Global and Planetary Change 127 (2015) 58–66

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Tree-ring $\delta^{18}O$ in African mahogany (*Entandrophragma utile*) records regional precipitation and can be used for climate reconstructions

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ARTICLE INFO

Article history:
Received 5 July 2014
Received in revised form 16 January 2015
Accepted 22 January 2015
Available online 29 January 2015

Keywords:
oxygen stable isotopes
tree rings
Entandrophragma utile
rainfall variability
climate reconstruction
Cameroon

ABSTRACT

The availability of instrumental climate data in West and Central Africa is very restricted, both in space and time. This limits the understanding of the regional climate system and the monitoring of climate change and causes a need for proxies that allow the reconstruction of paleoclimatic variability. Here we show that oxygen isotope values ($\delta^{18}O$) in tree rings of *Entandrophragma utile* from North-western Cameroon correlate to precipitation on a regional to sub-continental scale (1930–2009). All found correlations were negative, following the proposed recording of the 'amount effect' by trees in the tropics. The capacity of *E. utile* to record the variability of regional precipitation is also confirmed by the significant correlation of tree-ring $\delta^{18}O$ with river discharge data (1944–1983), outgoing longwave radiation (a proxy for cloud cover; 1974–2011) and sea surface salinity in the Gulf of Guinea (1950–2011). Furthermore, the high values in the $\delta^{18}O$ chronology from 1970 onwards coincide with the Sahel drought period. Given that *E. utile* presents clear annual growth rings, has a wide-spread distribution in tropical Africa and is long lived (>250 years), we argue that the analysis of oxygen isotopes in growth rings of this species is a promising tool for the study of paleoclimatic variability during the last centuries in West and Central Africa.

1 . Introduction

The availability of instrumental climate data in West and Central Africa is very limited in both space and time, and constrains the understanding of climate variability in the regional and the ability to predict future changes (Washington et al., 2013; Gebrekirstos et al., 2014). The restricted availability of instrumental data causes a need for proxies that allow the reconstruction of climatic variability in the past. Such proxies records in Africa include stable isotope time series from lake sediment cores (Shanahan et al., 2009), ice cores (Thompson et al., 2002), speleothems (Talma and Vogel, 1992) and rock hyrax middens (Chase et al., 2010). These records are often long (spanning millennia), but generally coarse-scaled (with several years to decades between measurement points). A relatively new and promising tool for high-resolution (annually resolved) climate reconstructions on a centennial scale is the study of stable oxygen isotopes ($\delta^{18}O$) in growth rings of tropical trees (Zuidema et al., 2013). From these oxygen isotopes, information on large-scale atmospheric processes and precipitation over vast areas has been derived (Brienen et al., 2012; Schollaen et al., 2013b). The relation between tree-ring $\delta^{18}O$ and climate is based on the ability of trees to record the $\delta^{18}O$ variability of rainwater, which in the sub-tropics and tropics, is strongly determined by the amount of rainfall (Dansgaard, 1964). Often, this relation is more pronounced between rainwater $\delta^{18}O$ and the precipitation amount on a regional scale than at the individual cloud level (Kurita et al., 2009). Trees that record the $\delta^{18}O$ variability of precipitation in their growth rings can thus be archives of the amount of precipitation on large spatial scales (e.g. Brienen et al., 2012).

