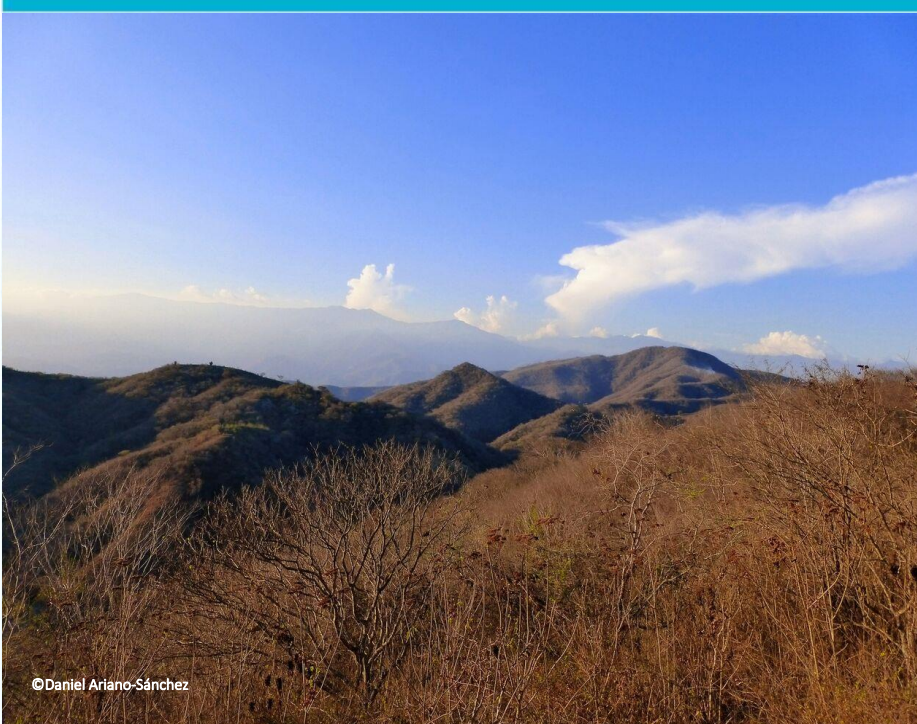


Ana Barrios

Dendroecological potential of two Neotropical tree species: climate-growth relationship in the Dry Forest of Guatemala



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This thesis is worth 60 study points

Summary

Seasonally dry tropical forests (SDTF) are biodiverse yet endangered ecosystems facing significant threats from various factors including climate change. Analysing the long-term effects of climatic conditions on tree growth is crucial for understanding the potential impacts of future climatic changes on SDTF and to provide insights into their age history. In this context, dendroecology is considered a valuable approach. Guatemala's SDTF are highly degraded and fragmented, with small, isolated forest patches, and remain poorly studied, lacking any prior dendroecological investigations. Therefore, in this study I investigated the dendroecological potential of two species belonging to prominent neotropical genera, *Swietenia humilis* Zucc. and *Cedrela salvadorensis* Standl., aiming at examining the relationship between climatic variables and their radial growth. Using standard dendroecological methods, I identified distinct annual growth rings in both species: 16 trees of *S. humilis* and 11 trees of *C. salvadorensis*, with an average age of 55 and 58 years, respectively. However, crossdating and chronology building proved unsuccessful, leading to inconclusive climate-growth analysis. Nonetheless, the presence of false rings alongside narrow growth rings suggests that the inter-annual growth variations in both species are influenced by rainfall seasonality and temperature. Further research is needed to validate these findings, focusing on anatomical characterisation through both macroscopic differentiation and microscopic examination. This will enhance the precision, measurement, synchronisation, and analysis of growth ring widths, facilitating the development of chronologies, crucial for climate-growth analysis in Guatemala's SDTF. Additionally, the relatively young age of the studied trees highlights the importance of long-term protection measures in SDTF nature reserves in Guatemala, particularly in the face of climate change and ongoing forest degradation. The findings of this study represent a pioneering endeavour in the SDTF of Guatemala, demonstrating the potential of *S. humilis* and *C. salvadorensis* for dendroecological investigations, given their distinct annual tree-ring formation.

Key words: tree rings, Meliaceae, climate sensitivity, wood anatomy, seasonally dry tropical forests.

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Foreword

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As a practical note, this thesis presupposes some knowledge of dendroecology and plant ecology. Supplementary figures and tables supporting this thesis can be found in the Appendix.

Norway, 2024

Ana Barrios

1 Introduction

Dendroecology is the study of tree rings to reconstruct past ecological and environmental impacts on the trees. It can be used to correlate growth variations of tree species and local climatic conditions, as well as global climatic phenomena like El Niño Southern Oscillation and teleconnections with sea surface temperatures (Mendivelso et al., 2016a; Aragão et al., 2019; Menezes et al., 2022). Such studies are necessary to understand how variations in climatic variables (e.g. temperature, precipitation, atmospheric and oceanic teleconnections) impact the growth dynamic in woody plants. From the perspective of the global warming acceleration, analysing the mechanisms that govern tree growth and forest dynamics such as water stress, is highly valuable to assess how forests will respond to the predicted climatic changes (Rozendaal and Zuidema, 2011; Rathgeber et al., 2016; Menezes et al., 2022). In addition, dendroecology can be used as a tool to reconstruct disturbance history of the forests and to promote sustainable forest management, by providing knowledge of tree ages and growth patterns and rates to quantify and forecast cutting cycles (Rozendaal and Zuidema, 2011; Mendivelso et al., 2016a; Groenendijk et al., 2017). In tropical regions the analysis of annual growth rings is a relatively new tool (van der Sleen et al., 2017) that has increasingly been applied in different types of ecosystems (e.g. Mangroves, Pine Forest, Oyamel Forest, Pine-oak Forest, Gallery Forest, and Mountain Mesophilous Forest) (Acosta-Hernández et al. 2017; Quesada-Román et al., 2022). Brienen et al. (2016) reported the confirmation of annual ring formation in 230 species of tropical trees across continents and climatic zones. However, there are forest ecosystems where tree ring studies are still rarely applied, such as the seasonally dry tropical forests (SDTF) (Rozendaal and Zuidema, 2011; Mendivelso et al., 2016a; Acosta-Hernández et al., 2017; Aragão et al., 2019; Menezes et al., 2022).

The SDTF occur in semi-arid regions and are characterised by seasonal precipitation. The dry season lasts three to six months with a monthly precipitation less than 100 mm, during which the vegetation is mostly leafless. During the other part of the year, the rainy season is characterised by a considerable amount of precipitation. The total annual mean precipitation is less than 1800 mm (Sánchez-Azofeifa et al., 2005; Pennington et al., 2009; Espinosa et al., 2012; Ariano-Sánchez, 2017a), and the average annual temperature ranges between 19 to 26 °C. Both precipitation and temperature may, however, vary with elevation above sea level (Ariano-Sánchez, 2018; Yang et al., 2022). The precipitation and temperature patterns of the SDTF leads to a seasonal water deficit

(Gotsch et al., 2010; Lima and Rodal, 2010), which determines the characteristic structure, morphology, phenology, and physiology of the vegetation in these forests (Elliott et al., 2006; Lima and Rodal, 2010; Espinosa et al., 2012; Nanda et al., 2014; Berdugo-Lattke and Rangel-Ch, 2015; Ariano-Sánchez, 2017a). The vegetation types within the SDTF includes diverse plant associations from tall forests in more humid dry forests to thorny thickets in the driest areas, such as forests within grasslands, shrublands, and savannas (Pennington et al., 2006; Ariano-Sánchez, 2017a). Gallery forests, mangroves and coastlines are also sometimes considered as SDTF (Sánchez-Azofeifa et al., 2005).

The SDTF harbour high levels of biodiversity and endemism, and the regions where they occur are often considered as being part of biodiversity hotspots (i.e., areas characterised by rich biodiversity and endemism that face significant threats from human activities) (Myers et al., 2000; Gillespie et al., 2014; Marchese, 2015; Portillo-Quintero et al., 2015; DRYFLOR et al., 2016; Escribano-Avila et al., 2017). Comprising 42% of the world's tropical ecosystems, SDTF are among the most endangered ecosystems globally (Janzen, 1988; Miles et al., 2006). The main threats to these forests are land use changes, such as human settlements, agriculture, pastures for livestock, and deforestation, leading to forest degradation and fragmentation. Climate change poses a significant threat to the SDTF as well (Miles et al., 2006; Allen et al., 2010; Portillo-Quintero and Sánchez-Azofeifa, 2010; Manchego et al., 2017; Powers et al., 2020). As extreme drought events are predicted to become more frequent and severe in SDTF landscapes, the tree species they harbour will change, and their biodiversity and capacity to store carbon may be compromised (Brienen et al., 2010; Naumann et al., 2018; Powers et al., 2020; Yang et al., 2022). Severe drought events have already been identified as a factor in heightened tree mortality rates in SDTF. Currently, these events are reshaping the ecological dynamics of SDTF across various regions of their range, encompassing the neotropics (Dorman et al., 2015; Powers et al., 2020; Huang et al., 2021).

In the neotropics the SDTF are not uniformly distributed through the continent, and 66% of their coverage has been converted to other land uses. In Northern and Central America, 72% of SDTF coverage was reduced due to agriculture and urbanisation (Portillo-Quintero and Sánchez-Azofeifa, 2010). In Latin America, these forests are severely threatened by human development, making ecological research and conservation measures important and urgent (Zanchez-Azofeifa et al., 2005; Portillo-Quintero and Sánchez-Azofeifa, 2010; Manchego et al., 2017; Ariano-Sánchez, 2021).

Moreover, given the high susceptibility of the SDTF to climatic variations (Brienen et al., 2010; Pennington et al., 2018; Powers et al., 2020), it becomes crucial to examine how these threatened ecosystems adapt to such changes and their potential impacts on the SDTF. In this regard, dendroecology emerges as a valuable tool for assessing the response of the SDTF to these climatic shifts (Aragão et al., 2019; Aragão et al., 2022; Zuidema et al., 2022; Costa et al., 2023). To conduct these climate change response analyses, it is necessary to understand the climate-growth relationship of the species in the SDTF (Brienen et al., 2010; Rathgeber et al., 2016).

Tree-ring investigations in neotropical SDTF have identified several tree species with potential for dendroecology, due to the formation of annual tree rings. These studies have unveiled correlations between tree rings and oceanic-atmospheric teleconnections, along with other local climatic factors like seasonal precipitation, total annual precipitation, and temperature, which influence radial tree growth (Brienen et al., 2010; López and Villalba, 2011:2020; Beltrán-Gutierrez and Valencia-Ramos 2013; Aragão et al., 2019, 2022; Menezes et al., 2022; Costa et al., 2023). Species from the genera *Cedrela* and *Swietenia* (Meliaceae) are commonly used in such studies, (e. g *Cedrela odorata* L., *Cedrela nebulosa* T.D.Penn. & Daza, and *Swietenia macrophylla* King in Hook.) (Dünisch et al., 2003; Rozendaal and Zuidema 2011; Callado et al., 2013; Layme-Huaman et al., 2018; Menezes et al., 2022; Costa et al., 2023). The findings of these studies have revealed that species in the SDTF are highly growth sensitive to drought (Allen et al., 2017; Powers et al., 2020; Brodribb et al., 2020; Aragão et al., 2022). However, the further implications of how trees in SDTF may respond to the projected climate change remain poorly explored (Brienen et al., 2010; Stan and Sanchez-Azofeifa, 2019).

The SDTF in Guatemala exhibit a high degree of degradation and fragmentation, with remaining forest patches notably small and isolated, contrasting with SDTF found in other neotropical countries (Portillo-Quintero and Sanchez-Azofeifa, 2010). To my knowledge, there have been no prior dendroecological investigations conducted within Guatemala's SDTF. This realm remains unexplored yet holds considerable promise for understanding climate change dynamics and guiding forest conservation and management strategies of Guatemala's SDTF. Hence, the aim of this study is to investigate the dendroecological potential of two species belonging to prominent neotropical genera, *Swietenia humilis* Zucc. and *Cedrela salvadorensis* Standl., (Muellner et al., 2010; Danquah et al., 2019). Additionally, it aims to examine the relationship between climatic variables and the radial

growth of these species. As far as I am aware, these species have not been subjected to dendroecological analyses previously, rendering this study pioneering in its approach.

