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ORIGINAL ARTICLE

"El Niño" events recorded in dry-forest species of the lowlands of northwest Peru

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Abstract

The northwest coast of Peru (5°S, 80°W) is very sensitive to and impacted by the climate phenomenon El Niño-Southern Oscillation (ENSO). Though mainly desert, this warm, dry region contains an equatorial dry forest. We report the first dendrochronological studies from this region and identify several species that have dendrochronological potential. Short ring-width chronologies of Palo Santo (*Bursera graveolens*) show a well-developed response to the ENSO signal over the last 50 years and good inter-site correlations. Preliminary isotopic studies in Algarrobo (*Prosopis* sp.) also show evidence of the 1997–98 El Niño event. ENSO events have a strong effect on the variability in the growth of several species and thereby on the economy of rural communities where the wood is used for housing, cooking, furniture, tools, fodder and medicinal uses. The extensive use of wood in archeological sites also offers the possibility of ultimately developing longer records for some of these species.

Keywords: Dendrochronology, ENSO, tropical dry forest

Introduction

The climate and environment of the northwest coastal region of Peru are very sensitive to and most strongly impacted by the El Niño-Southern Oscillation (ENSO). The fishermen of this region gave the name El Niño to the southward oceanic countercurrent of warming water (Carrillo, 1892) that is the most obvious manifestation of this phenomenon. The Spanish landed in this area in 1528 and their historical records provide the first historical documentation of an El Niño (though not by that name) in 1532 during the epoch of the Spanish conquest (Hamilton and Garcia, 1986). Some authors assume that Pizarro's march in this region "was possible only because he chanced to land upon the desert shores during one" (an El Niño year is usually a year of abundance; Sears, 1895; Murphy, 1926). Piura was the first Peruvian city found by the Spanish in July or August of 1532. The documentary records from this region are a primary source of the historical compilations of El Niño back into the mid sixteenth century (Quinn et al., 1987; Ortlieb, 2000).

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Given the sensitivity of this region to El Niño, it should be possible to develop natural proxy records for ENSO events including biological and geomorphological archives such as tree rings, sediments and beach-ridge series (Machare and Ortlieb, 1993). However, dendrochronological research in this region began at the University of Piura (UDEP) in the late 1980s and no prior work on the tree species of the region had been undertaken. In 2001, the first tree-ring laboratory in Peru was installed at UDEP with Inter-American Institute (IAI) for Global Change Research funding (Rodriguez, 2002). Using these facilities, we have explored the dendrochronological potential of several tropical species of the region and developed the first, short, dendroclimate series relative to ENSO in Peru. These results are presented briefly with some other potential applications of dendrochronology in this region.

The dry forests of northwest Peru

The extreme northwest of Peru is close to the equator and is the western-most area of South-America (approximately 5°S, 80°W, Fig. 1). This coastal region extends from 3°S to 7°S, is relatively flat and much wider than elsewhere in Peru, extending almost 140 km from the Pacific Ocean to the western slope of the Andean cordillera. Most of this area is covered by the Sechura desert between 6°S and 7°S (ca 3000 km^2). This relatively flat area is broken by a short SW–NE trending chain of hills called ''Amotape Mountain'' located at about 4°S.

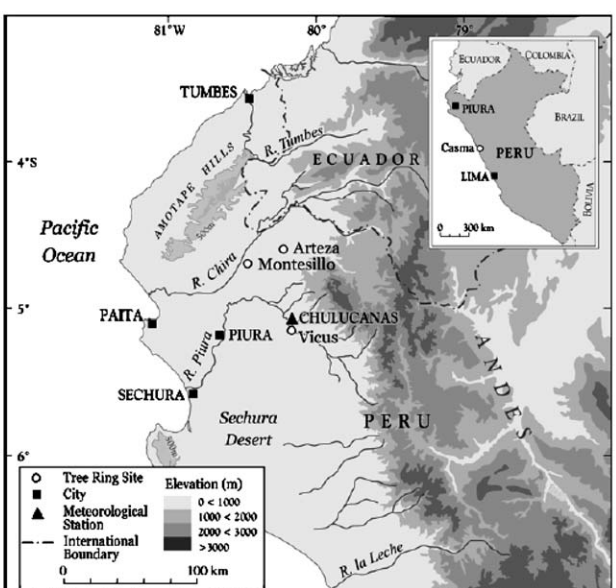

Fig. 1. Map of northwestern Peru showing the coastal region that contains the equatorial dry forest and Sechura desert.

