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Progress in Dendroclimatic Studies in Indonesia

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ABSTRACT

A 416-year (1514-1929) tree-ring width chronology of teak (Tectona grandis L. F.) from Cepu, Central Java, Indonesia (111°35'E, 7°06'S), first published by Berlage over 60 years ago, remains one of the few high-resolution paleoclimatic archives available for the western equatorial Pacific. Here we present an update of this chronology from 1880-1991, which extends the original series by 63 years. As was found for the original Berlage record, the updated chronology is correlated positively with rainfall and inversely with sea level pressure during the dry monsoon season (around May to October) just prior to the period of growth in Java. This teak record is also related to several indices of the El Niño-Southern Oscillation (ENSO), including sea level pressure at Darwin, Australia, Wright's rainfall index for the equatorial Pacific, and the Quinn historical record of ENSO. The years 1737 and 1925, rated as strong ENSO events by Quinn, are ranked among the three lowest index years in the Berlage teak record. 1967, which is not considered to be an ENSO year, has the lowest ring width index in the updated series from 1880-1991, and the lowest dry season rainfall on record for Jakarta, Indonesia (since 1869). The dry monsoon drought during the extreme 1982-83 ENSO event (although devastating for much of Indonesia) was not unusually severe based on either the tree-ring or Jakarta rainfall records.

(Key words: Tree rings, Paleoclimate, Monsoon, Indonesia)

1. INTRODUCTION

Rainfall in the Indonesian Archipelago is directly linked to convection associated with the Indonesian Low pressure cell, a key element of the El Niño-Southern Oscillation (ENSO) system (e.g. Hackert and Hastenrath 1986, Diaz and Kiladis 1992). Over much of Indonesia, there is a strong tendency for droughts to occur during the warm ENSO phase, when the Indonesian Low migrates eastward into the Pacific. Conversely, above normal rainfall and flooding tends to take place in Indonesia during the cool ENSO phase. It has been estimated that around 90% of the droughts in Indonesia are associated with regional El Niño events,

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and about 80% of such events linked with droughts (Quinn *et al.* 1978, Ropelewski and Halpert 1987). The link between Java rainfall and ENSO appears to be strongest during the dry monsoon season, from approximately June to November (Hackert and Hastenrath 1986, Nicholls 1981). This is also when teak growth appears to be most sensitive to variations in rainfall and ENSO (Murphy and Whetton 1989, Jacoby and D'Arrigo 1990).

Our understanding of ENSO has improved greatly as a result of recent analyses of the instrumental climatic record (e.g. Bradley *et al.* 1987, Allan 1988, Rasmusson *et al.* 1990) and climate modeling and prediction of ENSO dynamics (e.g. Zebiak and Cane 1987, Bengtsson *et al.* 1993). Yet, these instrumental observations and modeling studies are not suitable for resolving the long-term variability of the ENSO system. For this purpose, long, high-resolution (annual or better) paleoclimatic records (tree rings, corals, ice cores, varves) from ENSO-sensitive core regions (e.g. Indonesia and elsewhere in the low-latitude Pacific) and sites influenced by ENSO teleconnection (e.g. the southwestern United States, Lough 1992) need to be further developed and exploited.

Relatively few tree-ring chronologies have been developed for the tropics, including Indonesia (Jacoby, 1989). This is because temperature seasonality, which results in annual ring formation at higher latitudes, is largely absent in the tropical regions. Thus the seasonal nature of monsoonal rainfall or other environmental factors is required for the formation of well-defined annual rings at low latitudes. Other limitations are the relative scarcity of tree species with suitable longevity and anatomical structure, logging of old-growth forests in many tropical areas, and logistical difficulties.

Tree-ring data coverage has improved considerably for many subtropical regions of the globe in recent decades (e.g. Mexico, northern Argentina, South Africa, Morocco), augmenting the more extensive coverage at higher latitudes. Yet, coverage is still practically nonexistent for the equatorial band of the tropics from 10°N to 10°S. In this paper we present an update of a tree-ring record of teak for Cepu, Central Java, Indonesia (Berlage 1931). Our combined teak record demonstrates monsoon and ENSO-related variability spanning nearly 500 (478) years.

2. BERLAGE JAVA TEAK CHRONOLOGY

The Berlage tree-ring width chronology was first published in 1931 and has since been reanalyzed by DeBoer (1951), Murphy and Whetton (1989), and Jacoby and D'Arrigo (1990) (Figure 2). The original Berlage chronology (1514-1929) is comprised of radii from 28 wood sections. Most are only about 50 years in age and others range from 70-280 years, with two older sections about 400 years in age. The first 120 years of record are thus based on data from only the two oldest sections. An effort was made by Berlage (1931) to match (cross-date) the patterns of ring widths among the samples, retaining 50-year overlaps among the sections used. The sample size consists of 10-22 radii from 1514-1825, and 28-29 radii after 1825, although the number of actual trees used is not clear. Some disks were considered unsuitable and were not included in the final chronology (Berlage 1931). Only the final averaged measurements were presented by Berlage (1931); to our knowledge, neither the original wood samples nor the raw measurements for the individual radii are presently available for reanalysis. Interpreting his original study, it was inferred that the dating is probably correct back until at least 1650 (Jacoby and D'Arrigo 1990). Additional details can be found in Berlage (1931), Murphy and Whetton (1989) and Jacoby and D'Arrigo (1990).