Hypothesis and predictions

H1: The two dry forest tree species *S. humilis* and *C. salvadorensis* have potential for dendroecological analysis.

- P1: Both species show a distinct annual tree ring formation due to the seasonality in precipitation.

H2: The ring-width and hence secondary growth of *S. humilis* and *C. salvadorensis* is related to the climate variables precipitation and temperature.

- P2: As water is a limiting factor, more growth is expected with more precipitation compared to less precipitation.
- P3: Less growth is expected with higher temperatures compared to lower temperature.
- P4: Extremely dry years contribute to missing rings in *S. humilis* and *C. salvadorensis* due to the lack of radial growth induced by water stress.

2 Methods

2.1 Study area

Samples of trees were obtained from the Heloderma Nature Reserve (HNR) located in the village El Arenal in the municipality of Cabañas, Zacapa, in eastern Guatemala, Central America (Figure 1). The HNR is situated within one of the most extensive and well-conserved areas of SDTF in Guatemala (CONAP-ZOOTROPIC-CECON-TNC, 2011; Ariano-Sánchez, 2017b; Ariano-Sánchez, 2018). Nonetheless, the landscape surrounding the HNR features expansive cultivation of melon and watermelon, with a significant expansion in recent years (Secaira, 2008; Ariano-Sánchez, 2018). The HNR covers an area of 128 ha with elevations between 500 and 700 m.a.s.l. It is characterized by a SDTF ecosystem with two vegetation types: dry forest with more than 125 species identified, including trees that reach 25 m on the one hand and thorny scrub including cacti species from the genera *Nopalea* and *Opuntia* on the other hand. The dry season (Figure 2a, b) occurs between November and April and the rainy season (Figure 2a, c) occurs between May and October (Ariano-Sánchez, 2017b). Endemic species currently under critical threat, such as the Guatemalan beaded lizard (*Heloderma charlesbogerti*) and the Motagua spiny-tailed iguana (*Ctenosaura palearis*), both classified as endangered (EN) by the IUCN Red List of Threatened Species, have been documented within the HNR (Acevedo 2006; Ariano-Sánchez et al., 2020). The HNR is in close proximity to two weather stations: Pasabien, situated in Rio Hondo, Zacapa (15° 1' 48.7992" N and 89° 40' 45.3" W), approximately 21.4 km away from the reserve at an elevation of 260 m.a.s.l.; and San Agustín Acasaguastlán, located in El Progreso (14° 57' 1.01412" N and 89° 58' 25.9476" W), about 21.7 km from the reserve, at an elevation of 371 m.a.s.l (Figure 1). Based on data retrieved from the Pasabien station, the HNR exhibits an annual mean temperature of 27.3 °C and an average annual rainfall of 802 mm spanning the years 1970-2023.

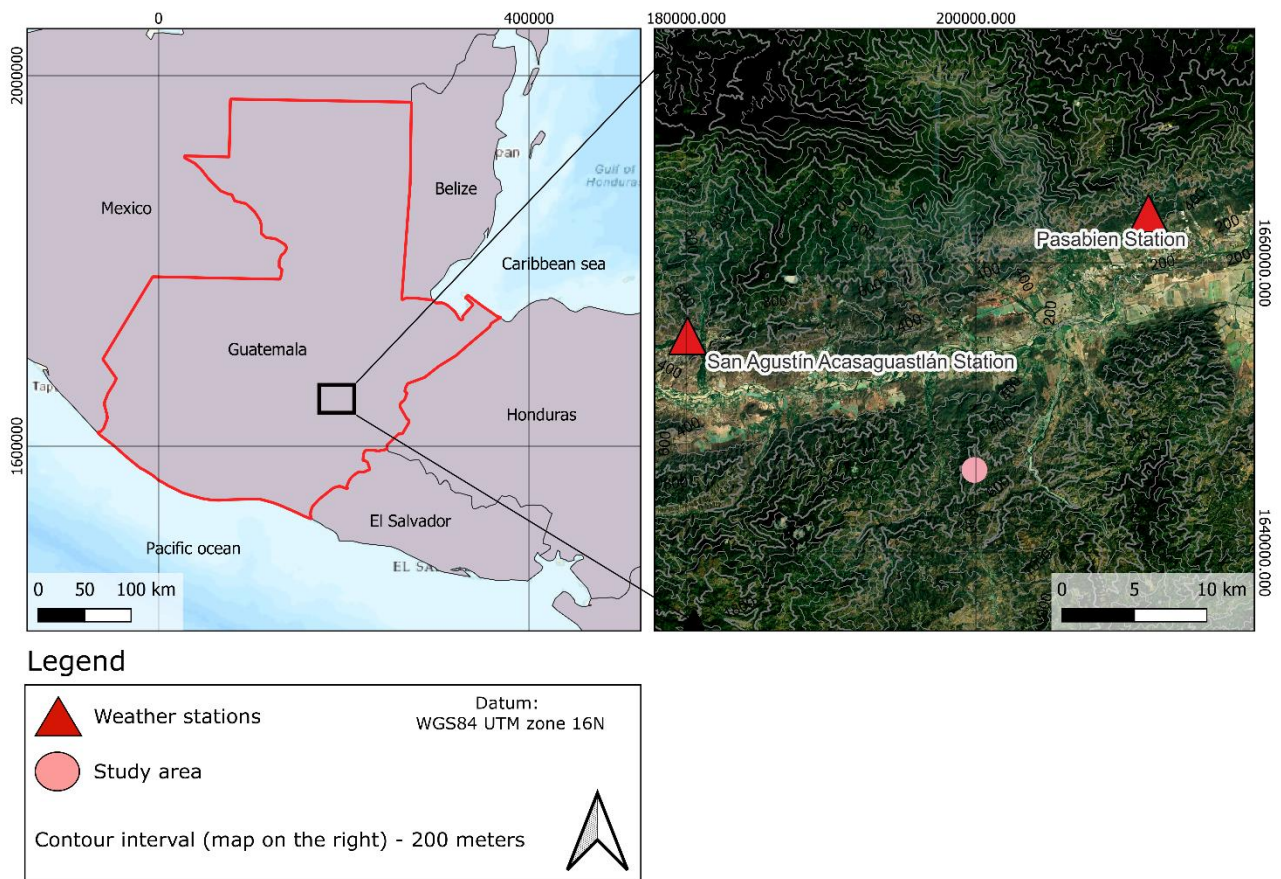
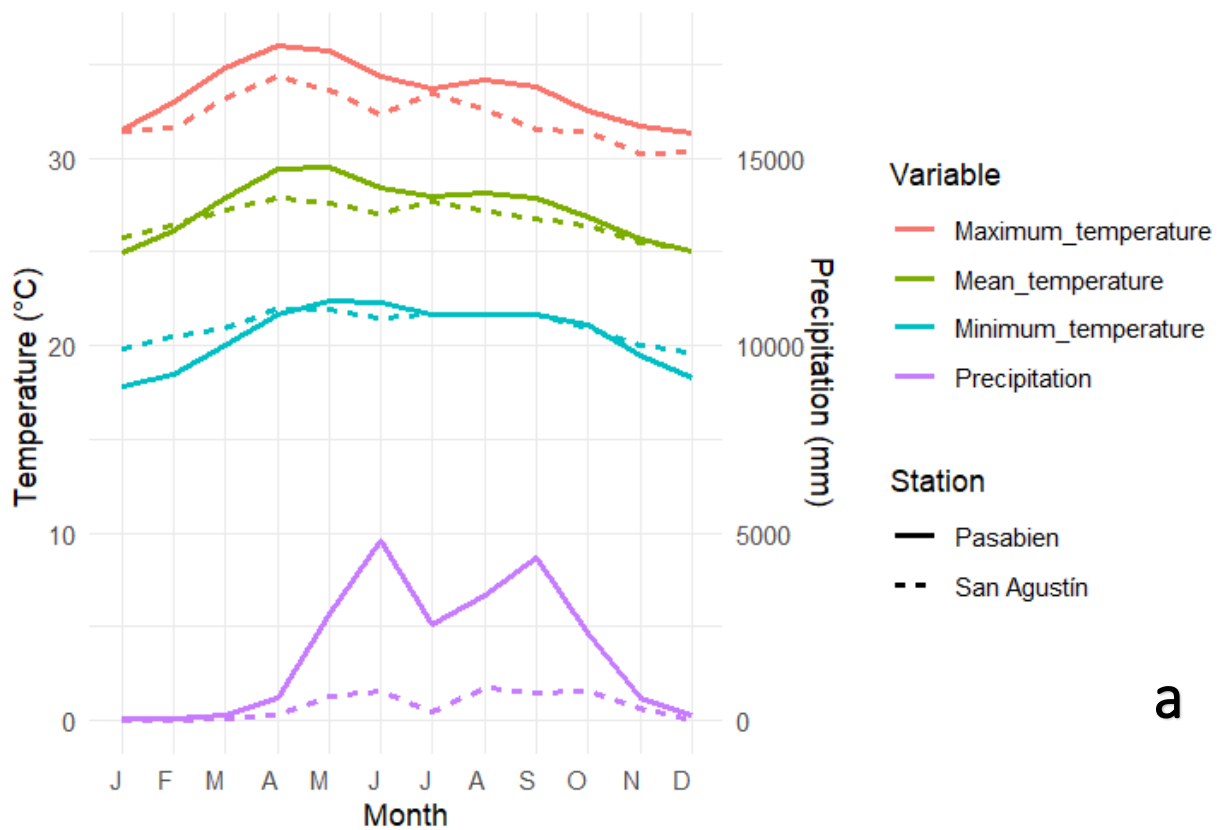
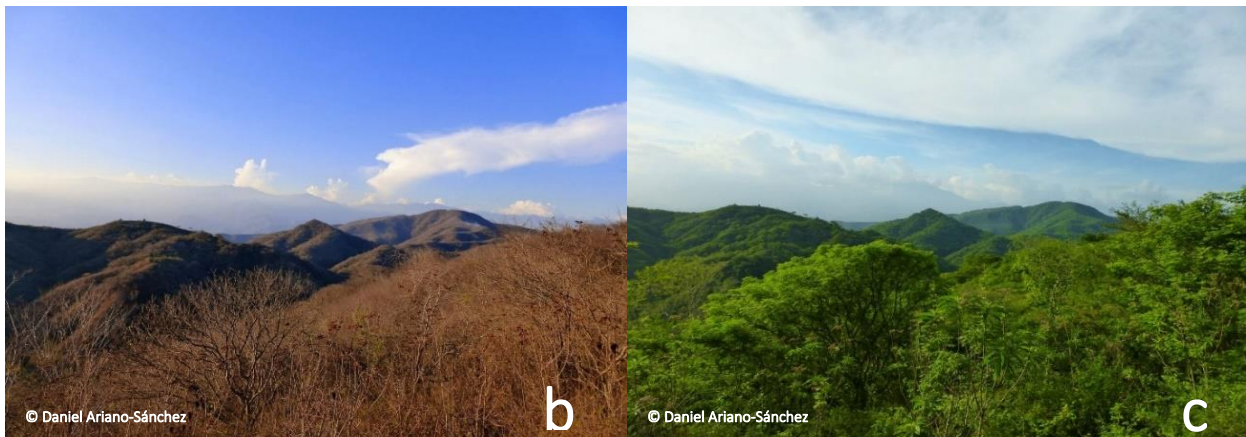


Figure 1. Location of the study area within the Heloderma Nature Reserve in eastern Guatemala, Central America, and the nearest weather stations: Pasabien and San Agustín Acasaguastlán.



a



b

c

Figure 2. Climatic diagram for San Agustín (data from 2010-2023) and Pasabien (data from 1970-2023) (a), as well as an impression of the vegetation phenology in the dry forest of the Heloderma Nature Reserve in Guatemala during the dry season (b) and the rainy season (c).