The Tumbes, Chira and Piura Rivers cross this region flowing through fertile valleys from the Andes to the coast. This region is occupied by the states of Tumbes and Piura with an area of ca. 40500 km^2 and by about two million inhabitants.

The climate of this area is normally warm and dry with a rainfall of less than 50 mm per year for altitudes below 500 m. It is strongly influenced by the cool oceanic current Humboldt which flows northwards along the Peruvian coast. During El Niño events this arid climate is replaced by a humid tropical climate rainfall in the coastal region that can exceed 1000 mm during a very strong El Niño year.

Parts of the lowlands and foothills of the Andes contain an *Equatorial dry forest* or ''*Algarrobal*'' between 3°S and 7°S with a wide range of tree species. The typical tree species in this habitat are Algarrobo (*Prosopis* sp.) Faique (*Acacia Macracantha*), Hualtaco (*Loxopterygium huasango*), Huayacan (*Tecoma* sp.), Palo Santo (*Bursera Graveolens*), Pasayo (*Eryotheca ruizii*), Overal (*Cordia Lutea*), Vichayo (*Capparis Ovalifolia*) and Zapote (*Capparis Angulata*). Algarrobo is the most common tree in the lowland part of this forest (Díaz, 1995). Some species show clear tree-rings indicating their potential use in dendrochronological research (Fig. 2).

ENSO events have important effects on tree growth in these dry forests. During El Niño precipitation events, the dry forest is transformed into a green forest with increased growth of all species that provides additional pasture and wood resources for rural communities. In this way El Niño has a positive impact on the economy of those communities. However, these benefits must be counterbalanced with the severe negative impacts related to ones to floods and fishing activities in some

Fig. 2. The dry forest of northwest Peru on Saucesito (04°29′S, 80°42′W) in Piura. The tree being cored is a Pasayo (*Eryotheca ruizii*). Photograph by M. Evans, June 2004.

extreme events. Flooding destroys transportation routes and farm infrastructures decreasing agricultural productivity. Fishing productivity is low because of the migration or death of species that are normally harvested in this environment during an ENSO (Glantz, 1998). Several changes in the flora and vegetation of the Algarrobal (desert forest) and Lomas (fog oasis) vegetation associations of the Peruvian coast have been observed during an El Niño event. The increased availability of water resources leads to large influx of species into these ecosystems which may persist for more than a year before the return to more ''normal'' conditions (Ferreira, 1993). In some cases major El Niño wet events can result in forest recolonization in arid areas of the Sechura desert. Recent dendroecological research on Algarrobo shows that these events are important triggering factors in the natural regeneration of this species into desert areas (Holmgren and Scheffer, 2001).

The first Peruvian dendrochronological records containing an ENSO signal

Exploratory studies have been carried out on the species of this forest to establish their dendrochronological potential and, if possible, find evidence of past ENSO events. So far we have identified six species with potential to be used in dendrochronological research. They are Algarrobo (*Prosopis Juliflora*), Hualtaco (*L. huasango*), Palo Santo (*B. Graveolens*), Pasayo (*E. ruizii*), and Overal (*Cordia Lutea*). All these trees are deciduous except for *Prosopis.* We have primarily

