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Potential of tree-ring analysis in a wet tropical forest: A case study on 22 commercial tree species in Central Africa

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ABSTRACT

Implementing sustainable forest management requires basic information on growth, ages, reproduction and survival of exploited tree species. This information is generally derived from permanent sample plots where individual trees are monitored. Accurately estimating growth rates and especially tree ages from plots is however challenging, as plots often contain only few individuals of the exploited species and monitoring periods cover only a fraction of the life-span of most trees.

Alternatively, tree-ring analysis is increasingly used to obtain accurate age estimates and growth rates for tropical tree species, especially in regions with seasonally harsh conditions. However, for species from wet tropical forests (>4000 mm year^{-1} rainfall) few tree-ring studies exist. Under persistent high levels of rainfall, formation of distinct tree rings is uncertain due to the lack of strong seasonal variation in climate factors. Here we evaluated the potential of applying tree-ring analysis on commercial tree species in a wet tropical forest in Central-Africa. For this purpose we screened the wood anatomy of 22 tree species for the presence of tree-ring structures and, on a subset of five species, we assessed crossdating potential and evaluated the annual character of tree-ring formation by radiocarbon dating.

A total of 14 of the 22 tree species showed distinct tree-ring boundaries. Radiocarbon proved annual tree-ring formation in four of the five tested species. Crossdating between trees was problematic for all species and impeded exactly dating each detected ring and building tree-ring chronologies. We also show that diameter growth rates vary strongly between and among species, with important consequences for the calculation of future timber yields.

Tree-ring analysis can thus be applied on tree species growing in wet tropical forests to obtain growth rates. We argue that tree-ring analysis should actually be applied on more tree species from different areas to obtain accurate, site specific growth data. This data is urgently required to design and improve sustainable forest management practices.

1. Introduction

While constituting the world's second largest tropical forest belt, the West and Central African rain forests are relatively poorly studied. Over 44 million hectares of these forests have been designated for selective logging (Bayol et al., 2012). Sustainable management of these forests is hence essential to ensure a continued supply of timber without affecting their services and functions (e.g., carbon retention). Planning sustainable forest management requires basic ecological information of the exploited species (e.g., age, growth trajectories, regeneration and survival). This information can for instance be used to calculate future timber yields in selective logging operations (e.g., Rozendaal et al., 2010). Despite the relevance for designing and evaluating forest management, such calculations have only been performed for a limited set of tropical tree species worldwide and are almost absent in Africa (Putz et al., 2012; De Ridder et al., 2013b). This paucity of studies is worrisome seen the importance of and great public attention given to sustainable management of (African) tropical forests.

In tropical forestry research, basic ecological information on exploited tree species – diameter growth rates and ages – is commonly obtained from measurements of trees in Permanent Sample Plots (PSPs). The contribution of PSPs to providing this information on African timber species has, however, remained very limited. PSPs are still scarce in tropical Africa (Verbeeck et al., 2011) and the uneven geographical distribution of PSPs implies that information on commercially important forest areas is missing (Picard et al., 2010). In addition, most PSPs are small, typically one hectare,

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and therefore contain only few individuals of commercial tree species, which typically occur at densities of <5 trees ha^{-1} (Poorter et al., 1996; Hall et al., 2003). And finally, the monitoring period of most PSPs spans just a fraction of the ages of trees, often resulting in biased tree-age estimations (Martínez-Ramos and Alvarez-Buylla, 1998) leading to a lack of accurate long-term data on ages and growth of commercial tree species.

An alternative and relatively fast approach to obtain tree ages and growth data is the use of tree-ring analysis (Brienen and Zuidema, 2006a; Schöngart et al., 2006; Rozendaal et al., 2010). Data obtained from tree rings typically consider information on growth across the entire life-span of trees and can thus be used to calculate ages and growth trajectories of logged trees. These data can also be used to calculate ages of trees to reach the legally set logging diameters (minimum cutting diameter, MCD). For forest management, tree-ring analysis can thus be used to supplement data from PSPs. In Africa, tree-ring studies have mostly been performed in dry, sub-tropical areas outside important wood-producing areas (e.g., Dunwiddie and LaMarche, 1980; Till and Guiot, 1990; Gourlay, 1995; Stahle et al., 1999; Tarhule and Hughes, 2002; Wils et al., 2010,2011). Despite the knowledge that many commercial tree species in tropical Africa form annual rings (Mariaux, 1967; Détienne, 1989), tree-ring analysis has hardly been applied to aid forest management in West and Central Africa (De Ridder et al., 2013b; Gebrekirstos et al., 2014) and never so in wet forests of these regions.