2.2 Focal species

The two focal species of the study, *S. humilis* Zucc., commonly known as Pacific coast mahogany, and *C. salvadorensis* Standl., known as Cedar (Figure 3), were chosen for this investigation based on recent studies demonstrating that species within these genera exhibit distinct tree rings marked by marginal parenchyma in the latewood. This feature facilitates accurate delineation of growth rings for chronology construction and climate-growth analyses (Dünisch et al., 2003; Dünisch and Latorraca, 2016; Susatya and Yansen, 2016; Layme-Huaman, 2018; Lisi et al., 2020; Menezes et al., 2022; Quesada-Román et al., 2022). Furthermore, they represent the sole species of their respective genera present in the study area (Ariano-Sánchez, 2018; 2021; Medina-Amaya et al., 2021). They are monoecious tropical tree species with deciduous habit and produce capsular fruits containing dry winged seeds that are dispersed by wind (Muellner et al., 2010; Rosas et al., 2011; Medina-Amaya et al., 2021). Both species occur along the Pacific coast of Mexico and Central America, and in Guatemala, they can also be found in the eastern region (Rosas et al., 2011; Danquah et al., 2019; Medina-Amaya et al., 2021). *C. salvadorensis* inhabits humid and dry forests as well as premontane forests (Muellner et al., 2010; Medina-Amaya et al., 2021) while *S. humilis* occurs in dry forests, mainly along riparian zones (Rosas et al., 2011; Ariano-Sánchez, 2018; 2021). Both species hold significant ecological and economic importance for the region due to their role in carbon sequestration and the value of their hardwood (Rosas et al., 2011; INAB, 2018; Ariano-Sánchez, 2018; Danquah et al., 2019; Medina-Amaya et al., 2021). *C. salvadorensis* is also employed in agroforestry as a shading agent in coffee crops and hedges, as well as for ecological purposes such as stabilising fluvial channels and rocky slopes (Fuentes, et al., 2019). The exploitation of their valuable hardwood, along with habitat degradation, poses significant threats to the survival of these species (Moya et al., 2013; Danquah et al., 2019; Barstow, 2019; Fuentes et al., 2019). *S. humilis* is listed as endangered (EN) by the IUCN with a declining population trend, whereas *C. salvadorensis* is catalogued as least concern (LC) with a stable population. Both are included in the appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Barstow, 2019; Fuentes, et al., 2019). In the Guatemalan list of threatened species (LEA), *S. humilis* is listed under category 2, which comprises species with restricted distribution or endemic. Conversely, *C. salvadorensis* is not listed (CONAP, 2009).

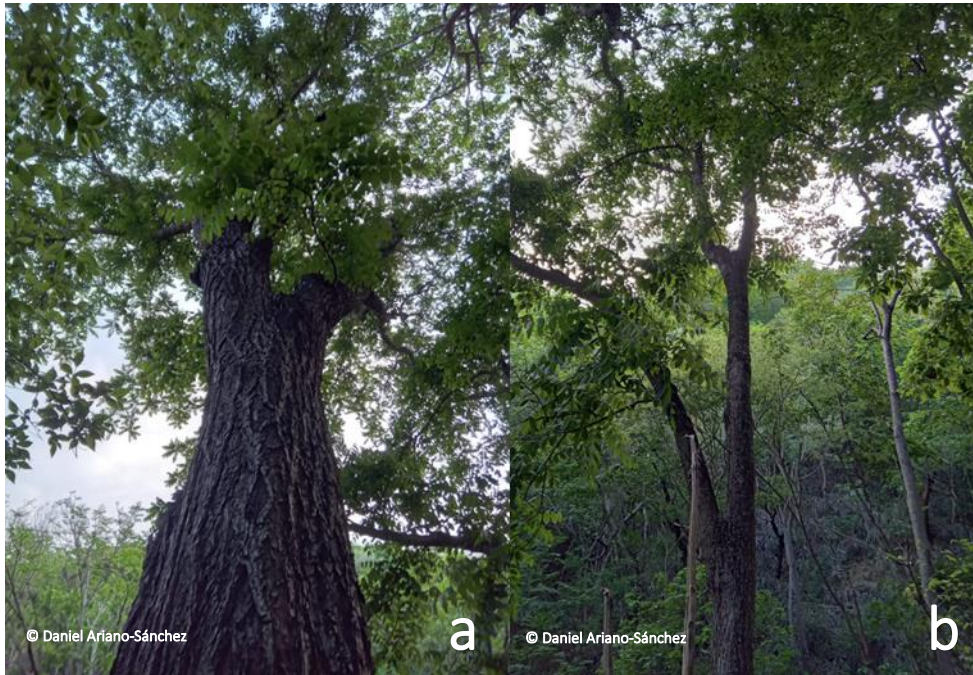


Figure 3. *Swietenia humilis* Zucc. (a) and *Cedrela salvadorensis* Standl. (b) (Meliaceae) in the seasonally dry tropical forest of the Heloderma Nature Reserve in Guatemala.

2.3 Tree core sampling

Between May and November 2023, personnel from the HNR collected core samples from the stems of 27 trees (16 from *S. humilis* and 11 from *C. salvadorensis*). The number of studied trees is based on the typical minimum number of trees used in other dendroecological studies with tropical trees (e.g., Layme-Huaman et al., 2018; Aragão et al., 2019; 2022), and the occurrence of tree individuals with a decent DBH (diameter at breast height) for dendroecological studies in the HNR. The trees were chosen in an opportunistic design. Individuals with a DBH (diameter at breast height) ≥ 40 cm were selected along the areas where populations of my two focal species occur. They were spaced approximately 50 m apart. Using an increment borer, one 5 mm radial sample from bark to pith was collected from each tree at breast height (Figure 4). The radial samples were packed in plastic straws and transported from Guatemala to Norway for further analyses.



Figure 4. Tree core sampling of *Swietenia humilis* Zucc. in the Heloderma Nature Reserve in Guatemala.

2.4 Climate data

The monthly precipitation and temperature data I utilized in this study were sourced from Pasabien station spanning the period from 1970 to 2023, while data from San Agustín Acasaguastlán covers the period from 2010 to 2023. The climatic data was provided by the National Institute of Seismology, Volcanology, Meteorology and Hydrology of Guatemala (INSIVUMEH) in collaboration with the Center for Environmental Studies and Biodiversity (CEAB) at the University of the Valley of Guatemala. For statistical analysis, I used only the data from the Pasabien station, given that the climatic records from the San Agustín Acasaguastlán station were limited to a relatively short period of time only.

2.5 Dendrochronological analysis

I processed the samples according to conventional techniques in dendroecology (Orvis and Grissino-Mayer, 2002; Mendivelso et al., 2016a; Gärtner et al., 2015;2023) in the laboratory at the University of South-Eastern Norway. The samples were dried at air temperature and mounted on wood supports. Afterwards I polished them with increasingly finer sandpaper (grit from 400 to 1000), to obtain a good visualisation of ring boundaries. I observed and demarcated the tree rings under a Zeiss® Discovery.V20 stereomicroscope at 10 to 50 times magnification, prior to measuring them. Subsequently, the samples were digitised with a high-resolution scanner (Epson Perfection V750 PRO with a resolution of 2000 dpi) in ".jpg" format.

Using CooRecorder and CDendro software (version 9.8.1 for Windows; Cybis, 2022) allowing for an accuracy of 0.01 mm (Maxwell and Larsson, 2021) I measured the ring widths. Then, I visually crossdated the ring width series between trees (Appendix 1) aided by the correlation curves in CDendro software and standard analyses using the Dendrochronology Program Library (dplR version 1.7.6; Bunn et al., 2023; Maxwell and Larsson, 2021) in R (R Core Team, 2024). To remove possible age-related trends in the ring width series of *S. humillis* and *C. salvadorensis* and reveal climate-driven trends in their growth (Sullivan et al., 2016), I standardised the series of both species by fitting the negative exponential detrending method. I firstly constructed chronologies (i.e., time series of mean growth across all sampled individuals per year) for each species using the dplR package (Bunn et al., 2023), calculated from the detrended series and the raw tree-ring series. As detrending, though often considered a necessity, may introduce artifacts that may even obscure the climate growth signal (McPartland et al., 2020) I have used both, the raw series and the detrended series. To evaluate the quality of the tree-ring crossdating and chronologies, I calculated standard descriptive statistics used in tree-ring studies (Fritts, 1975; Briffa, 1995) on the raw data and on the detrended chronologies. Here, the mean sensitivity (MS) expresses the relative change in ring widths from year to year; the Expressed Population Signal (EPS) evaluates the total signal present in the chronology, the Mean Series Intercorrelation (Rbar) measures the shared signal among the time series and the First-order Autocorrelation (AR1) indicates how much the tree growth of one year is affected by the tree growth of the previous year (Fritts, 1976; Briffa, 1996). However, any cross dating among samples and subsequent chronology building proved to be very difficult if not impossible (Appendix 1). This was due to a high variability and low correlation in the growth patterns of the raw series. These challenges were at least partly caused and further exacerbated by difficulties in identifying ring boundaries

consistently. Thus, to investigate if there is any possible relationship between climatic variables and the annual growth of the focal species, instead of using the chronology, I used the “best” sample from the sample collection of *S. humillis* and *C. salvadorensis* for analysing climate-growth relations. Appendix 1 describes the criteria I used to select the best sample from the sample collection of each species.

2.6 Analysis of climate-growth relationship

To explore the relationship between interannual variations of the growth of *S. humillis* and *C. salvadorensis* and local climate, I performed a correlation analysis between the “best” sample series of each species and temperature, as well as precipitation data from the weather station Pasabien. For the analysis, I used the treeclim R package (Zang and Biondi, 2015) and because treeclim requires datasets with complete yearly records, I calculated mean values for the months in which either of the climate variables was missing. To account for possible effects of climatic conditions during both the current and the previous year (de Carvalho-Nogueira et al., 2018; Pereira et al., 2018; Aragão et al. 2019), I analysed correlations starting from May of the year preceding the tree-ring formation to October of the year of the tree-ring formation.

3 Results

3.1 Anatomical structures and tree-ring measurements

The tree-ring boundaries of *S. humilis* and *C. salvadorensis* were visible at a macroscopic scale (Figure 5a-b). *S. humilis* showed growth rings delimited by a thin line of marginal parenchyma and *C. salvadorensis* showed tree rings delimited by a band of continuous marginal parenchyma associated with vessels forming a semi-porous ring. In both species, I often observed formations resembling elongated tubes within the wood tissue. These structures were commonly found near the tree-ring boundaries and frequently contained substances similar to resin (Figure 5c-d, 6). False rings were also observed in both species, in *S. humilis* they were characterised mainly by narrow rows of cells, forming irregular and discontinuous layers or variations in wood density (Figure 5c). In *C. salvadorensis* they were mainly characterised by variations in wood colour and density (Figure 5d). For both species, the observed anatomical differences between false and true rings allowed me to identify the true rings during the measurements and crossdating. However, the crossdating and chronology building was not successful for any species.

For most of the samples there was no clear growth synchrony (Figure 7, 8). For *S. humilis*, I dated a total of 16 series with trees aging from 30–80 years and an average series length of 55.8 years. For *C. salvadorensis*, I dated a total of 11 series with trees aging from 37–111 years and an average series length of 58.3 years. According to the descriptive statistics (Table 1) the R_{bar} was very low for both species (0.078 for *S. humilis* and 0.088 for *C. salvadorensis*), showing that there is not a common signal of growth between the tree-ring series. Regarding the high MS obtained for both species (> 0.5), it indicates a high variability among consecutive tree ring-widths. This is consistent with the low AR1 values obtained for *S. humilis* and *C. salvadorensis* (0.244 and 0.175 respectively) which indicate a weak autocorrelation between the tree-rings and therefore changes in growth patterns.