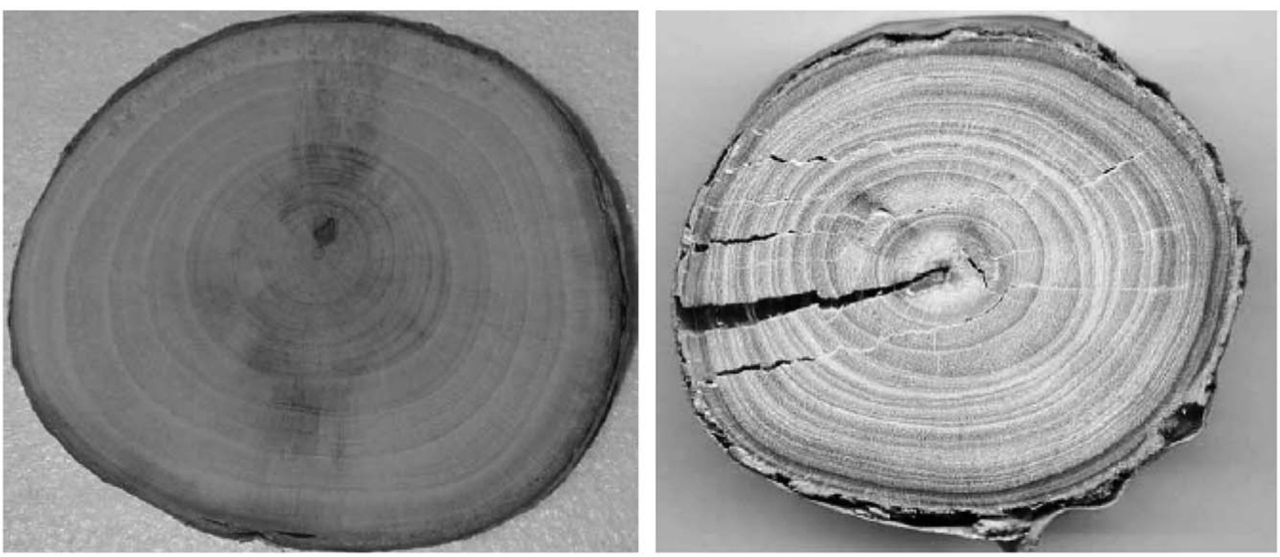

Fig. 3. Cross-sections of (left) Palo Santo (*Bursera graveolens*) and (right) Overal (*Cordia lutea*) which show clear annual tree rings.

Table 1. Summary of the chronology characteristics for the three Palo Santo chronologies

Site	Arteza Hill	Montesillo Hill	Vicus Hill	Composite
Latitude	04°35′43″S	04°41′36″S	05°09′00″S	
Longitude	80°13′21″W	80°27′54″W	80°10′00″W	
Altitude (m)	589	133	250	
Number of cores	11	19	43	
Mean length (cm)	30	38.6	28.2	
Mean ringwidth (mm)	8.03	5.73	5.29	5.39
% missing rings	5.15	2.18	4.62	
Chronology length	1967–2001	1953–2001	1964–2001	1953–2001
Mean inter-core correlation	0.68	0.53	0.71	
Mean sensitivity	0.65	0.62	0.73	
Inter-chronology correlation	ART/MON 0.85	MON/VIC 0.72	VIC/ART 0.74	
Correlation with precipitation	0.86	0.83	0.69	0.84

targeted Palo Santo because of the clarity of its tree rings but several other species show annual tree rings and the potential for crossdating and chronology development (Fig. 3). As with other dry-forest species, Palo Santo grows after precipitation events but, as these events are confined to the summer season (typically and mostly in January, February and March), it provides an annual ring. In this species the large earlywood cells and small latewood cells are well defined allowing relatively easy definition of ring boundaries. The crossdating of series between radii, between trees and between chronologies (see below and Table 1) confirms that the measured features are annual ring series. In this paper, we report the first tree-ring series obtained from Palo Santo.