Berlage's original study and the subsequent reanalyses have established that, despite uncertainties due to low sample size in the earlier part of the record and primitive dating techniques, there is a climatic signal related to monsoon rainfall and the El Niño-Southern Oscillation (ENSO) in this chronology (Berlage 1931, DeBoer 1951, Murphy and Whetton 1989, Jacoby and D'Arrigo 1990).

Berlage (1931, 1966) found a correspondence between his chronology and the length of the wet monsoon season concurrent with growth, as well as with the intensity and duration of the prior and subsequent dry seasons. He also compared his teak variations to historical/instrumental records representative of drought and the Southern Oscillation (Berlage 1966). DeBoer (1951), using Jakarta, West Java rainfall data for 1864-1929, found that the Berlage series was correlated with the number of dry months (r=-0.43), annual cloudiness (r=0.49), and the number of rain days per year (r=0.48).

More recently, Murphy and Whetton (1989) found a significant relationship between the Berlage series and Wright's (1989) Southern Oscillation Index or SOI (1852-1929). Jacoby and D'Arrigo (1990) determined that the Berlage series correlated with Java dry season (May-October) precipitation (1892-1929, r=0.50), the length of the dry season (r=-0.51), and the SOI. SOI-teak correlations were found to be significant (P< .05) during the March-May, June-August, September-November and December-February seasons just prior to and concurrent with growth. The correlations are slightly stronger during the June-August season (Murphy and Whetton 1989, Jacoby and D'Arrigo 1990), when there is also the strongest link between Indonesian rainfall and ENSO (Hackert and Hastenrath 1986).

3. UPDATED JAVA TEAK CHRONOLOGY

3.1 Tree-Ring Data

In August of 1992, teak samples were collected from sites in central and eastern Java and Bali, Indonesia for tree-ring analysis. Teak is deciduous, shedding its leaves and producing defined annual rings in response to the pronounced dry monsoon season in these areas. With the assistance of foresters from Perum Perhutani (the state-run forestry institute), teak trees growing in a natural (unmanaged) plantation forest in the hills near Cepu (Figure 1) were

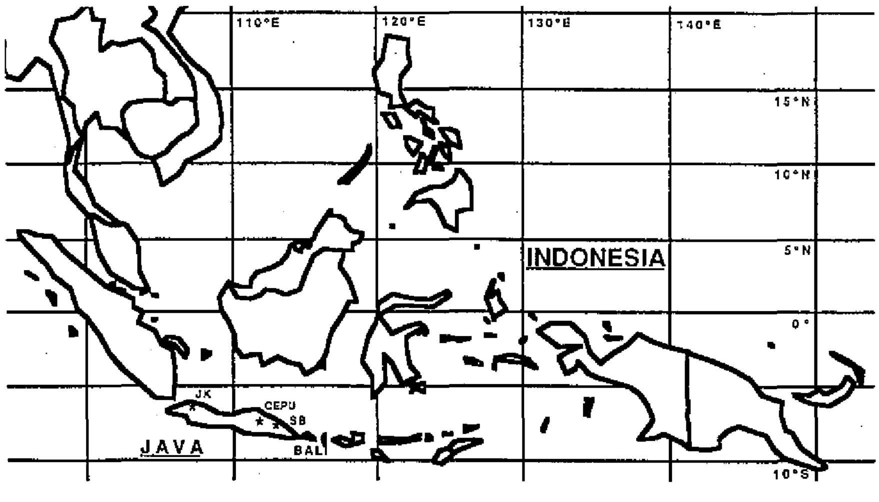

Fig. 1. Map of Indonesia and vicinity. JK = Jakarta, CEP = Cepu, SB = Surabaya.

sampled in order to update the original Berlage chronology. According to these foresters, these teak trees are among the oldest (about 100-150 yr) remaining on the island of Java for this commercially valuable species.

Figure 2 shows the original Berlage chronology (1514-1929) and Figure 3 a comparison with the recently-updated series (1880-1991). For the period of overlap (1880-1929), the correlation between the Berlage chronology and the updated series is +0.57 (Figure 3). The years 1928-1929, which Berlage (1931) suggested might have suspect values in his original data set, appear to show agreement between the two series: Berlage index in 1928=1.61, higher than previous year, 1929=.65; update index in 1928=1.189, higher than previous year, 1929=.667.