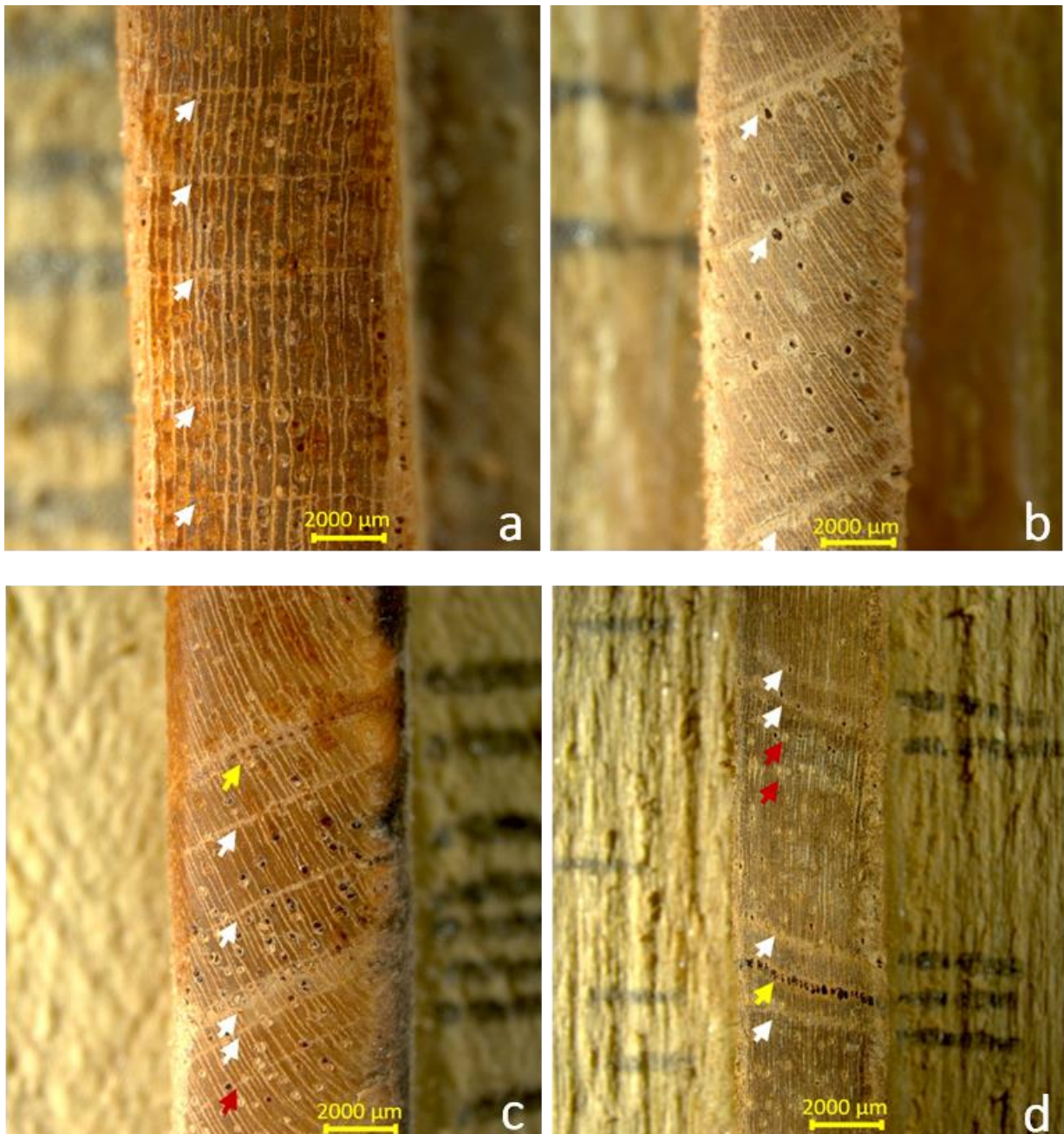


Figure 5. Macroscopic cross-sectional images of wood from *S. humilis* (a, c) and *C. salvadorensis* (b, d). White arrows indicate the boundaries of the growth rings. Yellow arrows mark elongated tube-like formations within the wood tissue containing resin. Red arrows indicate false rings. The variation in width observed between samples of *S. humilis* (a, c) and *C. salvadorensis* (b, d) is due to the sample processing (Appendix 2).

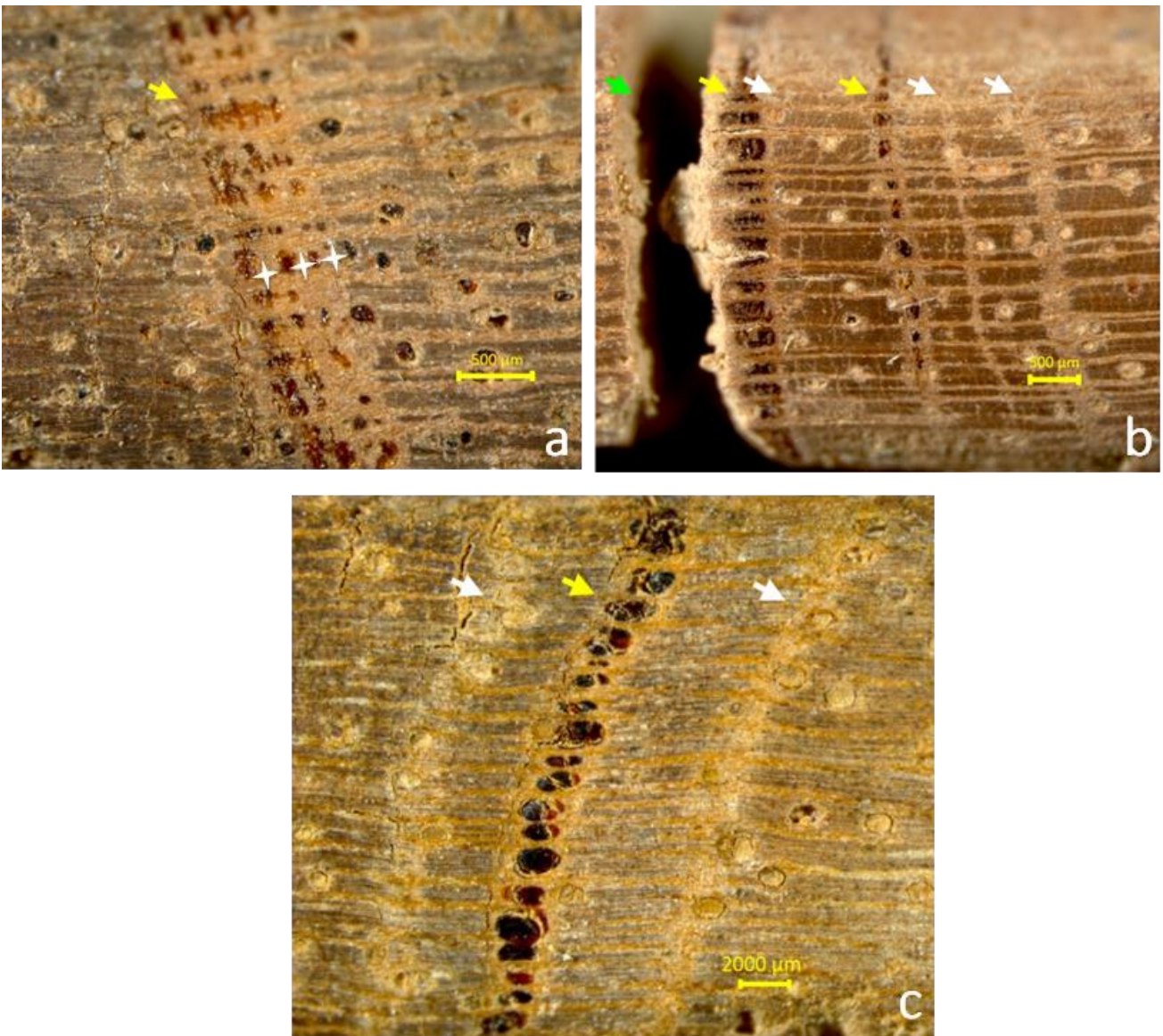


Figure 6. Wood samples of *S. humilis* (a, b) and *C. salvadorensis* (c) showing the association of narrow growth rings (indicated by white stars and arrows) and the elongated tube-like formations within the wood tissue, containing resin (highlighted by yellow arrows). The green arrow indicates a crack caused by the sample processing (Appendix 2).

Table 1. Summary of the statistical characteristics of the raw tree-ring width series of *S. humillis* and *C. salvadorensis* from a seasonal tropical dry forest, Eastern Guatemala. No. trees: number of analysed trees; Rbar: mean series intercorrelation; AR1: first-order autocorrelation; MS: Mean sensitivity.

Species	No. trees	Rbar	AR1	MS	Average series length (yrs.)	Period
<i>S. humillis</i>	16	0.078 (SD 0.166)	0.244 (SD 0.151)	0.758	55.8	1944-2023
<i>C. salvadorensis</i>	11	0.088 (SD 0.129);	0.175 (SD 0.216)	0.774	58.3	1913-2023

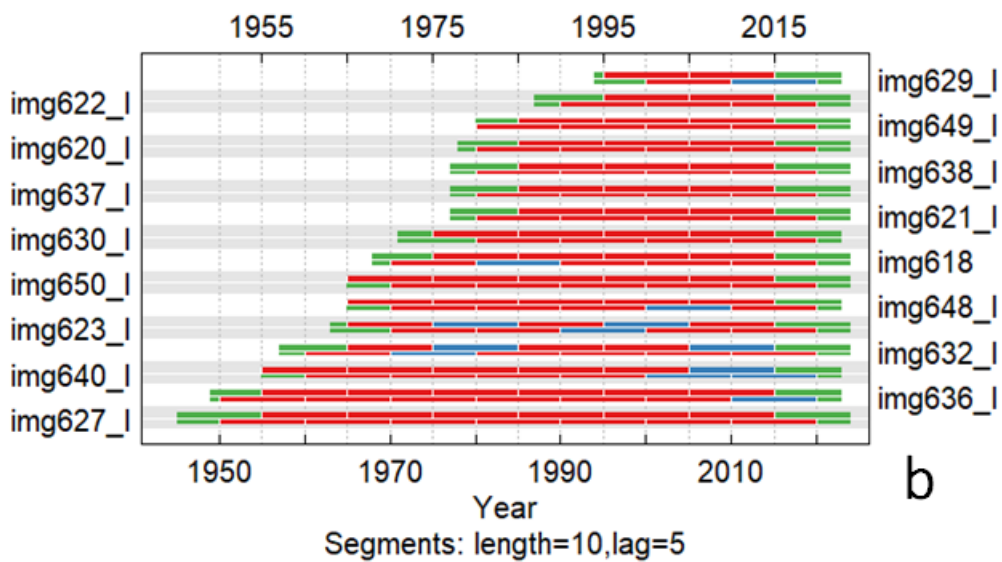
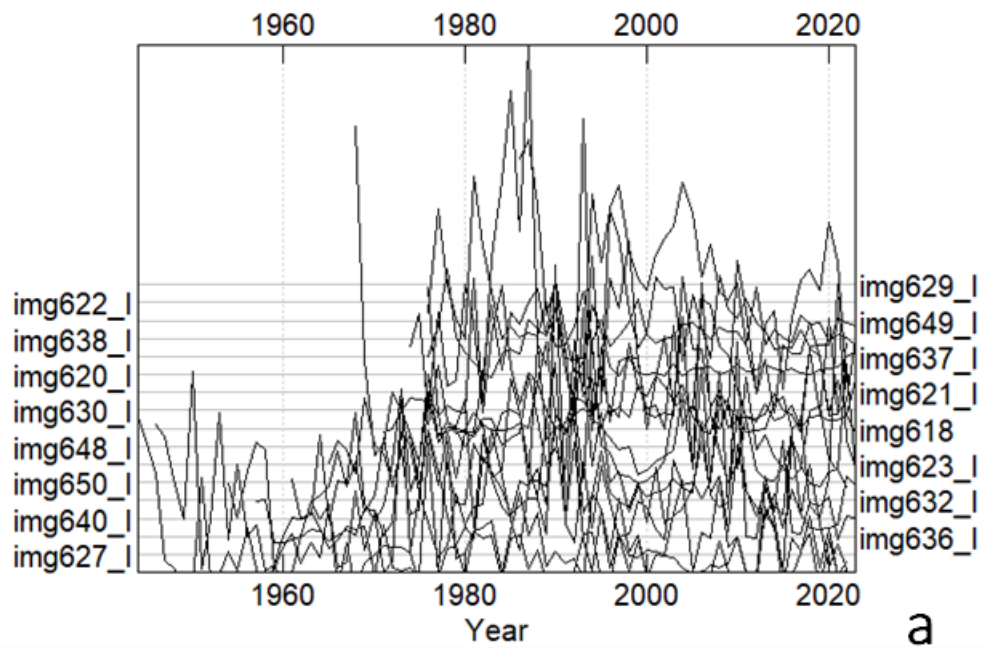


Figure 7. Spaghetti plot revealing the low synchrony of raw tree-ring widths within the series, indicating irregular variation in the response to environmental signals (a), and interseries correlation displaying a weak correlation between segments of the tree-ring series (b) of *S. humillis*.