The first preliminary chronology that we developed was for Palo Santo from Vicus Hill (5°09′S, 80°10′W), close to Chulucanas. This series was 38 years long (1954–2001) based on 23 cores and showed the record of two last major ENSO events (1982–83 and 1997–98) as wide rings in almost all cores sampled. Subsequent work with cores and cross-sections has revised this chronology to 38 years (1964–2001; the oldest cores no longer crossdate) based on 43 series with normally two cores per tree. The mean ring width of these series is 5.29 mm although in major El Niño years (1982–83, 1991–92, and

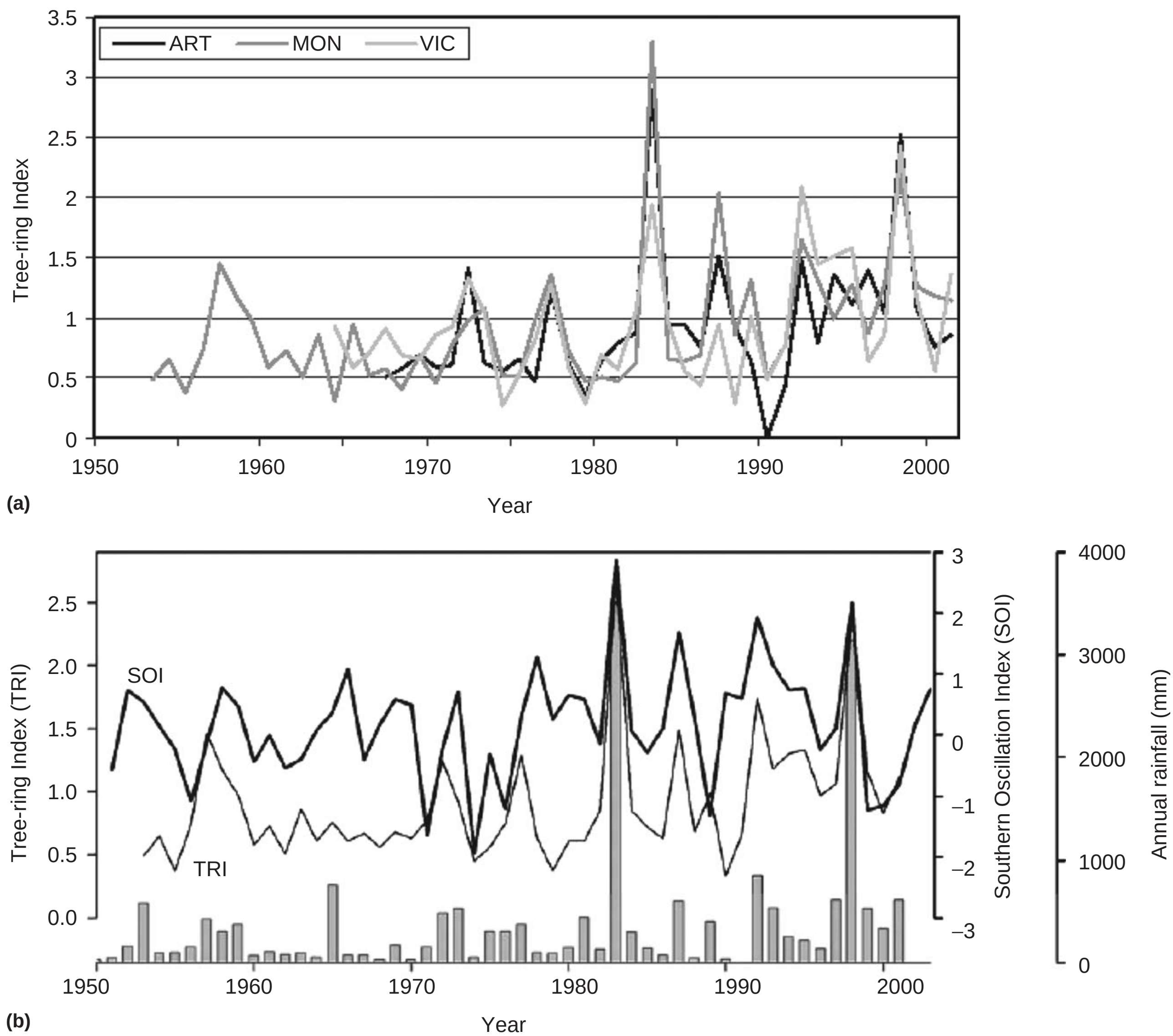

Fig. 4. (a) Standard ARSTAN tree-ring index chronologies of Palo Santo (*Bursera graveolens*) for three sites: Vicus, Montesillo and Arteza Hills, showing similar patterns of variations. (b) Comparison