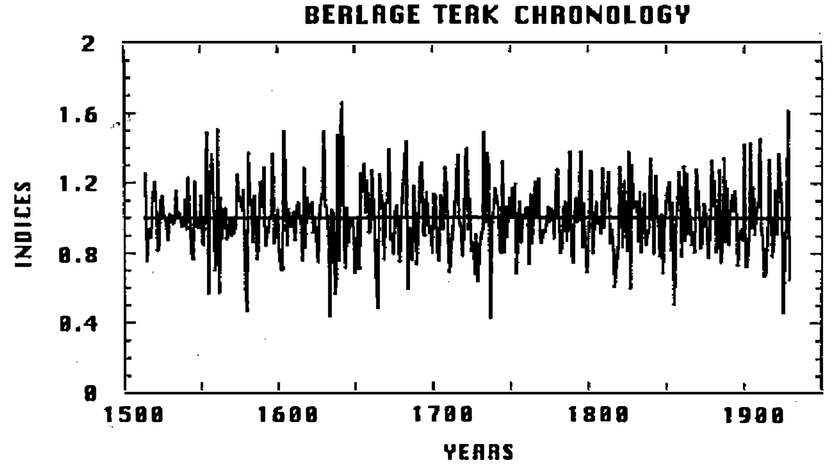

Fig. 2. Berlage (1931) teak chronology from 1514-1929. The original ring width chronology obtained from Berlage (1931) has been standardized using a 20-year smoothing spline.

The updated chronology is comprised of 19 cores from 10 trees. The series, which begins in 1870, was truncated at 1880 when there is a sample size of 4 cores from four trees. The 19 cores are a subset of those sampled at the site which could be clearly cross-dated with each other. Some attrition of samples was also mentioned by Berlage (1931). The mean correlation among all the cores in COFECHA, a computer-assisted, quality control tree-ring dating program (Holmes 1983), is 0.5. By convention, each annual ring is considered to have been formed in the year in which growth begins. In these teak trees the growing season, which coincides with the period of most abundant rainfall, is believed to begin around November (year t) and extends through to approximately May of the following year (year t+1) (Coster 1927, 1928). We decided to focus primarily on the higher-frequency variations associated with the ENSO bandwidth of around 3-7 years (Rasmusson *et al.* 1990, Barnett 1991). For this purpose, the tree-ring data were detrended using 20-year smoothing splines which remove 50% or more of the variance at frequencies over 20 years (Cook and Peters 1981, Cook *et al.* 1990). The detrending was performed as part of the standardization process using the program ARSTAN (Cook 1985).. The standard deviation of the updated chronology is .18, the mean sensitivity (an indication of high-frequency variance - Fritts 1976) is .20 and the first and second order autocorrelation coefficients are .02 and -.19.

The original and updated chronologies were merged by first creating dimensionless scores (obtained by subtracting the mean and dividing by the standard deviation) from the indices of each series for the period of overlap from 1880-1929, and then averaging the two sets of scores for this interval. Scores or growth departures for the earlier (1514-1879) Berlage series and the later (1930-1991) updated series were then spliced together on either end of the 1880-1929 interval. The resulting merged chronology is shown in Figure 4.

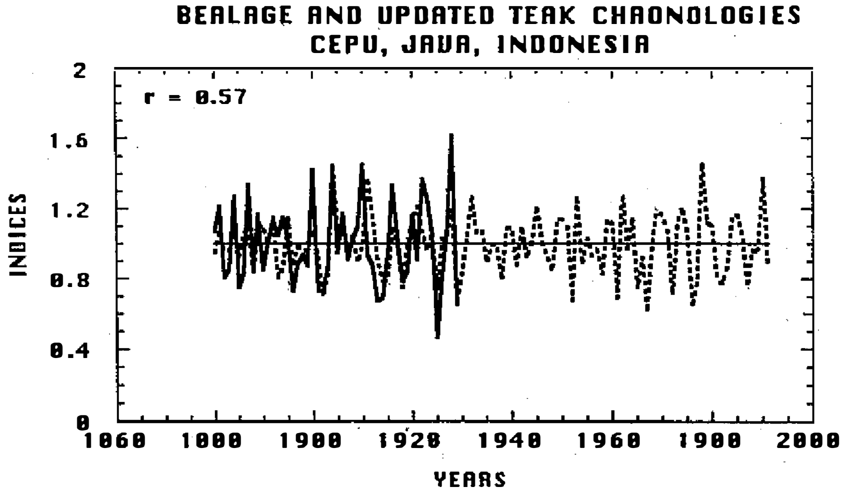

Fig. 3. Plot showing recent period of Berlage chronology and the updated chronology (1880-1991), including period of overlap from 1880-1929 (correlation between the two series for this period is 0.57).