Previous studies have related tree-ring $\delta^{18}O$ to basin-wide precipitation in the Amazon (Ballantyne et al., 2011; Brienen et al., 2012), regional precipitation in Thailand (Poussart and Schrag, 2005) and Indonesia (Schollaen et al., 2013b) and to El Niño Southern Oscillation (ENSO) variability in Laos (Xu et al., 2011). So far, a few pilot studies on tree-ring $\delta^{18}O$ have been conducted in dry African regions (Verheyden et al., 2004; Gebrekirstos et al., 2011), but to our knowledge no study has been conducted in Africa's wet tropics (precipitation > 1500 mm). Here, we evaluated the climate signals in tree-ring $\delta^{18}O$ of an African mahogany species (*Entandrophragma utile*) from North-western Cameroon. To this end, we assessed (1) if growth rings in *E. utile* can be reliably dated, (2) if $\delta^{18}O$ values of multiple trees show a strong common signal and (3) whether a common $\delta^{18}O$ signal can be correlated to climatic variables that record regional precipitation. Because reliable meteorological data are scarce in the region we also used indirect proxies for regional climatic variability, including river discharge data, sea surface salinity, sea surface temperature and outgoing longwave radiation. We consider *E. utile* to be a species with a high potential for usage in climate reconstructions, because of its wide-spread distribution in tropical Africa, the presence of clear annual growth rings and a long lifespan (>250 years).

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http://dx.doi.org/10.1016/j.gloplacha.2015.01.014
0921-8181/

2 . Material and methods

2.1. Regional setting

Trees were sampled inside the FSC-certified Forest Management Unit 11.001, of Transformation REEF Cameroon. This area is adjacent to the northwest border of Korup National park, in the Southwest Region of Cameroon, between 5°23′N, 9°09′E and 5°23′N, 9°12′E (Fig. 1a). The vegetation in the region consists of semi-deciduous lowland rainforest. The regional climate is equatorial, with a unimodal rainfall distribution and a dry season (with monthly rainfall < 100 mm) from December to February (Fig. 1b). Total annual precipitation varies strongly in the region. From 1968 to 2010, average annual precipitation amounted 2920 mm (range: 2070–3690 mm) at the Mamfé Airport weather station, ~40 km north of the study area, whereas at Mundemba meteorological station, ~40 km south of the study area, annual precipitation averaged 5220 mm (range: 3151–9345 mm). From these nearby records we estimate that at our site, annual precipitation is approximately 4000 mm and mean annual temperature approximately 26.5 °C (Fig. 1b).

2.2. Study species

The study species, *E. utile* (also known as Sipo), is a shade-tolerant from the family Meliaceae. The species is deciduous and leafless from around January and February. The potential growing season at this location runs roughly from March to November. *E. utile* is an emergent tree species, which can reach a maximum age of around 260 years (Nzogang, 2009), a maximum dbh of 250 cm and a total canopy height of up to 60 m (Voorhoeve, 1965). It is found in tropical Africa from Guinea to Togo and from Benin to Uganda and Angola, preferring fertile and well-drained soils in both upland evergreen forests and semi-deciduous moist- and dry forests (Poorter et al., 2004). The annual nature of ring formation in this species has been demonstrated by Hummel (1946), Mariaux (1981) and more recently by Groenendijk et al. (2014). Ring boundaries are characterized by the formation of a band of terminal parenchyma (Fig. 1c).

2.3. Sample collection and preparation

Entire stem discs at ~1 m height were collected from five large trees that were felled during selective logging operations in March–April 2012. No logging had taken place in the area prior to 2012. The trees were collected from an area of 1600 ha. After drying, the surfaces of the stem discs were polished with sandpaper of grids up to of 600 grains/cm^2. Part of the disc was also cut with razor blades to enhance the visibility of the rings. Ring identification took place using a LINTAB 6 measuring table (Rinntech, Germany), but ring widths were measured using high-resolution scans (1600 dpi) and WinDendro software (Regent Instruments, Canada). We checked the dating of the rings in two ways, first by visually cross-dating the ring-width series from different directions on the same disc and secondly, by cross-dating the ring-width series of different trees. Because the latter proved difficult, we checked the quality of dating by radio-carbon (^{14}C) dating (Worbes et al., 2003). ^{14}C-values were determined for 9 rings from three different trees (Accelerator Mass Spectrometer, University of Groningen, the Netherlands).