of a mean chronology of Palo Santo (*Bursera graveolens*) at Vicus, Montesillo and Arteza Hills with annual rainfall at Chulucanas, Piura and a mean November–April Southern Oscillation Index (SOI, Ropelewski and Jones, 1987). SOI monthly values were downloaded from the Climate Research Unit, University of East Anglia, UK (http://www.cru.uea.ac.uk/cru/data/soi.htm), and are inverted (multiplied by −1) to aid comparison with the tree-ring and rainfall data.

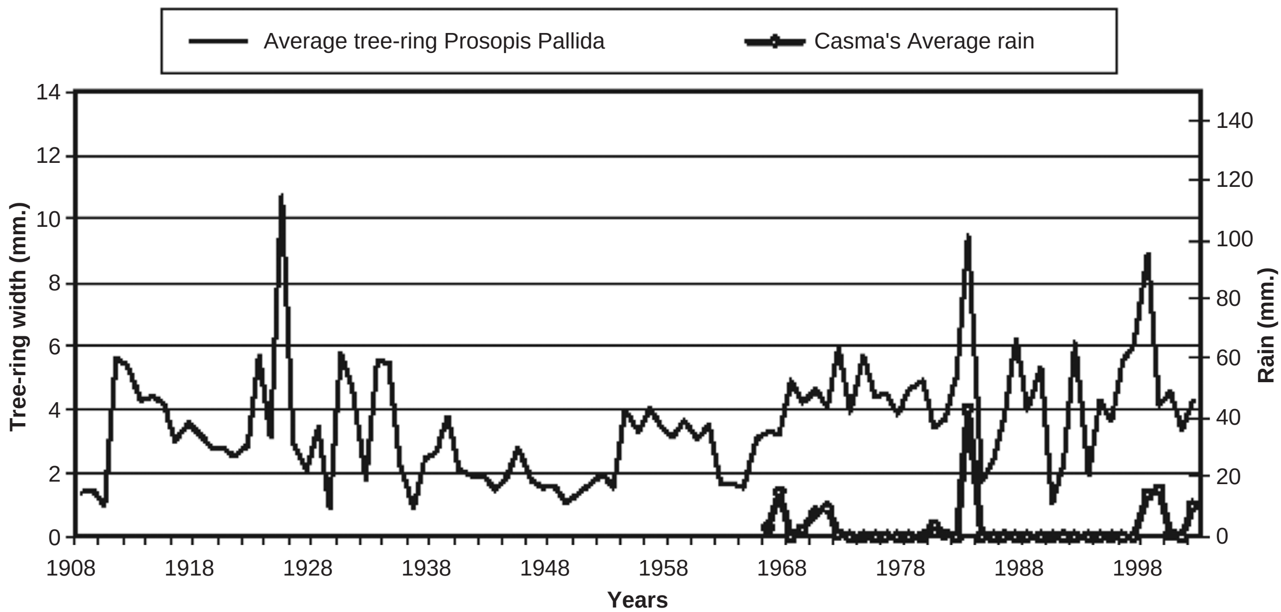

Fig. 5. 1906–2002 ring-width chronology for Algarrobo (Prosopis pallida) at San Rafael (Casma) compared with the instrumental record of precipitation at Casma.

1997–98) mean ring widths exceed 10 mm. The correlation between the ARSTAN standard chronology and January–December annual rainfall at Chulucanas is 0.69 ($n = 38, P < 0.001$).