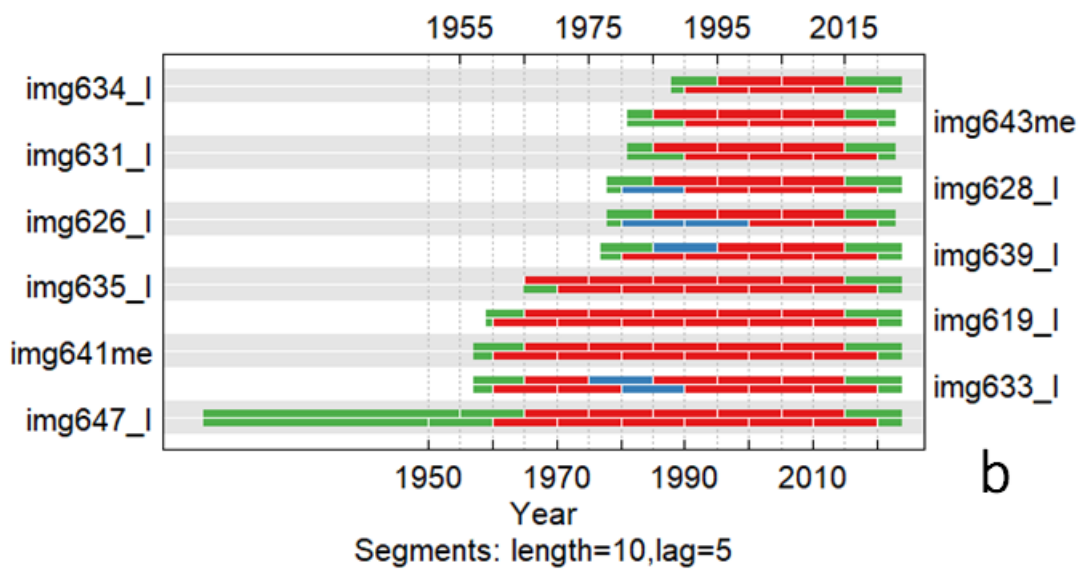
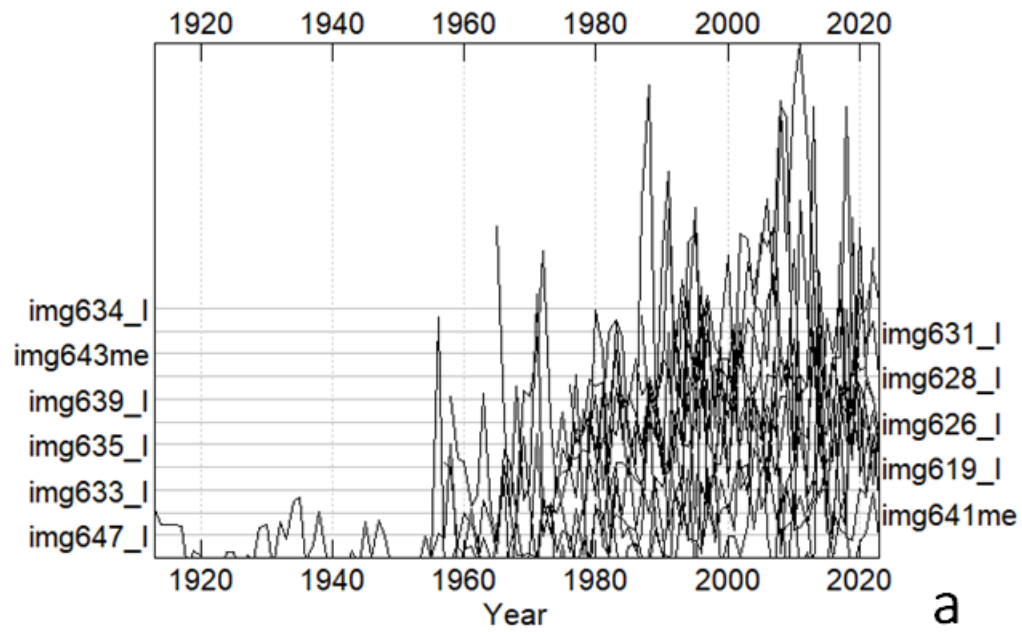


Figure 8. Spaghetti plot revealing the low synchrony of raw tree-ring widths within the series, indicating irregular variation in the response to environmental signals (a), and interseries correlation displaying a weak correlation between segments of the tree-ring series (b) of *C. salvadorensis*.

3.2 Climate-growth relationship

The standardised growth increments built on the detrended series of the “best” sample of *S. humilis* and *C. salvadorensis* cover a period of 1963-2023 and 1957-2023 respectively (Figure 9). The correlation analysis between annual growth increments and monthly temperatures showed a positive effect of the mean and maximum temperatures on the radial growth of *S. humilis* during the previous growing season (in June and October), while in the current growing season there was a negative effect during August (Figure 10, Appendix 4). The minimum temperatures did not seem to have any effect on the growth of *S. humilis* in the previous and current year (Appendix 4). Precipitation showed a negative effect during October of the current year’s growing season (Figure 10). For *C. salvadorensis*, the mean temperatures seemed to have a positive effect during the growing season of the previous year in August and September and in the current year in June, July, and August (Figure 11). The maximum temperatures did not seem to have a significant effect in the previous or the current year, while the minimum temperatures had a positive effect during August and October of the current year’s growing season (Appendix 5). Regarding precipitation, it showed no significant effect during the previous or the current year’s growing season (Figure 11). Moreover, the negative and positive correlations seemed to switch randomly revealing no consistent pattern on the effect of monthly temperatures and precipitation on the radial growth of *S. humilis* and *C. salvadorensis*.

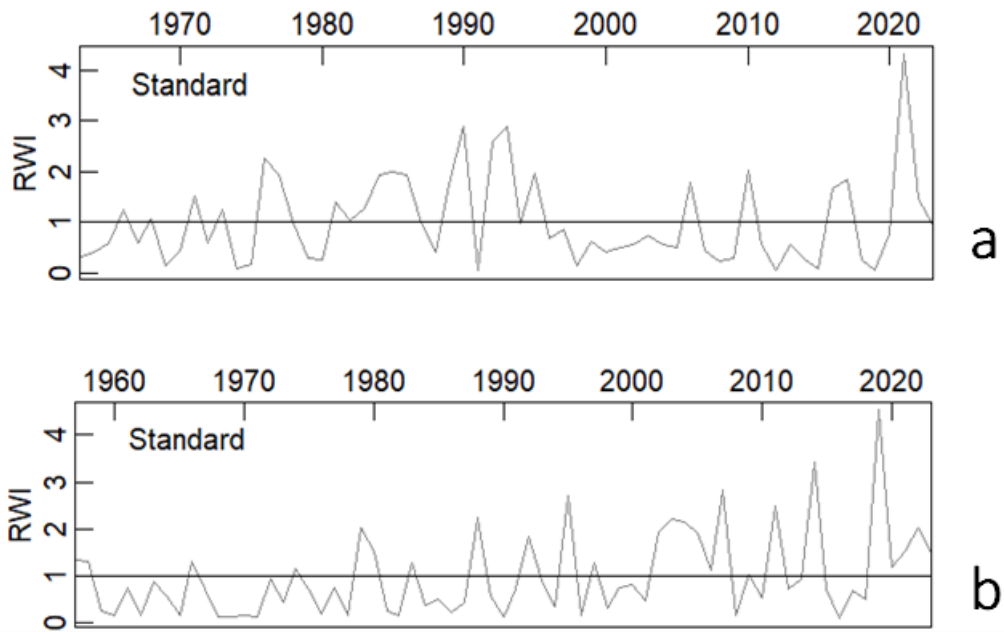
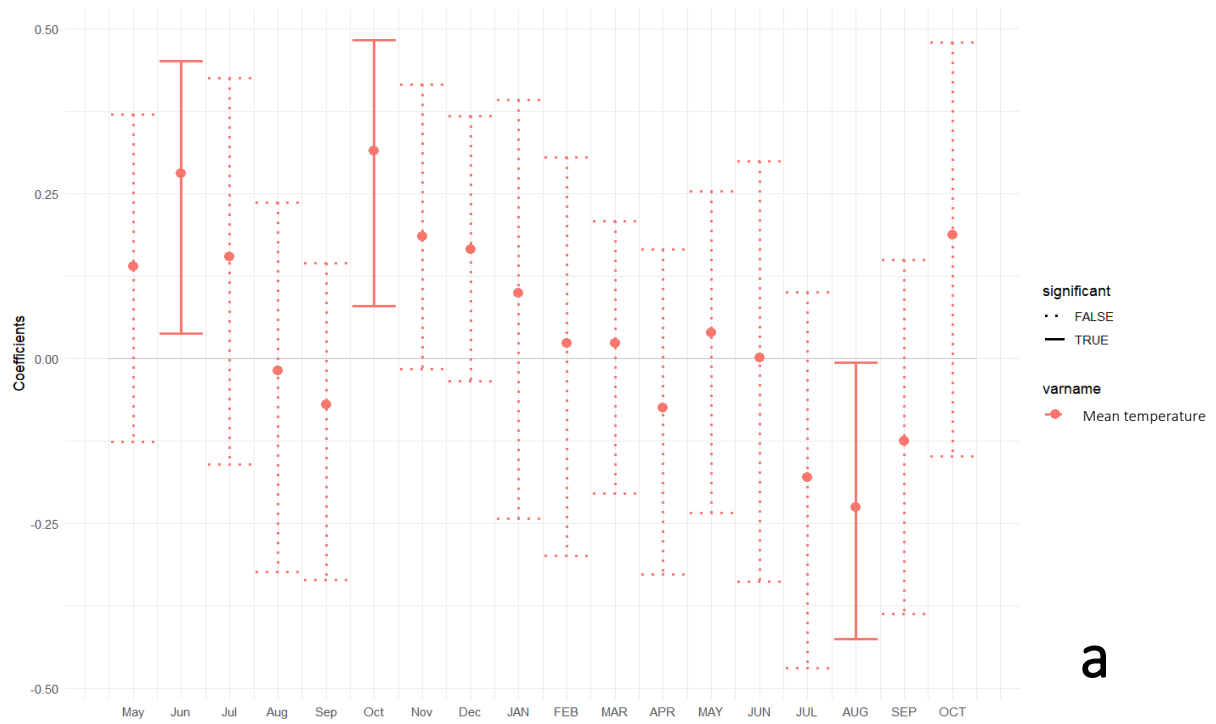
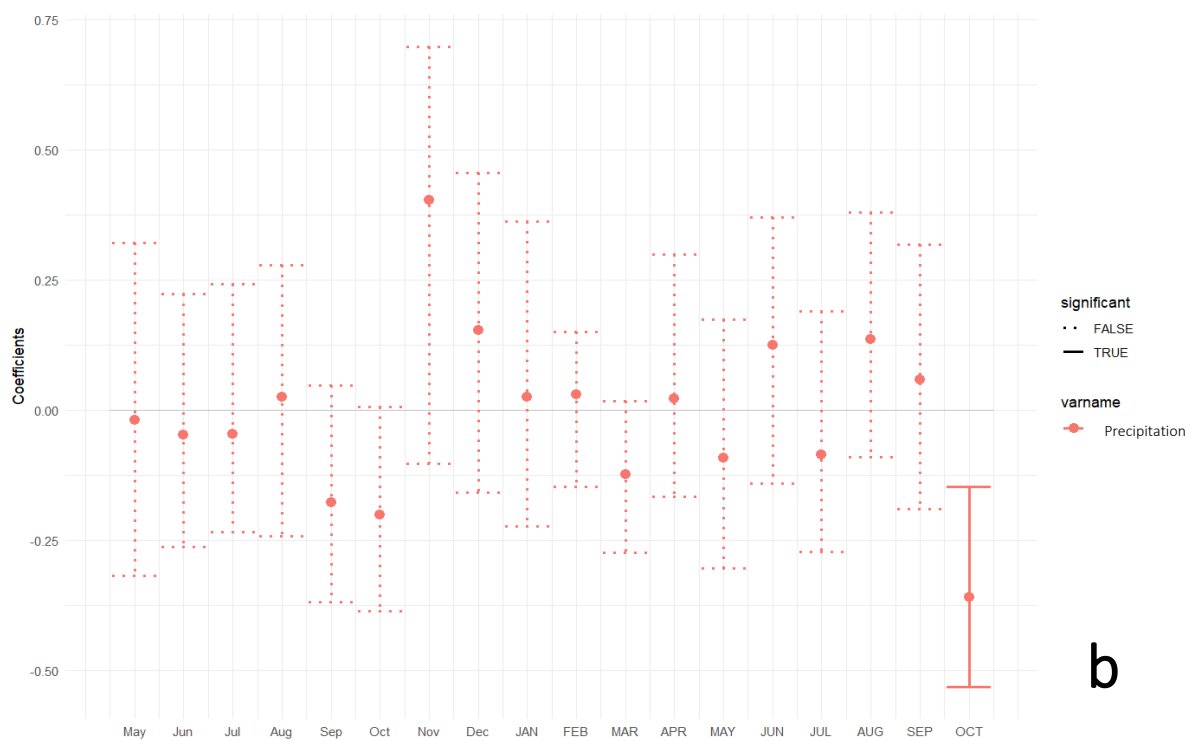


