Tree-ring record in Ethiopian church forests reveals successive generation differences in growth rates and disturbance events

Abraham Abiyu⁎, Mulugeta Mokria⁎⁎, Aster Gebrekirstos⁎⁎, Achim Bräuning⁎

⁎⁎ Amhara Agricultural Research Institute (ARARI), P.O. Box 527, Bahir Dar, Ethiopia
⁎⁎ World Agroforestry Centre (ICRAF), United Nations Avenue, P.O. Box 30677-00100, Nairobi, Kenya
⁎ Institute of Geography, Friedrich-Alexander-University Erlangen-Nuremberg, Wettbewerstrasse 15, 91058 Erlangen, Germany

A R T I C L E   I N F O
Keywords:
Sacred forests
Juniperus procera
Basal area increment
Disturbance
Tree longevity

A B S T R A C T
Forests provide fundamental ecosystem services. Environmental changes are predicted to affect forest growth directly through increased environmental stressors, and indirectly by amplifying disturbance. To increase our understanding of effects of environmental changes and disturbance on Afromontane forest growth, we used tree-ring data collected from Juniperus procera trees from church forests in the northwest highlands of Ethiopia. We used structural change models to detect structural shift in growth trends. We applied Linear Mixed Effect Models (LMM) to compare growth rate differences between successive tree generations. The running mean method and radial growth pattern analysis were used to detect disturbance events. Three groups of generations were identified based on Basal Area Increment (BAI) rates. There are significant differences (χ² = 204.64, P < .001) among generations in pace of BAI, indicating that old generation trees grew at a slower pace than younger ones. Radial growth patterns were homogeneous for the old generation, but diverse in young trees. The observed high growth rates in the younger generation may have a negative effect on the longevity of the individuals and positively affect carbon accumulation in the biomass. Disturbance was detected in all generations, but worsened in the 20th century. About 35% of disturbances matched with climate extreme events, providing evidence that the disturbance is both human-induced (i.e., site-specific) and climate-induced. Thus, forest management plans should emerge from a sound understanding of climate-forest-human interaction.

1. Introduction
Tropical forests play a significant role to mitigate climate change impacts through modulating the atmospheric carbon cycle and regional water fluxes (Canadell and Raupach, 2008; Ma et al., 2015; Miura et al., 2015). Tropical forests are also a major source of income, supporting the livelihoods of millions of forest-dependent people (Blackie et al., 2014; Miura et al., 2015, Mokria et al., 2016). Despite their multiple importance, tropical forests are increasingly degraded and thus become more vulnerable to negative impacts of environmental changes (Bugmann et al., 2005; Knake et al., 2016). Climate change-induced reduction in rainfall and increasing temperatures are another growing concern (IPCC, 2007; Allen et al., 2015), threatening the carbon sequestration potential of tropical forests (Sullie and Buchroithner, 2009; Allen et al., 2015, Mokria et al., 2015; Corlett, 2016; Hütlner et al., 2016) and aggravating direct and indirect impacts of forest disturbance (Seidl et al., 2017). Sustainable management of tropical forests is mandatory to enhance their role in hosting regional biodiversity, carbon storage capacity, and improved livelihoods; however, this requires knowledge on trees’ growth behavior and its response to environmental and climatic changes.

Tree-ring studies showed different results regarding growth responses of trees to biological aging and environmental changes. It was found that aging trees undergo reduced photosynthesis rates, a shift in carbon budgeting and allocation, and reduction in foliar efficiency (Kaufmann, 1996). Old growth forests will be in a state of structural complexity which will incur a high maintenance respiration cost, reduced efficiency of water transport (Ryan and Yoder, 1997) and hence reduced growth (Pennisi, 2005). In general, ultimate growth decline with age is expected due to physiological constraints such as reduced carbon gain and reduced photosynthetic efficiency, nutrient decrease, hydraulic constraints, and resource allocation (Gower et al., 1996; Ryan et al., 2004). On the other hand, aging is not the sole factor for growth decline. For instance, protracted growth in older trees was reported in subtropical forests of the eastern US (Johnson and Abrams, 2009). Sustained growth was also observed by adjusting leaf positioning, nutrient content and angle of leaves within canopies (Coomes et al., 2012). Moreover, instead of being senescent carbon stores, older trees

⁎ Corresponding author.
E-mail addresses: abraham.abiyu@gmail.com, abraham.abiyu@boku.ac.at (A. Abiyu).

