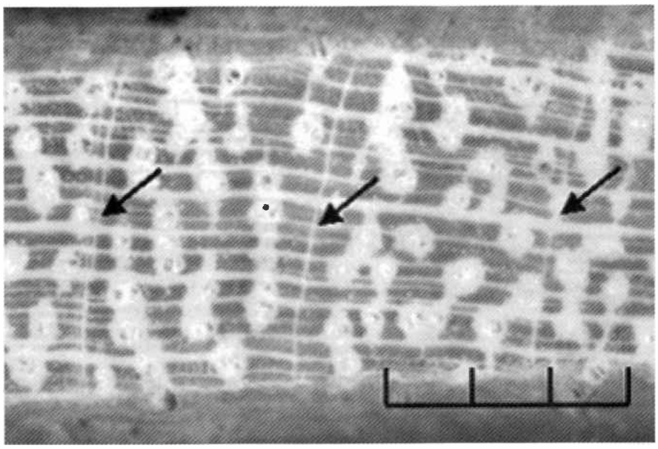

Figure 9. *Acacia seyal.*

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.

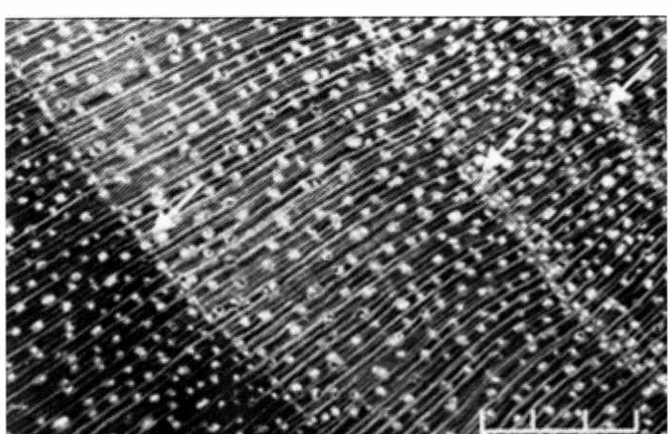

Figure 10. *Khaya senegalensis.*

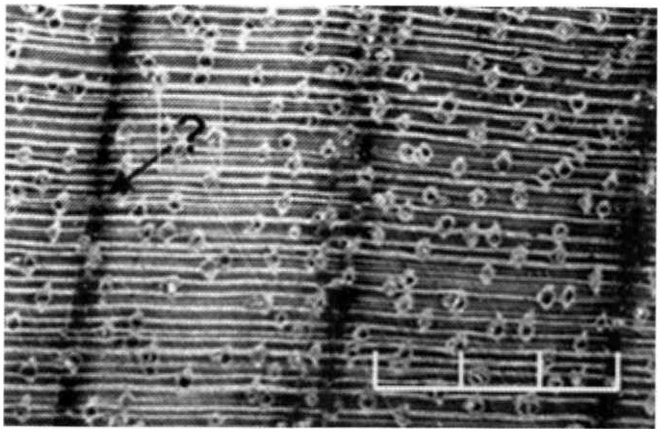

Figure 11. *Detarium macrocarpum.*

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

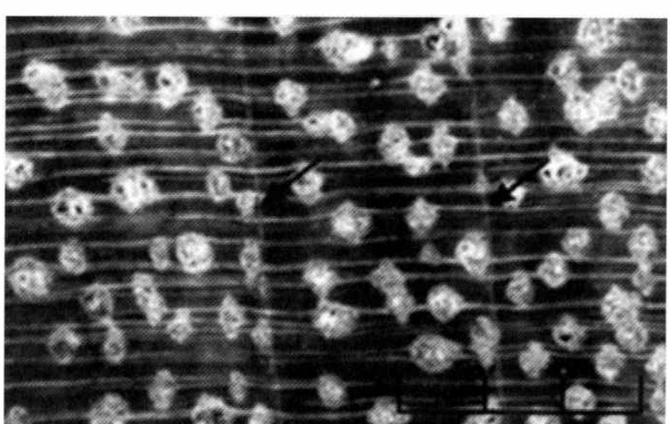

Figure 12. *Boscia senegalensis.*

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, Caesalpiniaceae, Mimocaceae, 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.

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