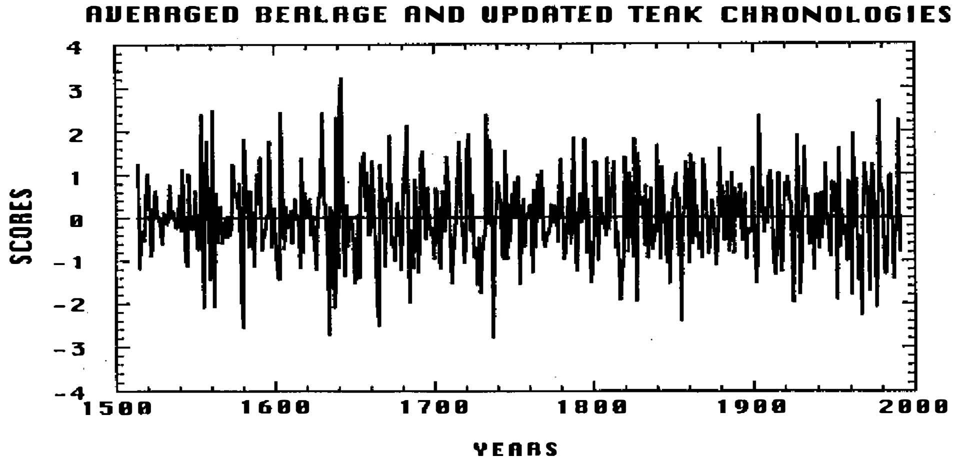

Fig. 4. Combined Berlage and updated teak chronologies for Cepu, central Java for 1514-1991. Data were merged by first calculating dimensionless scores (subtracting the mean and dividing by the standard deviation) for each of the two series for the 1880-1929 interval, and then averaging. Scores for the earlier period (Berlage, 1514-1879) and later period (update, 1930-1991) were then spliced to both ends of the overlapping data.

Palmer and Murphy (1993) have also updated the Berlage series. Their samples were obtained from ten trees at a teak plantation near Bojonegoro, east of Cepu. They have developed a chronology based on these samples which extends from 1920-1989 and overlaps the original series by ten years.

3.2 Climatic Response

The updated Cepu time series (Figure 3) demonstrates a similar climatic response to that found in the original chronology. It is well-correlated with Jakarta, West Java rainfall ($r = +.39$, $P < 0.01$) averaged over the dry monsoon months of June to September (Figure 5). Jakarta rainfall was used since it is a more complete rainfall record than the stations in East Java, allowing a comparison from 1880-1988. With this longer data set it appears that rainfall over much of the dry season, rather than only the transitional months, are influential to growth (Jacoby and D'Arrigo 1990). As was found previously, teak seems to be relatively insensitive to the amount of wet season rainfall, when moisture is generally adequate for growth (Figure 5) (Berlage 1931, 1966, Jacoby and D'Arrigo 1990). These correlations and those shown below did not differ significantly following prewhitening of the instrumental data (Box and Jenkins 1970).

The updated teak record is also significantly correlated with sea level pressure (SLP) in Jakarta, Surabaya (east of Cepu in East Java) and Darwin, northern Australia (Figures 1 and 6). Higher SLP values at these locations are associated with the warm ENSO phase, drought over Indonesia and decreased growth of teak. Darwin is one of two stations (along with Tahiti)

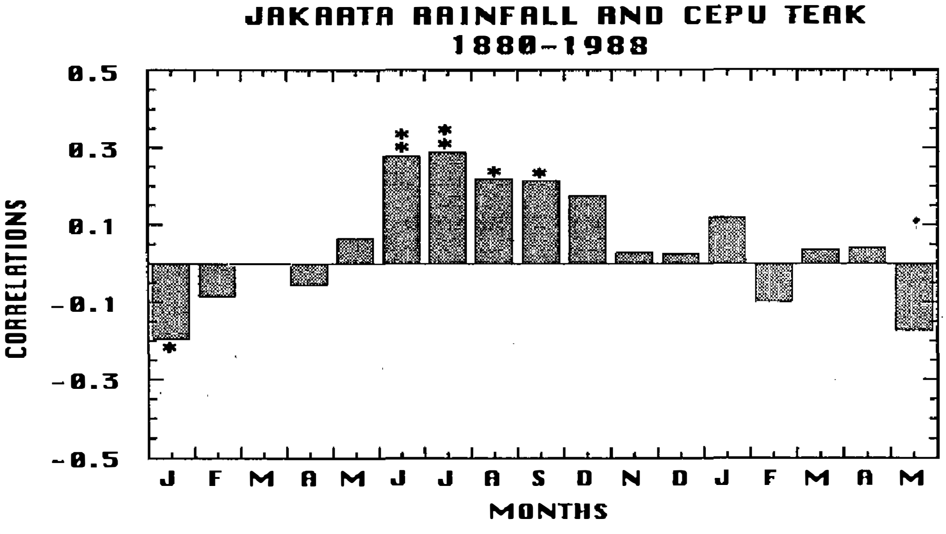

Fig. 5. Pearson correlations between monthly Jakarta precipitation and teak updated series for the common period from 1880-1988. Comparison is from January of the year that growth begins (year t) until May of the following year (t+1). Growing season for teak is from around November (year t) until May (year t+1). Significant correlations at or above the .05 (*) and .01 (**) levels are indicated. Note significant (positive) correlations with rainfall during the dry (east monsoon) season immediately preceding growth, from June to September.