We have begun to extend the spatial network and length of Palo Santo chronologies across the region. Chronologies for Montesillo (1953–2001, 19 cores) and for Arteza Hills (1967–2001, 11 cores) show similar results to those from Vicus Hill (Fig. 4a). A composite chronology from these three series clearly shows an ENSO signal with an average recurrence period of about 5 years (Fig. 4b). This composite chronology has a positive correlation of 0.84 ($n = 49, P < 0.001$) with annual precipitation (Fig. 4b). The correlation coefficient of the log-transformed series is somewhat less but still highly significant ($r = 0.73, n = 49, P < 0.001$). A statistically significant negative correlation of -0.54 ($n = 49, P < 0.001$) was also found with a mean November–April Southern Oscillation Index (SOI, Ropelewski and Jones, 1987, Fig. 4b). In addition to work with Palo Santo, we have also developed a 95-year-long chronology for Algarrobo at Casma that clearly shows the strong El Niño events of 1925, 1982–83 and 1997–98 (Fig. 5). This chronology has a significant correlation ($r = 0.53, n = 35, P < 0.001$) with January–December annual rainfall totals at Casma. Although the records we have developed to date are short, these results clearly indicate the potential to recover proxies for annual precipitation data and reconstruct El Niños from these equatorial tree-ring species.

Many tropical tree species do not contain well-defined annual rings and, in conjunction with the Laboratory of Tree-Ring Research (LTRR) at the University of Arizona, we are also working to develop stable isotope records from several species in this region. These may allow us to estimate past rainfall variations associated with ENSO and also, possibly, provide chronological control for trees with well-defined intra-annual isotopic variation. Preliminary results from a single Algarrobo from the Piura area indicate a strong isotopic "signal" probably related to the 1997–98 ENSO event (Evans and Schrag, 2004, Fig. 6).

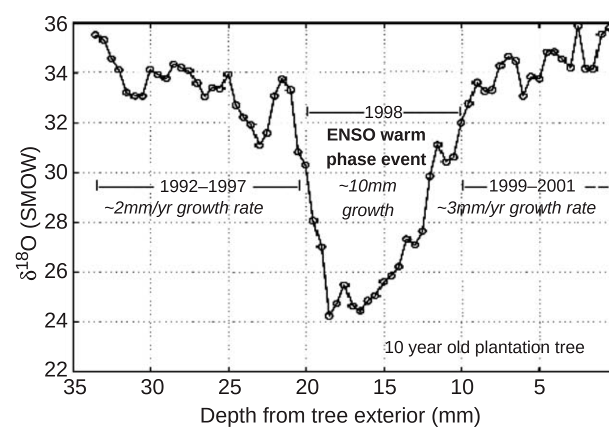

Fig. 6. Oxygen isotope (δ^{18}O) analysis of a Prosopis sample from Piura carried out at Laboratory of Tree-ring Research (LTRR), University of Arizona, USA. It shows isotopic variation along a 35 mm long section from a 10-year old tree. There is a strong signal probably due to the ENSO event of 1997–98 (After Evans and Schrag, 2004).

Applied studies

These tree-ring studies provide the first data on tree growth and productivity for several species in this dry and normally arid environment. Many rural communities depend on the dry forest for products that are the basis of their life and economic activity. They use the wood of the dry-forest species (and particularly Algarrobo) for housing, furniture, fuel and in some cases sell it as firewood or charcoal (Díaz, 1995). Palo Santo is a light aromatic wood used for boxes, medicinal purposes and is burnt to keep away mosquitoes. The dry forest also provides pasture for domestic animals that villagers rise for food and commercial purposes. As wood availability and animal pasturage depend on forest growth, variations in forest productivity and growth can have considerable economic impacts on the rural population. It is therefore important to document this productivity to determine long-term sustainable yields from these forests.

Conclusions

Lowland, coastal and equatorial, this environment is not one where conventional dendrochronological studies would be expected to yield promising results. However, although the chronologies developed to date are quite short, these studies have demonstrated that several species have dendrochronological and dendroclimatic potential. Much work will be needed to extend these chronologies back in time but there is considerable additional potential from historical buildings and archeological sites that range in age between 10000 BC and 1532 AD. Even limited floating chronologies may provide useful information about the former environments of these sites. Preliminary isotope dendroclimatology studies also indicate the potential to recover past rainfall variability from some species that may also be used in reconstructions of paleoenvironments of archeological sites as well as more contemporary environments.

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