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Local and regional climatic signals recorded in tree-rings of *Chukrasia tabularis* in Bangladesh

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ABSTRACT

We developed the first tree-ring chronology of *Chukrasia tabularis* from a moist tropical forest in Bangladesh, spanning the 102-year period 1911–2012. The species showed wood anatomically clear annual tree-ring boundaries which crossdated between tree individuals. Bootstrapped correlation analyses revealed that the ring-width index was significantly negatively correlated with current year mean and minimum temperatures. This relationship was stronger during the dry season (November–March), the pre-monsoon (February–April) and the post-monsoon season (September–November) than during the main monsoon season (May–August). We interpret this result as an indication that temperature-driven higher evapotranspiration outside the main rainy season leads to water stress limiting tree growth. This is confirmed by negative correlations of the ring-width index with the Palmer Drought Severity Index (PDSI) during the dry season. Precipitation did not show significant relationships to tree growth, except in current year June. However, cloud cover strongly negatively affected tree growth, likely by reducing photosynthetic capacity particularly during the rainy summer (May–August) monsoon season. On a regional scale, the ring-width index was correlated with both Indian Ocean and Pacific Ocean sea surface temperature (SST) anomalies, but during different seasons. Ring width of *C. tabularis* was also significantly correlated with the El Niño Southern Oscillation (ENSO). Monthly Niño 3.4 region positive temperature anomalies enhanced current year tree growth but negative temperature anomalies reduced tree growth in the following year mainly through modulating local climate. Hence, tree-ring variations of *C. tabularis* in Bangladesh record local and regional climate signals and are a potential proxy to reconstruct local and regional paleoclimatic variability during the past centuries.

1. Introduction

Tree-rings are important natural archives of paleoclimatic information and are key ecological indicators of environment and climatic changes (Fritts, 1976; McCarroll and Loader, 2004; Zhang, 2015). In comparison to other natural archives such as deep-sea and lake sediments, peat bogs and ice cores, tree rings are advantageous since they provide paleoclimatic information which is annually resolved, continuous, and dated to the precise year (Cook, 1992; McCarroll and Loader, 2004; Zhang, 2015). Such information is of great importance particularly in the tropics; not only for understanding past climate variability but also for modeling tropical forests' response to future climate changes (Hiltner et al., 2016), since tropical forests are currently experiencing some of the most rapid rates of warming in recent geological times (Marcott et al., 2013).

Bangladesh comprises a wide range of tropical forest types including tropical evergreen, semi-evergreen and mixed deciduous forests (Hill forests), mangroves and freshwater swamp forests. The forest ecosystems of Bangladesh are highly sensitive to climate changes because of the country's geographic position, being one of the largest deltas in the world surrounded by the Himalayas in the north and the Bay of Bengal in the south. Hence, Bangladesh is highly vulnerable to natural disasters like cyclones, flooding, and salinity intrusion (Huq et al., 2004; Huq and Ayer, 2008). In addition, increasing trends in temperature and severity of droughts in many parts of Bangladesh (CCC, 2007) may have adverse effects on forest productivity. To derive realistic estimates about future carbon sequestration potential and resilience to future climate change, it is crucial to better understand regional past climate variability and the growth response of Bangladeshi tropical forest trees to climatic factors. However, long-term instrumental climate records are lacking in Bangladesh. In this context, tree rings can be used as an indirect evidence of past climatic variations to put recent climatic trends in a long-term context of climate variability (Yadav et al., 1997; Bräuning, 2001; Cook et al., 2003; Fan et al., 2008; Yang et al., 2011;

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Chen et al., 2012; Cai et al., 2013; Arsalani et al., 2015; Nadi et al., 2016).

Tree-rings are understudied in the tropics as compared to temperate and boreal forest ecosystems. In South Asian countries, tree-ring studies were mainly concentrated to coniferous species and only few broad leaved species were studied so far (Bhattacharyya and Shah, 2009; Worbes, 2002; Rozendaal and Zuidema, 2011; Pumijumnong, 2013). Annual growth rings are formed in tropical trees when they experience cambial dormancy due to unfavourable environmental conditions such as in a dry season in areas with distinct climate seasonality (Worbes, 1999). A distinct dry season (monthly rainfall < 100 mm) with at least five month duration triggers the formation of annual growth rings in tropical deciduous and semi deciduous forests (Gentry, 1995; Graham and Dilcher, 1995). In evergreen forests, even a short dry period may trigger formation of annual tree-ring boundaries (Dünisch et al., 2003; Fichtler et al., 2003; Volland-Voigt et al., 2011). It is therefore of high relevance to test if the trees in tropical semi-evergreen forests (deciduous canopy and evergreen understory) of Bangladesh, which experience a marked dry season from November to March, form annual growth rings and record local and large scale climate signals.

Inter-annual climate variability in Bangladesh is modulated by large-scale climatic drivers like sea surface temperatures (SSTs) of the Pacific and Indian Oceans (Cash et al., 2010). These large-scale climatic phenomena have been reported to affect tree growth over very long distances either directly or indirectly through modulating local climate (Schöngart et al., 2004; Buckley et al., 2005; Bhattacharyya and Shah, 2009; Brienen et al., 2010; D'Arrigo et al., 2011; Pucha-Cofrep et al., 2015; Locosselli et al., 2016). Therefore, besides studying climate-growth relations with local climatic conditions, understanding the relationships between tree growth and SSTs is also important. In the present study, we report the first tree-ring chronology of *Chukrasia tabularis* growing in a tropical semi-evergreen forest of Bangladesh and evaluate the climate signals contained in that chronology. The main objectives were: (1) to evaluate the crossdating potential of *C. tabularis*; (2) to investigate if ring-width series of multiple trees show a common signal; (3) to test whether a common growth signal can be correlated to local climatic variables (temperature, precipitation, cloud cover, or relative humidity) or integrative climatic parameters like the Palmer Drought Severity Index (PDSI); (4) to investigate the relationships between tree growth and large-scale climate drivers (SSTs).