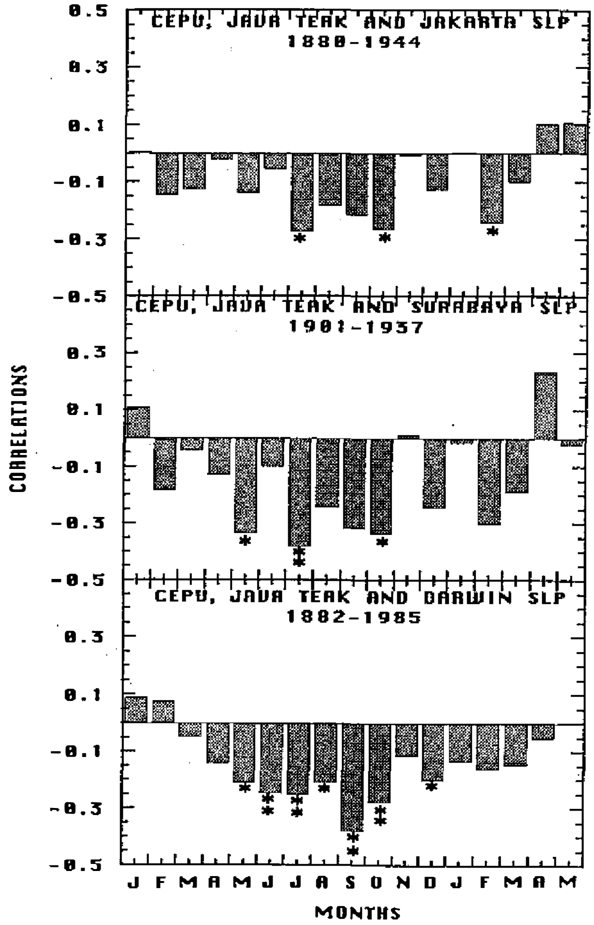

Fig. 6. Pearson correlations between monthly sea level pressure and teak updated series for three stations for available common periods: Jakarta, West Java (top), Surabaya, East Java (middle) and Darwin, northern Australia (bottom).. Levels of significance as in Figure 5. As for rainfall (Figure 5), the strongest (negative) correlations are found between teak growth and sea level pressure during the dry season just prior to period of growth.

generally used to estimate the state of ENSO in the SOI (Wright 1989). Wright's (1989) rainfall index for the central equatorial Pacific, another indicator of large-scale ENSO, shows an inverse correspondence with Java rainfall indices and with teak growth (Figures 7 and 8). This inverse relationship reflects the tendency for the Indonesian Low to migrate eastward during the warm ENSO phase, resulting in drought over Indonesia but abundant rainfall over the central and eastern Pacific (e.g. Diaz and Kiladis 1992). In most of our comparisons between teak growth and the above indices, we have found a decline in the strengths of the correlations from around 1930 to the 1950s. Also noted by other investigators, this decline may reflect a weakening in the amplitude of ENSO during this time (Michaelsen and Thompson 1992, Cole *et al.* 1993).

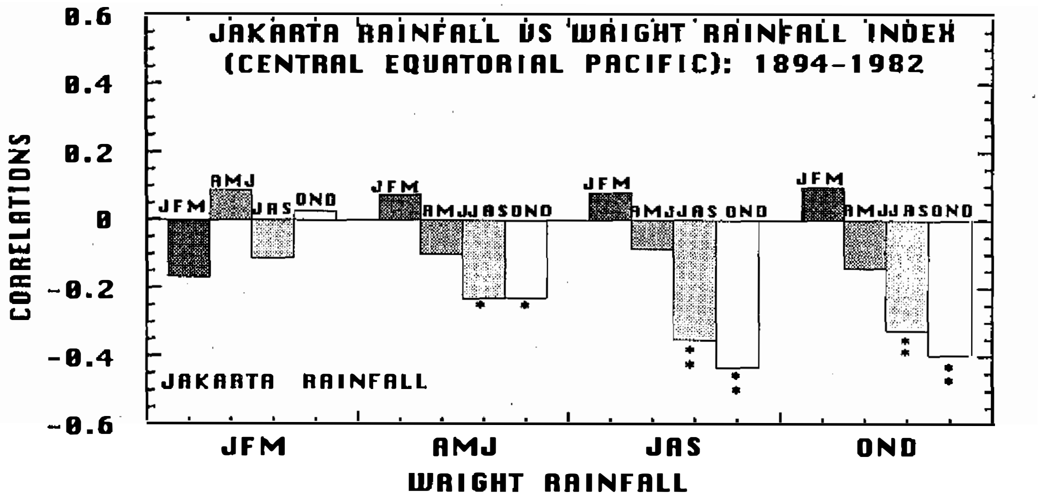

Fig. 7. Zero lag Pearson correlations between Wright's (1989) rainfall index and Jakarta rainfall for the January-March (JFM), April-June (AMJ), July-September (JAS) and October-December (OND) seasons. Levels of significance as in Figure 5. Strongest correlations occur in dry season months prior to growth period and at onset of growth period.