Figure 9. Standardised growth increments built on the detrended series of the “best” sample of *S. humilis* (a) and *C. salvadorensis* (b).

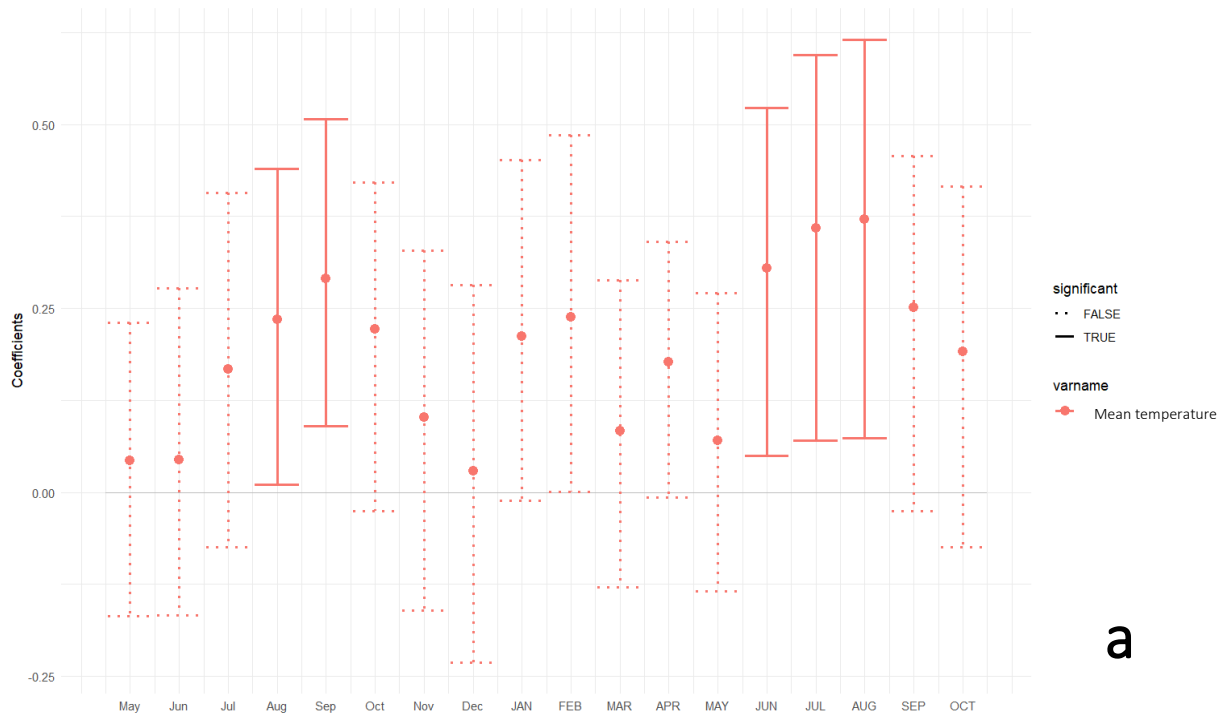


a

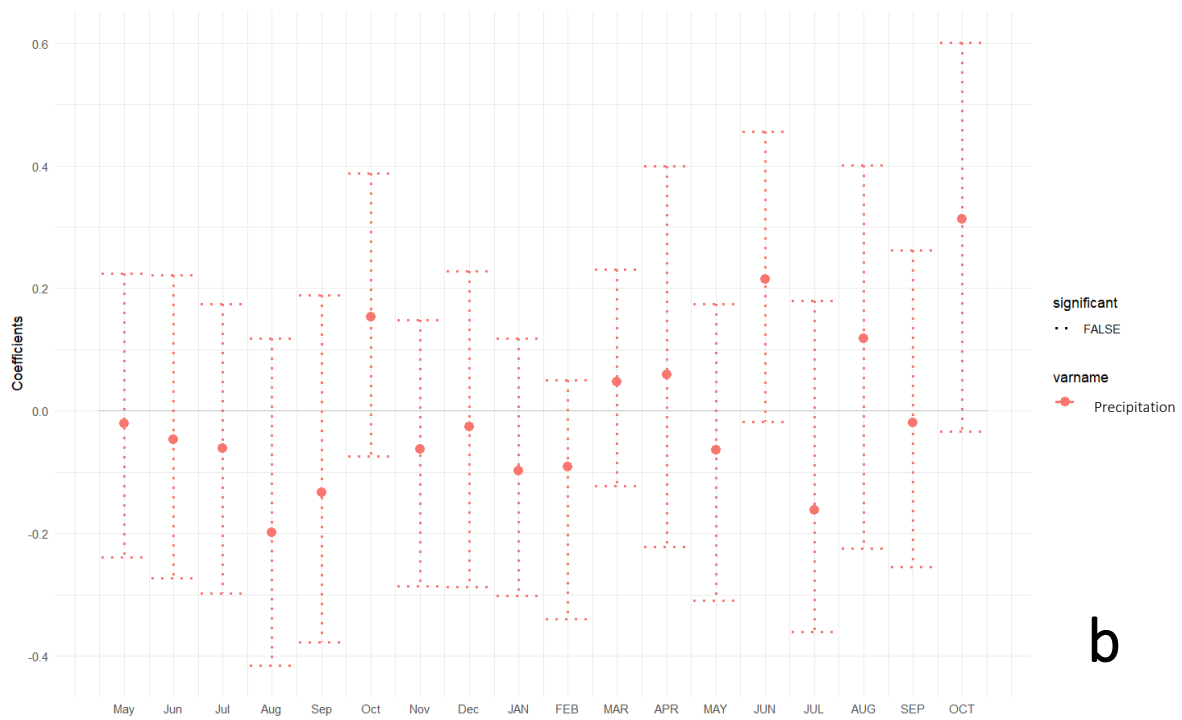


b

Figure 10. Correlation between detrended and standardised annual growth increments of the “best” *S. humilis* sample and monthly mean temperatures (a) and monthly precipitation (b) at Pasabien (months of the current year given in capital letters and in lower case letters for the previous year). Shown is the mean correlation over the entire lifespan of the sample, where solid lines indicate significance ($p < 0.05$).



a



b

Figure 11. Correlation between detrended and standardised annual growth increments of the “best” *C. salvadorensis* sample and monthly mean temperatures (a) and monthly precipitation (b) at Pasabien (months of the current year given in capital letters and in lower case letters for the previous year). Shown is the mean correlation over the entire lifespan of the sample, where solid lines indicate significance ($p < 0.05$).

4 Discussion

4.1 Anatomical structures and tree-ring measurements

The results confirm the expected formation of distinct annual growth rings in both species. *S. humilis* exhibited growth rings delineated by a thin line of marginal parenchyma, consistent with the descriptions reported by Moya et al. (2013) in their investigation of wood anatomy of threatened tropical tree species, including *S. humilis*, as well as with the descriptions in studies involving other species from the same genus (e.g., *Swietenia macrophylla* King in Hook.) (Dünisch et al., 2002). *C. salvadorensis* exhibited tree rings delimited by marginal parenchyma accompanied by vessels forming a semi-porous ring, consistent with the descriptions provided for this species by Moya et al. (2013), and similar to the descriptions from other studies on species within the same genus (e.g., *Cedrela odorata* L. and *Cedrela nebulosa* T.D.Penn. & Daza) (Laymen-Huaman et al., 2018; Menezes et al., 2022; Costa et al., 2023). The tube-like formations filled with resin, that I typically found adjacent to the growth rings of *S. humilis* and *C. salvadorensis*, bear a resemblance to structures observed in other Meliaceae species (e.g. *C. odorata*) which are known as traumatic channels (Lisi et al., 2020; Menezes et al., 2022) as will be subsequently referred to. These structures are commonly linked to injuries inflicted by animal activity on the wood, mechanical impact, or human intervention and are formed during healing processes (Lisi et al., 2020).

The exhibited occurrence of false rings in the wood anatomy of *S. humilis* and *C. salvadorensis* has also been documented in prior studies on species belonging to the *Swietenia* and *Cedrela* genera (Dünisch et al., 2002; Lisi et al., 2020; Costa et al., 2023), and are a common feature observed in various tree species from tropical forests (Brienen et al., 2016; Aragão et al., 2019; 2022; Cerano-Paredes et al., 2020; Giraldo et al., 2020). Studies conducted on other tropical tree species (Priya and Bhat, 1999; Palakit, et al., 2015) have demonstrated that false rings are associated with narrow width rings, as observed in *S. humilis* and *C. salvadorensis*, often occurring during periods of drought in the rainy season. According to Palakit et al. (2015) in their study with *Tectona grandis* L.f., (Lamiaceae) false rings associated with narrow width rings are formed in dry years with high temperature, followed by a wet year, suggesting that the formation of false rings is an indicator of adverse environmental conditions that affect the growth of the trees during the growing season. Thus, the false rings I found in *S. humilis* and *C. salvadorensis* might indicate a response to unfavourable climate conditions during the rainy season. Nevertheless, further analysis is needed for a better

understanding of extreme events that might be influencing the formation of false rings in these species. For example, analysing the occurrence of false rings and their association with narrow annual ring widths formation and fluctuations in temperature at the beginning of the growing season (e.g., Palakit et al., 2015).

Concerning the statistics commonly used in tree-ring science (Fritts, 1976; Briffa, 1995) to estimate the extent of interannual radial growth variability alignment among trees, it appears that the trees I examined for each species did not demonstrate a consistent signal in interannual growth fluctuations (Table 1). These findings are inconsistent with the results reported in other studies conducted on species of the Meliaceae family (e.g. *C. odorata* and *C. nebulosa*)(Layme-Huaman et al., 2018; Lisi et al., 2020; Menezes et al., 2022), as well as with those of studies on other SDTF species from different botanical families (e.g., López and Villalba, 2011; Camarero et al., 2020; Aragão et al., 2019; 2022). Technical issues encountered during the sample processing (Appendix 2, 3) are likely to have caused these unexpected results.