Working with tree rings in tropical wet forests presents specific challenges. Under such persistently wet conditions, growth of trees has suggested to be continuous (Raven et al., 1999) and distinct annual tree rings to be absent (Swaine, 1994; Kurokawa et al., 2003). Although annual tree-rings formation has been proved for species growing in wet tropical forests (Fichtler et al., 2003), the absence of strong growth-limiting environmental factors can result in only weak variation in cambium activity. This weaker cambium activity with increasing precipitation levels may thus lead to less variation in wood anatomy and hence in tree-ring visibility (Moya and Filho, 2009). Lack of a growth-limiting factor that synchronises cambium activity in a given species also leads to varying growth patterns among individual trees, as local growing conditions are likely more influential than climate factors. This reduction of the 'common signal' in tree growth also affects crossdating and hampers chronology building for tree populations growing under very wet conditions (Fritts, 1976). Thus, for tree-ring studies in wet tropical forests, identifying ring boundaries and investigating their annual character is essential prior to obtaining growth data and tree ages.

Here we present results of a tree-ring study on commercial tree species in a wet (~4100 mm rainfall year^{-1}) lowland tropical forest in the Southwest province of Cameroon. We first performed a screening for tree-ring boundaries in the wood of 22 commercial species. We expected to find distinct tree-ring boundaries in several species. The presence of a dry season and the seasonality in phenology (15 of the 22 species have a (brevi-)deciduous character) may induce periodic cambial dormancy, causing the formation of tree-ring boundaries. Next, we performed a more detailed analysis on a subset of five species showing clear tree-ring boundaries. We assessed the crossdating potential of these species and tested the annual character of tree-ring formation by radiocarbon dating. Finally, we described diameter-growth patterns and determined maximum tree ages and ages at minimum cutting diameters for this subset of species.

2. Materials and methods

2.1. Study area

Samples were collected inside the Forest Management Unit (FMU) 11.001, of Transformation REEF Cameroon (TRC, 2008). This FMU is certified by the Forest Stewardship Council (FSC) and is located in the Southwest Region of Cameroon, between 5°23′N, 9°09′E and 5°23′N, 9°12′E, adjacent to Korup National Park (Fig. 1). The vegetation of the region consists of semi-deciduous lowland rainforest (~200 m a.s.l.) of the Guineo-Congolian type (cf. White, 1983), dominated by Leguminosae–Caesalpinioideae. Soils in the area are deep, skeletal (lithosols), with high sand content and a low pH (Gartlan et al., 1986). Due to leaching by the high rainfall, soils are nutrient poor and only a thin organic layer is present (Newbery et al., 1997). Regional climate is equatorial, with an unimodal rainfall distribution and a dry season from December to February (monthly rainfall < 60 mm, cf. Worbes, 1995). Rainfall amounts vary between nearby weather stations: at the Bulu station (40 km to the South of the study area) annual rainfall averaged 5220 mm, whereas at the Mamfé Airport station (40 km to the North) it averaged 2920 mm (Fig. 1). Although total rainfall amounts vary between stations, both stations show an unimodal rainfall distribution. At our site, we expect annual rainfall to be intermediate, and similar to the 4082 mm measured at the Nguti weather station, located 27 km to the East (data not available; Nchanji and Plumptre, 2003). Temperature data was only available for the Mamfé station and shows little variation between months: maximum temperature averaged 30.2 °C and minimum 23.7 °C. A climate diagram for the Mamfé station is presented in Fig. 1.

2.2. Study species, sample collection and preparation

Between June 2010 and May 2012, we collected samples of 601 individuals belonging to 22 tree species (Table 1). Nearly all 22 species belong to the top-35 most logged species in Central Africa (Ruiz-Pérez et al., 2005) and commercial names, guild, distribution and uses are given in Table 1. We collected cross-sectional samples (discs) from 177 felled trees and increment cores from 424 standing trees, in three to four directions, using 5.15 mm increment borers (type Suunto and Haglof). Samples were taken at 1 m stem height or above anomalies or buttresses. Each sampled tree was geo-referenced (Garmin GPS60X) and we measured diameter at breast height (dbh) using a diameter tape.

About 90% of the samples were collected in a stratified random sampling design, inside an unlogged and seemingly undisturbed area of the FMU (TRC, 2008). For this purpose, we installed circular plots of c. 1 hectare at random coordinates inside 16 cells of 300 × 300 m (located in a virtual grid of 4 × 4 cells). Inside these plots, all trees >5 cm dbh of our target species were sampled. The remaining samples were collected non-randomly, from large trees or from individuals of less abundant tree species. These samples were collected to increase the amount of species and the amount of large and presumably old trees in our analysis. For some rare species we collected only a few individuals or only increment cores, as rare species were spared from logging or because there was no commercial demand at the time (Table 2).

To allow inspection of tree-ring structures, all samples were air dried. Discs were polished with increasingly finer sandpaper, from grain 40 up to 1000, and increment cores were either polished or cut using a large sliding microtome (Gärtner and Nievergelt, 2010).

2.3. Tree-ring analysis

We investigated the potential for tree-ring analysis of the 22 commercial tree species (henceforth called 'screened species') by assessing the presence of distinct tree-ring boundaries. On a subset of five species, the 'subset species', we performed a detailed analysis to assess their cross-dating potential, test the annual character of tree-ring formation by radiocarbon dating, and assess their general growth patterns. The subset species were selected based on the presence of clear tree-ring structures, tree abundance in the