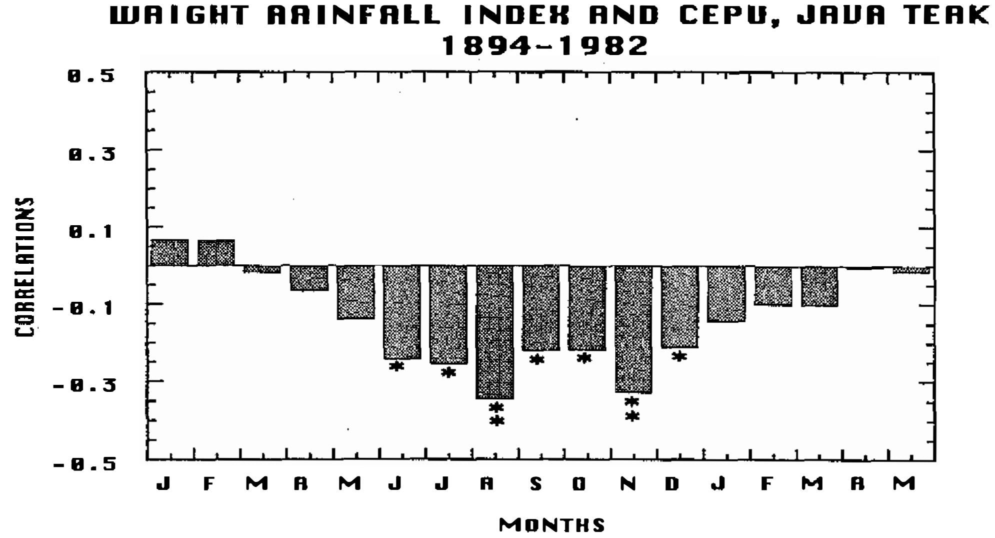

Fig. 8. Pearson correlations between Wright's (1989) rainfall index of the El Niño-Southern Oscillation for the central equatorial Pacific and the teak updated series. Levels of significance as in Figure 5. In this case the relationship with rainfall is inverse, because the migration of the Indonesian Low during the warm ENSO phase is associated with drought and decreased tree growth in Java.

3.3 Ranking of Extreme Teak Years vs. the Quinn Historical ENSO Record

We have ranked the most extreme low and high growth years in the teak series and compared them to Quinn's (1992) listing of large-scale ENSO events. Based on historical records from sites across the Pacific and Indian Ocean areas, Quinn's (1992) compilation is more likely to relate to the teak record than his regional listing of El Niños for western South America (Quinn *et al.* 1987). Previously, Jacoby and D'Arrigo (1990) compared the original Berlage record to the regional El Niño listing (Quinn *et al.* 1987). Figure 9 shows a graphical comparison between the updated Java teak chronology and Quinn's (1992, Table 6.1) large-scale ENSOs for 1880-1991. Most below-average teak departures were found to coincide with ENSO event years (starred values in Figure 9). There is a very good correspondence considering that not all ENSO events are associated with Indonesian drought (Quinn *et al.* 1978, Ropelewski and Halpert 1987). There are also some discrepancies, as discussed below.

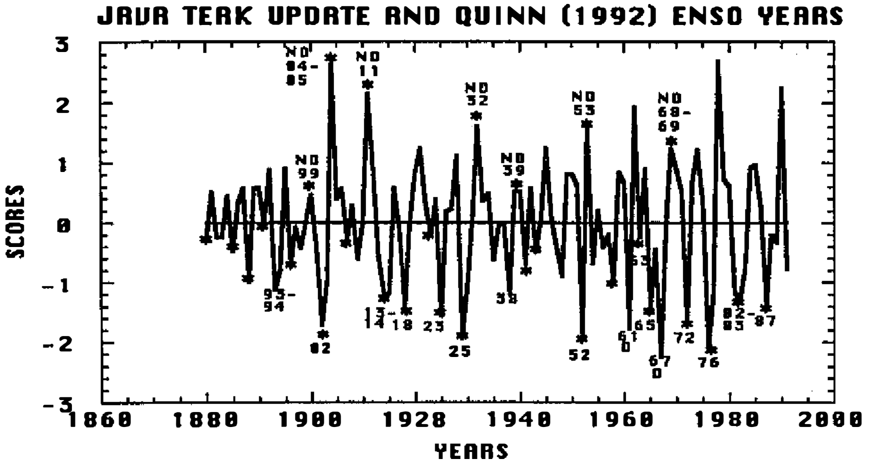

Fig. 9. Updated teak chronology scores compared with designated large-scale ENSO years (starred values) listed in Quinn (1992, Table 6.1). In most cases, below-average teak growth occurs during ENSO years. Exceptions include years of drought (D) and below-average teak growth (but not ENSO) and ENSO years of above average teak growth but no drought (ND) (see text for details).

For the original Berlage chronology from 1514-1929, the first to third lowest growth indices occur in 1737, 1634 and 1925. Both 1737 and 1925 are listed as strong (S) large-scale ENSO years in Quinn (1992), although 1737 was not listed in the regional El Niño record (Quinn *et al.* 1987). 1634 is an S event in the regional listing of Quinn *et al.* (1987) but only a moderate (M) event (in 1635) in the large-scale listing (Quinn 1992). The 1876-1878 ENSO, rated as very strong or VS (Quinn 1992), coincided with only moderate drought in Jakarta and moderately decreased teak growth. The three highest teak values, in descending order, are in 1642, 1928 and 1641 (the latter is actually rated as an S+ ENSO year by Quinn 1992).