In studies involving other tropical tree species, samples that couldn't be crossdated were omitted from the analysis (e.g., Aragão et al., 2022). However, in this study, due to only one sample being collected per tree, damaged samples weren't excluded from the analysis, impacting the measurements and impeding crossdating. Therefore, when conducting research with tropical species, particularly considering the difficulty associated with obtaining high-quality cores from large hardwood trees (e.g., species from the Meliaceae family), it is advisable to collect a minimum of three or more cores per tree for tree-ring analyses (Gärtner et al., 2015; Danquah et al., 2019; Caetano-Andrade et al., 2021).

Another potential factor contributing to the unsynchronised growth patterns observed in *S. humilis* and *C. salvadorensis* was the presence of traumatic channels. Their proximity to the growth rings as evidenced in samples from *S. humilis* and *C. salvadorensis*, poses challenges in accurately identifying ring boundaries, leading to alterations in radial measurements (Lisi et al., 2020). In some instances, these structures were linked with narrow growth rings, complicating the width measurements. In tree ring analyses on *C. odorata* (Lisi et al., 2020), the use of multiple samples from the same tree facilitated comparison during the measurement and synchronization of growth ring widths, particularly in cases where identifying false rings and the presence of traumatic channels was

problematic. As a final consideration for the unsynchronized growth patterns observed in the growth series of *S. humilis* and *C. salvadorensis*, it is plausible that the trees used in this study have experienced fluctuating environmental conditions associated with microclimatic variations. However, the climatic data utilized in this study are general data for the study area and do not specifically reflect the conditions at the exact site where the analysed trees are situated. Consequently, drawing conclusive insights about microclimatic variations from this data may not be appropriate.

Although the formation of annual growth rings was confirmed in *S. humilis* and *C. salvadorensis*, the presence of structures such as false rings and traumatic channels could pose analytical challenges by distorting radial measurements of the growth rings. Therefore, I recommend conducting a thorough analysis of their growth rings that integrates methodologies for microscopic anatomical examination. Contemporary advancements in methodology for tropical dendroecological studies have introduced techniques aimed at enhancing the visualisation, delimitation, and subsequent analysis of tree rings. X-ray densitometry, in combination with anatomical characterisation through macroscopic differentiation and microscopic examination using histological sections, has been demonstrated to enhance the precision in identifying annual tree ring boundaries. Additionally, this approach improves the characterisation of various anatomical features of tropical growth rings, including fibre zones, ring porosity, and marginal parenchyma (Albuquerque et al., 2016; Pagotto et al., 2017; Quintilhan et al., 2021; Rodriguez et al., 2022). These methodologies have been applied to various tropical tree species with differing wood densities, including two species from the Meliaceae family (*Cedrela fissilis* Vell. and *C. odorata*) (Albuquerque et al., 2016; Lisi et al., 2020; Quintilhan et al., 2021; Rodriguez et al., 2022). Hence, I propose conducting further analysis utilising this approach, along with increased core samples per tree, to improve the characterisation, measurement, synchronisation, and analysis of the growth ring widths of *S. humilis* and *C. salvadorensis*.

Finally, concerning the average series length, it amounted to 55.8 years for *S. humilis* and 58.3 years for *C. salvadorensis*. In comparison to other studies involving tree species within the same genera (e.g., *S. macrophylla*, *C. fissilis* and *C. odorata*) with ages exceeding 150 years (Dünisch et al., 2003; Pereyra-Espinoza et al., 2014; Pereira et al., 2018), the trees examined in this analysis are relatively young. This observation could indicate that disturbances associated with human activities have impacted the SDTF in the HNR or that there are missing rings due to measurement inaccuracies

(Appendix 1-3). Both scenarios are plausible. Nevertheless, it's essential to highlight that Guatemala's SDTF have suffered a substantial loss of 86% of their natural cover due to human-induced factors (Portillo-Quintero and Sánchez-Azofeifa, 2010), resulting in their current highly fragmented and degraded state (Ariano-Sánchez, 2018). Moreover, cultivation of melon and watermelon has had a significant expansion in recent years in the landscape surrounding the HNR (Secaira, 2008; Ariano-Sánchez, 2018). Therefore, it is more likely that the SDTF examined in this study is a young secondary forest, with relatively contemporary dominant trees. On the other hand, *S. humilis* and *C. salvadorensis* are species known to be over-exploited due to the economic value of their high-quality wood (Moya et al., 2013; Danquah et al., 2019; Medina-Amaya et al., 2021; Barstow, 2019; Fuentes et al., 2019), which could also explain the relatively young age of the analysed trees. These findings emphasize the importance of employing dendroecological analysis within Guatemala's SDTF, providing valuable insights into reconstructing the disturbance history of these forests. Moreover, this data can facilitate additional exploration of tree age determination, which I recommend for developing strategies aimed at implementing long-term protection measures for the HNR and other SDTF reserves in Guatemala.

4.2 Climate-growth relationship

The correlation analysis of annual growth increments in *S. humilis* and *C. salvadorensis* with climatic variables showed no consistent pattern in the influence of monthly temperatures and precipitation on radial growth in these species. These findings diverge from other tree-ring investigations conducted in SDTF involving Meliaceae species (e.g., *S. macrophylla*, *C. odorata* and *C. fissilis*), where radial growth exhibited a positive correlation with precipitation during the rainy season, coinciding with the cambial activity (Dünisch et al., 2003; Costa et al., 2023; Mendivelso et al., 2016b; Pereira et al., 2018; Aragão et al., 2019; Lisi et al., 2020; Menezes et al., 2022).

In tropical environments, most species are expected to exhibit sensitivity to rainfall, as demonstrated in studies involving other *Cedrela* and *Swietenia* species (Dünisch et al., 2003; Mendivelso et al., 2016b; Menezes et al., 2022; Costa et al., 2023). Tropical species have widely been observed to undergo periodic cambium reactivation and xylem growth dependent on rainfall seasonality, with growth being reduced during dry and hot periods (Dünisch et al., 2003; Mendivelso et al., 2016b; Brienen et al., 2016; López et al., 2019; Menezes et al., 2022). Species demonstrating

reduced sensitivity to seasonal changes employ different strategies to cope with water deficits (Rodríguez-Robles et al., 2020; Costa et al., 2023). Costa et al. (2023), studied the differences in climate-growth relationships between *C. odorata* (Meliaceae) and *Ceiba glaziovii* (Kuntze) K.Schum. (Malvaceae) in a SDTF, demonstrating that despite the similarities of the rainfall effect on their growth variability, *C. odorata* showed a higher sensitivity as also demonstrated in other studies with this species (Lisi et al., 2020; Menezes et al., 2022). The lower sensitivity observed in *C. glaziovii* is due to its ability to store water in the trunk to use it during the dry season, which gives the trunk a swollen appearance (Costa et al., 2023). The presence of water reserves in the trunk was also observed in oak trees of a semi-arid forest in Mexico, where in addition to this strategy, the presence of deep roots reaching the water stored in fractures of rocks was observed (Rodríguez-Robles et al., 2020). However, studies with species from the Meliaceae family have demonstrated a high sensitivity to seasonality, and their growth appears to be closely synchronized with precipitation (Dünisch et al., 2003; Pereyra-Espinoza et al., 2014; Pereira et al., 2018; Lisi et al., 2020; Menezes et al., 2022; Costa et al., 2023). Thus, I expect *S. humilis* and *C. salvadorensis* to have a high sensitivity to seasonality. The anomalous effects of temperature and precipitation observed in the correlation analysis are more likely due to inaccuracies in the tree-ring measurements, rather than strategies to avoid drought (Appendix 1-3).

The overall high sensitivity of tree growth to climate, particularly the positive response to precipitation, has been shown across various tree species in different vegetation types of SDTF (Aragão et al., 2022). In general, tree-ring studies in SDTF with tree species of the Meliaceae family (Pereyra-Espinoza et al., 2014; Venegas-González et al., 2018; Lisi et al., 2020; Menezes et al., 2022) and other botanical families (López and Villalba, 2011; 2020; Aragão et al., 2019; 2022) have shown a positive correlation between the radial growth and precipitation. Whereas high temperatures with less precipitation are negatively correlated (López and Villalba, 2011; Venegas-González et al., 2018; López and Villalba, 2020; Aragão et al., 2019; 2022; Menezes et al., 2022). These findings highlight the vulnerability of the SDTF to the drought expected due to climate change (Powers et al., 2020; Aragão et al., 2019; 2022). They also underscore the importance of understanding the climate sensitivity and response of SDTF species to hydrological seasonality. This knowledge is crucial for assisting the conservation and restoration efforts of these endangered ecosystems (Aragão et al., 2019; 2022; Menezes et al., 2022; Costa et al., 2023). Thus, I highly recommend further climate-

growth relationship analysis with *S. humilis* and *C. salvadorensis* in the SDTF of Guatemala, which are promising species for dendroecological studies, due to their distinct annual tree-ring formation.

5 Conclusions and perspectives

The observed distinct annual tree-ring formation of *S. humilis* and *C. salvadorensis* offers potential for dendroecological studies. Although crossdating and chronology building proved unsuccessful, my findings regarding the anatomical structure suggest that their inter-annual growth variations appear to be influenced by rainfall seasonality and temperature, given the presence of false rings alongside narrow growth rings. Additional research focusing on anatomical characterization through macroscopic and microscopic analysis, coupled with larger sample sizes and individual counts, will enhance the understanding, measurement, synchronization, and analysis of their growth rings. This will aid in the construction of chronologies for *S. humilis* and *C. salvadorensis*, enabling more comprehensive climate-growth analyses.

My findings also suggest a relatively young age of the trees examined. This young age can potentially be linked to human activities in the past, before the establishment of the HNR. This emphasizes that dendroecological analysis can be used to comprehend the response of the SDTF to climate change and their disturbance history, serving as a baseline for future management. Furthermore, it highlights the necessity for developing restoration and conservation strategies for these endangered ecosystems and their climate-sensitive species. As such, this study represents a pioneering effort in Guatemala's SDTF, where dendroecology represents an unexplored yet promising avenue for investigating climate change and conducting research on forest conservation and management, especially in light of their significant degradation and fragmentation.

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7 Appendix

Appendix 1. Crossdating process of *S. humilis* and *C. salvadorensis* using CooRecoder and CDendro software (version 9.8.1 for Windows; Cybis, 2022) and standard analyses in the Dendrochronology Program Library (dplR version 1.7.6.)

I measured the grow ring widths of *S. humilis* and *C. salvadorensis* using CooRecoder, and since, to my knowledge, no previous dendrochronological analysis has been conducted on these species, there is no master series or reference curve available for assessing the crossdating. Therefore, following the instructions to build a synchronised collection from unsynchronised members on the CDendro homepage <https://www.cybis.se/forfun/dendro/addbest/index.htm> I selected the best member from the collections of *S. humilis* and *C. salvadorensis* to synchronise the rest of the members of the sample collection, towards the best member. Nevertheless, because of the high variability in the growth patterns of the samples of both species, in the cross-correlation matrix obtained for each species, the TTest value of matches for all members of the collection, was lower than $T \geq 6.0$ expected following the procedure described by Cybis (see link above). Thus, I selected samples for each species collection based on several criteria. I chose those with the most matches against other members of the collection and the highest TTest values. Additionally, I ensured that the samples had no damaged sections throughout their entire length. This was to guarantee that all true rings were visible under the stereomicroscope and could be measured accurately. The best member from the collection of *S. humilis* was the sample img623_I. It had eight matches with TTest values of 4 or above and no damaged sections. Other possible best members had similar numbers of matches with TTest values (Matrix 1), but they had damaged sections. For *C. salvadorensis*, the best member was sample img633_I. It had six matches with TTest values of 4 or above and no damaged sections. Other possible best members had similar numbers of matches with TTest values (Matrix 2) but had damaged sections. The rest of the members from the collection of each species were synchronised towards the best member selected and the collection of series obtained was normalised using the Negative exponential detrended method. The characteristics of the chronologies for *S. humilis* and *C. salvadorensis* are shown in Appendix 1.2.

Matrix 1. Best correlations between each checked member and all other checked members of the *S. humilis* collection.