Received 8 August 2017; Received in revised form 7 December 2017; Accepted 8 December 2017
0378-1127/ © 2017 Elsevier B.V. All rights reserved.
may accumulate biomass and carbon disproportionally higher than many young trees (Stephenson et al., 2014). While some studies found a decreasing sensitivity of trees to climate change with increasing age, implying that young trees are more vulnerable to climatic factors than old trees (Madrigal-González and Zavala, 2014), contrasting evidence was reported by Prior and Bowman (2014).

Sufficient light availability, increased atmospheric CO2 concentration, warming temperatures and increased precipitation create favorable growing conditions for trees (Pretzsch et al., 2014). Experimental evidence showed that increased CO2 concentration might have a fertilizing effect and lead to increased tree growth (Ceulemans and Mousseau, 1994; Baker, 2004; Lewis, 2004; Ciais et al., 2008). However, carbon fertilization effects may be counterbalanced by environmental stressors like insufficient precipitation (Wagner et al., 2016), and evidence substantiated a net decrease in biomass accumulation due to CO2 accumulation (Battipaglia et al., 2015). In line with increasing atmospheric CO2 concentrations, water use efficiency increased in many tropical and subtropical tree species (Bonan, 2008; van der Sleen et al., 2015).

According to the concept of the linear aggregate model, tree growth is determined by the combination of an age-related growth trend, climatic control, stand wide exogenous disturbances, local endogenous disturbances, and unexplained year-to-year variability (Cook, 1990). The effects of climate and exogenous stand wide disturbances create common signals, which are important to synchronize tree-ring series and date the exact year of tree-ring formation (Stokes and Smiley, 1968; Fritts, 1976). In contrast, local endogenous disturbances and unexplained inter-annual variability create individual signals characteristic for each tree and are strongly related to inter-tree competition and site disturbance (Cook, 1990; Nowacki and Abrams, 1997). In line with this, tree rings have been used to reconstruct forest growth dynamics and disturbance regimes (Rozas, 2001; Salzer et al., 2009; Rozendaal and Zuidema, 2011; Bräuning et al., 2013; Gebrekristos et al., 2014), to study the impact of environmental changes on forest growth (Fan et al., 2009; Krepkowski et al., 2011), and to detect and reconstruct effects of disturbance and climate on radial growth (Rozas, 2001). Information is yet limited on how climate-related common signals and disturbance-related individual signals affect radial growth and biomass accumulation of remnant Afrotropical montane forests, which are a major forest ecosystem in the highlands of eastern Africa. In the highlands of northern Ethiopia, which experienced persistent historical deforestation, patchy remnant old age forests are found mainly around Ethiopian Orthodox Churches (Wasse et al., 2005). In many cases, only patches of such forests hosting up to multi-century-old trees exist as sacred groves related to churches in an otherwise completely transformed cultural landscape (Wasse et al., 2005; Aerts et al., 2016). We hypothesized that (1) there are changes in the growth trends of church forests during the past centuries; (2) there may be differences in growth potential among trees of equal size but recruited in different generations; (3) disturbance intensity and regime might have changed through time.

2. Materials and methods

2.1. 1 Study area and climate

The present study was conducted in the upper Blue Nile catchment, north-western Ethiopia (Fig. 1). The catchment is characterized by mountainous topography and by a monsoonal unimodal rainfall pattern, with a rainy season lasting from June to September. Based on instrumental climate data for the years 1952–2014 provided by the National Meteorology Agency of Ethiopia, the study area receives a mean annual rainfall of 1109.7 (± 164.5 SD) mm. However, rainfall shows high temporal variability, with mean monthly rainfall ranging from 2.6 to 304 mm, with the peak monthly rainfall occurring in July and August (Fig. 2a). Monthly mean maximum and minimum temperatures range from 22.6 to 28.8 °C and from 11.2 to 15.4 °C, respectively (Fig. 2b).