For the more recent interval coinciding with the updated series (1880-1991), the first to third lowest index years are 1967, 1976 and 1929. 1967 is not considered to be an ENSO year (Allan and Pariwono 1990, Quinn 1992), while 1976 and 1929 are rated as M and M+ events, respectively (Quinn 1992). The ENSO years 1972 (S+) and 1925 (S) rate among the ten lowest teak values from 1880-1991. In the Palmer and Murphy (1993) update, 1967, 1972 and 1976 are not unusually low-growth years relative to adjacent rings.

The 1982-83 very strong (VS) ENSO had drastic effects in many areas of the globe, including much of Indonesia (Rasmusson and Wallace 1983, Malingreau 1987). Yet the teak growth and Jakarta dry season rainfall departures, although below average, were not extreme when taken into long-term context (Figures 3-4). This is in agreement with the results of Palmer and Murphy (1993). The 1940-41 VS event was also only slightly below average in our teak record; indices were near-average in the Palmer and Murphy (1993) series in these years. The three highest teak values in the recent record, in descending order, are 1978, 1904 and 1990. 1978 and 1904 are years of above-average Jakarta dry season rainfall; 1990 data were not available. For the combined record from 1514-1991, which were evaluated as normalized departures, 1737 and 1634 remain the lowest growth years. The ENSO years 1967, 1976 and 1925 are the sixth, ninth and 13th lowest growth departures in the combined record.

Years of ENSO but no drought: The 1904-05 (S), 1907 (M+), 1911-12 (M+), 1932 (M+), 1939 (M+), 1953 (M) and 1968-9 (M-) large-scale ENSO events did not coincide with below-average teak growth (Figure 9). These ENSOs, none of which are strong events, include several which were not associated with drought based on the Jakarta rainfall record and the listing of east monsoon drought in Table 6.3 of Quinn (1992) (Figure 9). For example, Jakarta dry season rainfall exceeded two standard deviations in 1904, and was only slightly below average in 1905 (although listed as a drought in Table 6.3). Neither the 1939 nor the 1968-69 ENSOs coincided with drought years in Indonesia, according to either Quinn's (1992) Table 6.3 or the Jakarta rainfall record.

Years of drought but no ENSO: The lowest teak tree-ring index value for the 1880-1991 updated series, as well as the most severe drought based on the Jakarta rainfall record, took place in 1967, a non-ENSO year except for the region of Australasia (Allan and Pariwono 1990). Drought also occurred in 1961 (the fourth most severe in the Jakarta rainfall record and the fifth in the updated teak series) and in 1963, a year of slightly below-average teak growth (Figure 9). No ENSO was recorded in 1961, and only a weak ENSO event was recorded in 1963 (Quinn 1992, Table 6.1). 1893-94 and 1938 were years of decreased teak growth which are not explained by ENSO's and/or dry season drought, based on either Quinn's Table 6.1 or the Jakarta rainfall record.

In some cases, discrepancies between the teak and Quinn records may be explained by decoupling between large-scale ENSO and its regional manifestation as east monsoon drought in Indonesia (Rasmusson and Wallace 1983, Quinn 1992). Differences in the seasonal phasing of ENSO, monsoon rainfall or teak growth may also account for some discrepancies. There are also uncertainties which have been acknowledged in both the Quinn (1992) and teak records (Jacoby and D'Arrigo 1990).

3.4 Integrating High-Resolution Proxy Records of ENSO

Taken together, paleoclimatic records of ENSO can reveal how individual ENSO events vary spatially across the equatorial Pacific core region and over areas of ENSO teleconnection influence (Baumgartner *et al.* 1989, Diaz *et al.* 1992). As one example we compared the updated teak chronology with coral records recently developed for sites in the equatorial Pacific (Cole *et al.* 1992, 1993). Several El Niño/ENSO events absent in the teak series are also not represented in a 96-year oxygen isotope coral record from Tarawa, at 1°N, 172°E (Cole *et al.* 1993). These include events in the years 1907 and 1932 (both M+ years in Quinn *et al.* 1992). ENSO warm anomalies were recorded in short coral records from the Galapagos, Tarawa and Bali (just east of Java) in 1963, 1965, 1969, 1972, 1976, 1982-83 and 1986-87 (Cole *et al.* 1992). All but the relatively weak 1969 event are also represented in the teak record. A weak ENSO year in 1963 is recorded in the Tarawa and Galapagos corals (Cole *et al.* 1992) and in the teak record. 1965 (S) is a stronger event than 1963 in both the teak and coral records. The 1972 and 1976 events are well represented in both the teak and coral records, with 1976 being the strongest of the two in both cases (although only listed as an M event in Quinn 1992). Yet in the Bali coral, the 1972 event is stronger than 1976. The extreme 1982-83 event, only slightly below normal in the teak record and in Jakarta dry season rainfall, was near-normal in the coral and instrumental data for Tarawa (Cole *et al.* 1992). As in the teak, the 1982-83 ENSO in the Bali coral was a less strong event than 1972. The 1986-87 (M) event is indicated by a slightly narrow ring in the teak record and is weakly recorded at Bali, although more moderately at Tarawa. During the very low growth and below average dry season in Java in 1967, there were cool-phase anomalies in Tarawa and the Galapagos, but drier conditions indicative of the warm phase were recorded in the Bali coral and instrumental records, suggesting decoupling of the westernmost Pacific from the large-scale ENSO system in 1967 (Allan and Pariwono 1990, Cole *et al.* 1992). 1961 also appears to be an example of a more regionalized, western Pacific event.