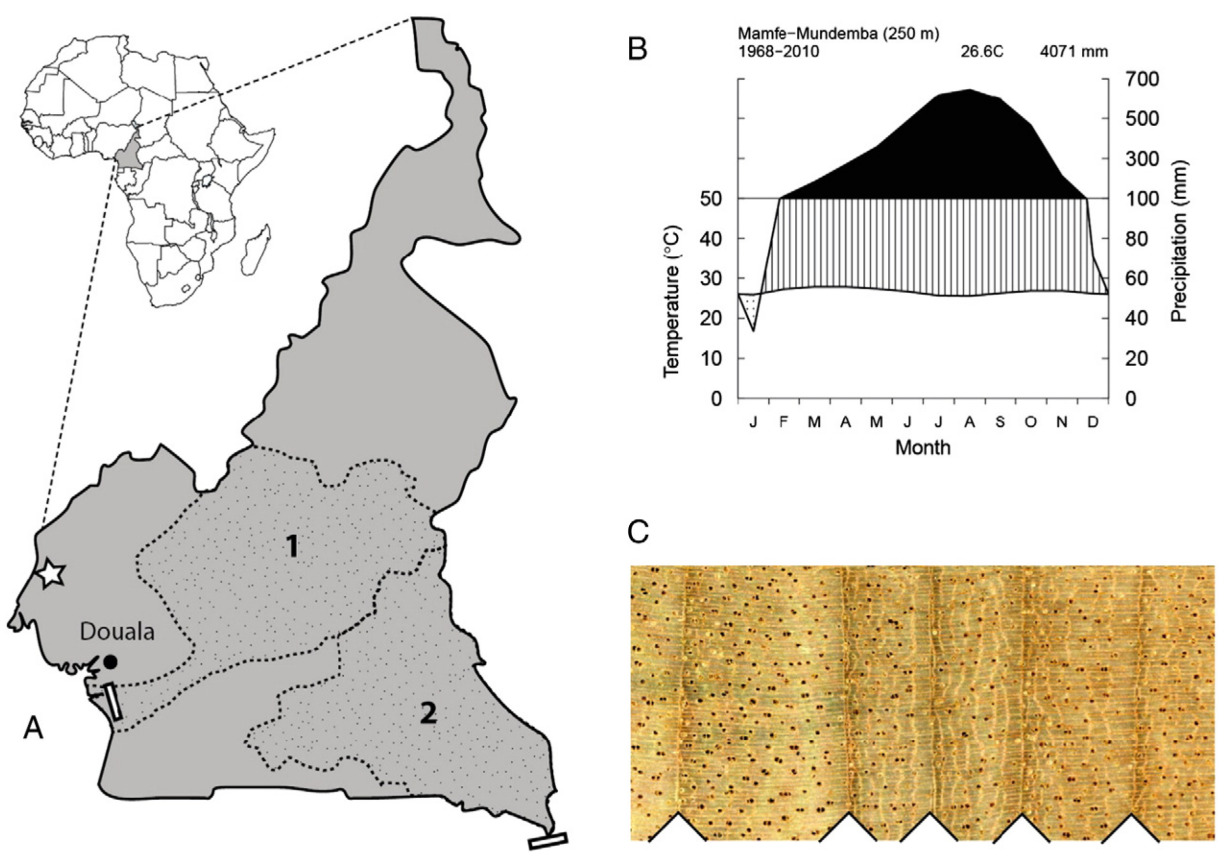

Fig. 1. (A) Map of Cameroon with the location of the sampled trees (indicated by the star), the Sanaga river basin (1) and the Cameroonian half of the Sangha river basin (2). White blocks indicate where river discharge was measured; black scale bar represents a distance of 200 km. (B) Climate diagram for the study site. Monthly precipitation and temperature (1968–2010) of two nearby stations were averaged: Mamfé Airport weather station (40 km north of study site) and Mundemba (40 km south of the study site). Dotted area indicates the dry season (precipitation < 100 mm/month), black area the rainy season (> 100 mm/month). (C) Growth rings in the wood of *Entandrophragma utile*. Triangles indicate ring boundaries (characterized by a band of terminal parenchyma).