2.2. Sample collection, growth-ring measurement, and crossdating

Increment cores were collected from Juniperus procera trees grown in three protected church forests, namely Meskeleyeysus (hereafter ME, 37°48’11.16”E, 13°0’50.17”N, 2650 m a. s. l), Abtera Samuel (hereafter SM, 37°47’54.87”E, 13°3’12.07”N, 2691 m a. s. l), and Dequa Kidanemenoberet (hereafter DQ, 37°50’55.15”E, 13°1’43.03”N, 2654 m a. s. l). The average nearest neighbor distance between the churches was less than five km. They are located on the broad volcanic plateau of Northern Ethiopia. The churches were selected based on the presence of J. procera trees which vary in size. Unpublished documents in the churches show that ME and SM were established by Iyasu I, also called ‘Adyam Seged Eyasu’, who reigned in Ethiopia between 1682 and 1706. SM was established 10 years earlier than MS. DQ was established during the time of Yeshak or Isaac who reigned in Ethiopia during 1414-1429. The king established the church after defeating the revolt of Beta Israel around the area.

From each study site, 20 trees were sampled from different diameter size classes. Increment cores from two perpendicular sides were taken from each tree at breast height with a Swedish increment borer. In addition, from one of the churches, three discs were taken from a juniper log, which was used as a bench. Samples were air dried and polished with increasingly finer grit size from 60 to 1200 mm to ensure visibility of growth-ring boundaries and wood anatomical features.

To avoid double counting of multiple rings, anatomical features of growth-ring boundaries such as a change in tracheid size and thickness of the tracheid cell walls were used to mark all concentric growth rings (Wills et al., 2009, 2011). Growth ring marking and measurement were conducted under a stereo microscope. Ring widths were measured to the nearest 0.01 mm precession with a semi-automatie device (LINTAB5, RimTech, Heidelberg, Germany), supported by TSAP-Win software (Rinn, 2003). Tree-ring series were cross-dated to their exact year of formation using standard dendrochronological techniques (Cook and Kairiukstis, 1990). The statistical cross-dating between growth-ring series was performed using TSAP-Win software based on GLK (‘Gleichtäflichigkeitsoefficient’ = coefficient of parallel run; sign-test), Student T-value and Cross date Index (CDI) (Bailie and Pilcher, 1973). The computer program COFECHA was used to check dating accuracy (Holmes, 1983).

Ring width (mm yr^-1) values were changed into Basal Area Increment (BAI, mm^-2 yr^-1). BAI is a more reliable proxy for growth studies because it is less affected by the biological growth trend (Rubino and McCarthy, 2000; Biondi and Qeadan, 2008; Silva and Anand, 2013). Cumulative BAI curves of each tree-ring series were calculated and averaged to obtain mean BAI curves for each generation of trees. The conversion was conducted using dplR package of R (Bunn, 2008, 2010).

2.3. Statistical analysis

Testing and dating of structural changes in linear regression approach was used in this study. This approach statistically detects changes in the mean of time series and coefficients of linear regression which coincide with historical events that caused the observed breaks or changes (Bai, 1997; Zeileis et al., 2002; Vanoni et al., 2016). We used this method to detect regime change in growth and determine the timing of positive changes in BA. This method employs fitting linear horizontal regression lines over segments of comparable growth rates, which were separated by break points. The analysis was performed with the strucchange package (Zeileis et al., 2002) of R (R core team, 2016) by applying the function ‘breakpoints’ which determines the optimum number of break points in a time series based on minimum values of Bayesian Information Criterion (BIC) (BIC = –2 log (likelihood) + k X log (n)), where k is the number of parameters and n the sample size).
Download English Version:


Download Persian Version:

https://daneshyari.com/article/6541990

Daneshyari.com