4. SPECTRAL ANALYSES

Singular spectral analysis (SSA) was performed on the teak series (Cook and D'Arrigo 1993). As mentioned, a 20-year spline was used in standardizing the teak data (Jacoby and D'Arrigo 1990) in order to remove any possible effects of forest thinning, low-frequency effects due to multiplier adjustments, and any underlying decreasing age trends (Berlage 1931). Thus only higher-frequency fluctuations were investigated herein using SSA.

In SSA, principal components analysis is applied to the autocorrelation function of that process in order to identify detailed spectral properties of time series, including amplitude and phase modulations over time (Vautard and Ghil 1989). Four significant spectral peaks ($p<.05$), ranging from 5.24-6.13 years (average = 5.68), were identified in the combined teak record. These spectra are well within the (low-frequency) bandwidth of ENSO (Rasmusson *et al.* 1990, Barnett 1991). Together, they account for over 20% of the variance in the teak chronology, and are similar to a peak of 5.8 years detected in the Tarawa coral record (Cole *et al.* 1993). The peak in the teak record is amplitude-modulated with a strong signal in the first 30 years of this century (Cook and D'Arrigo 1993). The teak spectra differ, however, from some other paleoclimatic records of ENSO. For example, a tree-ring based winter SOI reconstruction which reflects the Gulf of Mexico region of ENSO teleconnection shows a strong spectral peak at 4 years (Cleaveland *et al.* 1992). Preliminary SSA analyses indicate possible shifts in the amplitude of the teak 5.68-year period over time which are being further investigated.

Significant periodicities in the ENSO bandwidth (3-7 years) were also found in other investigations of the teak chronology (DeBoer 1951, Berlage 1966, Murphy and Whetton 1989, Palmer and Murphy 1993). For example, Palmer and Murphy (1993) found significant (95% level) peaks at 5.7 and 5.3 years, very close to our findings and to the Cole *et al.* (1993) coral series. Lower-frequency fluctuations with cycles of around 50 years and 89 years were detected by DeBoer (1951), and more recently described in detail by Murphy and Whetton (1989) and Palmer and Murphy (1993). The 89-year cycle may be linked to solar forcing, according to De Boer (1951) and Murphy and Whetton (1989). Significant (95% level) spectral peaks at 50 years and at around 30 years are described by both Murphy and Whetton (1989) and Palmer and Murphy (1993). Palmer and Murphy (1993) note that the dominant 50-year peak could be climatic in origin but may also be an artifact of chronology development of the original Berlage series.

5. FUTURE PROSPECTS

Future dendroclimatic research in Indonesia will require the identification of additional remote sites with seasonal rainfall, where old growth trees may still exist. Tree species in addition to teak which are capable of producing well-defined annual rings also need to be identified. Besides sampling at Cepu in 1992, we collected teak samples from several remote forest reserves with pronounced dry seasons, including Baluran and Alas Purwo in easternmost Java, and in western Bali. All of the teak sampled at these locations were young trees, only a few decades in age, from plantation sites. Baluran, in the northeastern and driest part of Java, was an exception, where samples from a few isolated teak trees growing in more natural wooded settings were obtained. Still, these samples only date back to the 1930s. Sulawesi, an Indonesian island less developed than Java, has pronounced rainfall seasonality and may yield remaining specimens of natural teak or other species. It may also be possible to derive chronologies by obtaining samples from historical and archaeological ruins or structures. Several tree species endemic to Irian Jaya, Indonesia and Papua New Guinea (Ogden 1982), including some which grow in alpine environments, may be sensitive to variations in temperature or precipitation related to changes in the monsoon and ENSO. As additional chronologies are developed for Indonesia, they will contribute to a growing network of chronologies of teak, pine and other species being produced for other sites in Southeast Asia (see other papers this volume).

6. SUMMARY

An update of a teak chronology from Java has been presented. The combined series provide nearly 500 years of climatic information for the data-sparse equatorial western Pacific region. Despite reservations, particularly concerning the early part of the teak record, the climatic sensitivity of this record has now been clearly demonstrated through a number of studies. The relationship with prior dry season rainfall is found to hold through the recent period. Because dry season rainfall in Java is closely linked to the behavior of the ENSO system (e.g. Hackert and Hastenrath 1986), the Java teak chronology is also found to be an index of ENSO-related variability in the western equatorial Pacific. Over 20% of the variance was retained in the teak record using SSA as a data-adaptive band-pass filtering procedure, with the aim of emphasizing the "ENSO" frequency band. Comparison with coral records from the equatorial Pacific reveals good agreement and several examples of decoupling of western Pacific anomalies from the larger-scale ENSO system. A denser network of high-resolution paleoclimatic data from both the core and teleconnection regions of ENSO will greatly improve our understanding of long-term ENSO temporal and spatial variability in the future.

*Note: Data is available on request from the authors.

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