2. Material and methods

2.1. Study site and regional climate

The study was conducted in Lawachara Forest, Bangladesh (24°18′ − 24°21′ N and 91°45′ − 91°49′ E, Fig. 1). The study forest covers a total area of 1250 ha and was declared a national park in 1996 (Canonizado and Rahman, 1998; Riadh, 2007). The site is one of the finest wildlife venues in the country which forms a part of 2740-hactare protected zone known as the West Bhanugach Reserve (Butler, 2000; FSP, 2000). The Lawachara forest is classified as a moist semi-evergreen and mixed deciduous forest composed of a deciduous canopy with an evergreen understory (Ahsan, 2001). During the first two decades of the last century a substantial amount of natural patches were replaced by both native and exotic species, making the forest an intimate mixture of old growth natural and secondary forest patches (Feeroz, 1999). The canopy height varies from 10 to 40 m with occasional emergent trees reaching up to 50 m. The top canopy comprises mainly *Chukrasia tabularis*, *Tectona grandis, Dipterocarpus turbinatus, Ariocarpus chaplasha, Hopea odorata,* and *Toona ciliata* (Islam and Feeroz, 1992). Topography is undulating with hillocks of 10–50 m height (Riadh, 2007) that are interspersed with numerous streams crossing the forest. Soils of Lawachara forest range from sandy-loam to clay-loam of Pliocene origin (Hossain et al., 1989) with an average moisture content of about 22% (Islam et al., 2016).

Lawachara National Park is characterized by a monsoonal climate with a marked dry season from November to March (Fig. 2A). Annual precipitation from 1950 to 2010 averaged 2387 mm, of which 65% falls during the summer monsoon season. Unlike many other parts of Bangladesh, where the summer monsoon season begins in June, monsoon starts early in May in our study area in the north-eastern part of Bangladesh, and lasts till August. During the summer monsoon season, monthly rainfall averages more than 300 mm whereas it is below 100 mm during the dry season. Mean annual temperature ranges from 23.73 °C to 25.76 °C, with a long-term mean of 24.8 °C averaged over 1950–2010. While mean annual rainfall and annual maximum temperature in the study area do not show significant trends in the period 1950–2010 (Fig. 2B), mean annual temperature and minimum temperature increased significantly since the mid-20th century. The average rate of warming over the last 60 years was 0.13 °C per decade, which is consistent with the global trend reported by IPCC (2013).

2.2. Climate data

Precipitation and temperature data of the Sreemangal meteorological station located nine km away from the study site were obtained from SAARC Meteorological Research Centre (SMRC). SST anomalies from the Niño 3.4 region were accessed from the Climate Prediction Center (CPC) of the National Oceanic Atmospheric Administration (NOAA). The Climatic Research Unit (CRU) Time-Series (TS) Version 3.23 (CRU TS3.23) of high resolution gridded data (temperature, precipitation, relative humidity, cloud cover) and HadSST3.1 dataset were accessed through KNMI Climate Explorer (The Royal Netherlands Meteorological Institute; http://climexp.knmi.nl/). Beside temperature and precipitation data, we also used integrative climatic parameters like PDSI (CRU scPDSI 3.21) which uses readily available temperature and precipitation data to estimate relative dryness. As it uses temperature data and a physical water balance model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration (van der Schrier et al., 2006).

2.3. Tree-ring material, ring width measurement and chronology building

C. tabularis is a deciduous tree of up to 40 m height with a diameter at breast height (dbh) of up to 120 cm (Kalinganire and Pinyopusarerk, 2000). It is usually found scattered in lowland evergreen or deciduous forests. It is a dominant tree, occurring in the top canopy in natural forests and is regarded as a pioneer species. The species is native to south and south-east Asia and China. *C. tabularis* prefers well-drained soil in plains and on hills. Growth ring boundaries are distinct and characterized by a marginal parenchyma band (Vlam et al., 2014) (Fig. 1C). Annual growth-ring formation has been confirmed by a cambial wounding experiments (Baker et al., 2005) and previous tree-ring studies (Vlam et al., 2014).

Trees were sampled throughout the 1250 ha area of the study forest. Cores were taken from 50 trees with a dbh > 20 cm growing isolated or in small groups. Trees with highly irregular stems were not sampled as these might contain asymmetric growth rings. Trees were cored at the end of the growing season during mid-September to mid-October in 2012 using a 5 mm increment borer (Haglöf increment borer, Sweden). Two cores were extracted from each tree at breast height (around 1.30 m). Taking multiple cores allowed us to measure rings over at least two different radii, thereby correcting for radial variations in diameter increment and facilitating the detection of very narrow and partially missing rings (Stokes and Smiley, 1968). Core extraction areas were left untreated because wound treatments were not found to have clear advantage in comparison with untreated wounds (Dujesiefken et al., 1999). After mounting the cores on a wooden support in the laboratory, we cut them perpendicular to the ring boundaries by using a large sliding microtome (WSL; Swiss Federal Institute for Forest, Snow and Landscape Research, Switzerland). We sanded the wood surface with