		Rest	img629_I	img649_I	img632_I	img630_I	img648_I	img640_I	img627_I	img636_I	img623_I	img650_I	img618	img620_I	img622_I	img637_I	img638_I	img621_I
Dated:			2022	2023	2023	2022	2022	2022	2023	2022	2023	2023	2023	2023	2023	2023	2023	2023
Sortkey			4,1	3,9	3,9	3,8	3,8	3,7	3,7	3,7	3,7	3,7	3,6	3,4	3,3	3,3	3,3	3,2
	Year s	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap
Rest			0,36 2,0 29	0,33 2,3 43	0,41 3,0 47	0,39 2,9 46	0,60 4,0 30	0,45 2,7 31	0,41 3,3 54	0,47 3,4 42	0,30 2,4 60T*	0,46 3,0 36	0,38 3,0 55	0,43 2,7 34	0,60 4,1 32	0,49 3,6 45	0,42 3,1 47	0,37 2,7 48
img629_I	30	0,36 2,0 29		0,66 4,5 29	0,50 3,0 29	0,34 1,9 29	0,41 2,3 29T	0,59 3,8 29	0,37 2,0 29	0,40 2,3 29	0,62 4,1 29	0,29 1,6 29	0,42 2,4 29	0,35 1,9 29	0,17 0,9 29T	0,18 1,0 29	0,41 2,3 29	0,27 1,4 29
img649_I	48	0,33 2,3 43	0,66 4,5 29		0,44 3,3 47*	0,43 3,1 45*	0,47 3,5 47	0,33 2,0 35	0,37 2,6 43	0,43 3,0 41	0,51 3,6 38	0,41 3,0 47	0,26 1,8 47*	0,46 3,2 41	0,50 3,3 34	0,44 2,7 33	0,39 2,8 45	0,27 1,6 37
img632_I	67	0,41 3,0 47	0,50 3,0 29	0,44 3,3 47*		0,51 4,2 50	0,31 2,2 47	0,48 3,8 49	0,41 3,6 66	0,36 2,5 45	0,35 2,4 43	0,46 2,8 32	0,31 2,2 48	0,31 2,2 47T	0,44 2,7 32	0,37 2,5 42	0,49 3,7 47	0,32 2,3 49
img630_I	52	0,39 2,9 46	0,34 1,9 29	0,43 3,1 45*	0,51 4,2 50		0,30 2,2 50*	0,55 3,7 33	0,52 3,3 31	0,43 3,1 44	0,29 2,1 51*	0,34 2,5 51	0,34 2,5 49*	0,51 3,5 37	0,30 1,8 37*	0,41 2,8 41	0,42 3,1 47	0,33 2,3 47
img648_I	58	0,60 4,0 30	0,41 2,3 29T	0,47 3,5 47	0,31 2,2 47	0,30 2,2 50*		0,46 2,7 30	0,56 3,6 30	0,53 3,9 41	0,40 2,9 45	0,38 2,8 49	0,47 3,8 52	0,54 3,4 30	0,44 2,6 31	0,55 3,6 33	0,33 2,3 47	0,29 1,6 31
img640_I	69	0,45 2,7 31	0,59 3,8 29	0,33 2,0 35	0,48 3,8 49	0,55 3,7 33	0,46 2,7 30		0,42 3,2 50	0,47 3,3 41*	0,37 3,0 59T*	0,56 3,6 30	0,38 2,9 55*	0,40 2,4 31	0,48 3,2 36	0,38 2,8 47	0,39 2,8 46	0,31 2,3 49
img627_I	80	0,41 3,3 54	0,37 2,0 29	0,37 2,6 43	0,41 3,6 66	0,52 3,3 31	0,56 3,6 30	0,42 3,2 50		0,45 3,3 46	0,40 3,1 53	0,46 3,0 36	0,48 3,9 55	0,45 3,4 47	0,42 2,7 37	0,29 2,0 47	0,40 2,9 47	0,45 3,0 37
img636_I	77	0,47 3,4 42	0,40 2,3 29	0,43 3,0 41	0,36 2,5 45	0,43 3,1 44	0,53 3,9 41	0,47 3,3 41*	0,45 3,3 46		0,41 2,6 35	0,52 3,8 42	0,43 3,2 45	0,48 3,5 42	0,47 3,2 37	0,38 2,6 43	0,37 2,1 30	0,24 1,7 49
img623_I	61	0,30 2,4 60T*	0,62 4,1 29	0,51 3,6 38	0,35 2,4 43	0,29 2,1 51*	0,40 2,9 45	0,37 3,0 59T*	0,40 3,1 53	0,41 2,6 35		0,36 2,2 36	0,42 3,0 44	0,31 2,2 47	0,53 3,4 32	0,50 3,1 32	0,26 1,7 40	0,38 2,8 48
img650_I	63	0,46 3,0 36	0,29 1,6 29	0,41 3,0 47	0,46 2,8 32	0,34 2,5 51	0,38 2,8 49	0,56 3,6 30	0,46 3,0 36	0,52 3,8 42	0,36 2,2 36		0,48 3,2 37	0,41 2,9 43*	0,50 3,1 32	0,44 2,7 32	0,40 3,0 47	0,48 3,6 46*
img618	56	0,38 3,0 55	0,42 2,4 29	0,26 1,8 47*	0,31 2,2 48	0,34 2,5 49*	0,47 3,8 52	0,38 2,9 55*	0,48 3,9 55	0,43 3,2 45	0,42 3,0 44	0,48 3,2 37		0,43 3,0 41	0,37 2,3 37	0,48 3,1 33	0,35 2,3 40*	0,25 1,7 48
img620_I	48	0,43 2,7 34	0,35 1,9 29	0,46 3,2 41	0,31 2,2 47T	0,51 3,5 37	0,54 3,4 30	0,40 2,4 31	0,45 3,4 47	0,48 3,5 42	0,31 2,2 47	0,41 2,9 43*	0,43 3,0 41		0,46 3,0 36	0,43 2,9 39	0,37 2,3 35	0,40 2,4 31
img622_I	38	0,60 4,1 32	0,17 0,9 29T	0,50 3,3 34	0,44 2,7 32	0,30 1,8 37*	0,44 2,6 31	0,48 3,2 36	0,42 2,7 37	0,47 3,2 37	0,53 3,4 32	0,50 3,1 32	0,37 2,3 37	0,46 3,0 36		0,36 2,3 37T	0,35 2,1 32	0,38 2,4 36
img637_I	48	0,49 3,6 45	0,18 1,0 29	0,44 2,7 33	0,37 2,5 42	0,41 2,8 41	0,55 3,6 33	0,38 2,8 47	0,29 2,0 47	0,38 2,6 43	0,50 3,1 32	0,44 2,7 32	0,48 3,1 33	0,43 2,9 39	0,36 2,3 37T		0,29 2,0 44	0,27 1,8 41*
img638_I	48	0,42 3,1 47	0,41 2,3 29	0,39 2,8 45	0,49 3,7 47	0,42 3,1 47	0,33 2,3 47	0,39 2,8 46	0,40 2,9 47	0,37 2,1 30	0,26 1,7 40	0,40 3,0 47	0,35 2,3 40*	0,37 2,3 35	0,35 2,1 32	0,29 2,0 44		0,42 3,0 43
img621_I	50	0,37 2,7 48	0,27 1,4 29	0,27 1,6 37	0,32 2,3 49	0,33 2,3 47	0,29 1,6 31	0,31 2,3 49	0,45 3,0 37	0,24 1,7 49	0,38 2,8 48	0,48 3,6 46*	0,25 1,7 48	0,40 2,4 31	0,38 2,4 36	0,27 1,8 41*	0,42 3,0 43	
		Rest	img629_I	img649_I	img632_I	img630_I	img648_I	img640_I	img627_I	img636_I	img623_I	img650_I	img618	img620_I	img622_I	img637_I	img638_I	img621_I
MinimumCorr		0,30	0,17	0,26	0,31	0,29	0,29	0,31	0,29	0,24	0,26	0,29	0,25	0,31	0,17	0,18	0,26	0,24

Correlation calculus based on P2YrsL: Proportion of last two years growth LIMITED Minimum overlap required: 30

Sorted by mean T-value of 3 best matches.

An '*' indicates that the best T-value selected anyhow has a lower corr coeff value than the next best available T-value (because of differences in overlap)

A 'T' indicates that a best matching point corresponds to the current offset within the collection.

Sum by stem is ON

"Rest" on a row or a column refers to the rest of the collection (comp. Test towards rest of collection).

Groups are: <Best corrCoeff value, Best T-test value, Overlap> RBAR (mean series intercorrelation based on NORMALIZED curves) for 16 series and 0 combinations.

RBAR= 0,00 when CC >= 0,5, T >= 7,0 and Overlap >= 20

Matrix 2. Best correlations between each checked member and all other checked members of the *C. salvadorensis* collection.

		Rest	img647_l	img631_l	img628_l	img626_l	img639_l	img619_l	img635_l	img633_l	img641me	img643me	img634_l
Dated:			2023	2022	2023	2022	2023	2023	2023	2023	2023	2022	2023
Sortkey			4,2	4,0	3,8	3,8	3,6	3,5	3,4	3,4	3,4	3,2	3,0
	Years	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap	CorrTTest Olap
Rest			0,41 3,2 54 *	0,61 4,3 34	0,56 4,6 47	0,35 2,5 48	0,41 2,9 43 *	0,32 2,7 65	0,53 3,4 32	0,47 3,4 41	0,27 2,3 69 *	0,39 2,7 42 *	0,59 4,3 36
img647_l	111	0,41 3,2 54 *		0,61 4,3 34	0,49 3,8 47	0,38 2,8 48	0,56 4,4 43	0,30 2,4 63	0,43 3,6 58	0,33 2,8 66	0,35 3,1 69	0,45 3,2 42 *	0,49 3,2 35
img631_l	42	0,61 4,3 34	0,61 4,3 34		0,39 2,3 32	0,60 4,3 35	0,48 3,0 32	0,32 2,1 41 *	0,34 2,3 41	0,49 3,4 40 *	0,34 2,3 41	0,40 2,3 30	0,31 1,9 36
img628_l	48	0,56 4,6 47	0,49 3,8 47	0,39 2,3 32		0,58 3,9 33	0,43 2,7 34	0,49 3,7 46	0,47 3,4 41	0,39 2,4 34	0,44 3,3 47	0,34 2,2 38	0,44 2,8 36
img626_l	49	0,35 2,5 48	0,38 2,8 48	0,60 4,3 35	0,58 3,9 33		0,36 2,0 30	0,43 3,1 44	0,38 2,7 46	0,40 2,9 48 *	0,39 2,9 48 *	0,43 2,6 30	0,24 1,5 36 *
img639_l	49	0,41 2,9 43 *	0,56 4,4 43	0,48 3,0 32	0,43 2,7 34	0,36 2,0 30		0,49 3,1 33	0,35 2,4 41 *	0,40 2,5 35	0,52 3,4 34	0,42 2,9 42	0,39 2,3 32
img619_l	66	0,32 2,7 65	0,30 2,4 63	0,32 2,1 41 *	0,49 3,7 46	0,43 3,1 44	0,49 3,1 33		0,44 3,3 48	0,40 3,2 57	0,49 3,5 41	0,35 2,3 40	0,30 1,9 36
img635_l	59	0,53 3,4 32	0,43 3,6 58	0,34 2,3 41	0,47 3,4 41	0,38 2,7 46	0,35 2,4 41 *	0,44 3,3 48		0,27 2,1 58	0,34 2,5 51	0,28 1,8 42 *	0,42 2,7 36 *
img633_l	67	0,47 3,4 41	0,33 2,8 66	0,49 3,4 40 *	0,39 2,4 34	0,40 2,9 48 *	0,40 2,5 35	0,40 3,2 57	0,27 2,1 58		0,36 2,7 49 *	0,50 3,6 42	0,44 2,8 36
img641me	70	0,27 2,3 69 *	0,35 3,1 69	0,34 2,3 41	0,44 3,3 47	0,39 2,9 48 *	0,52 3,4 34	0,49 3,5 41	0,34 2,5 51	0,36 2,7 49 *		0,35 2,4 42 *	0,37 2,3 36
img643me	43	0,39 2,7 42 *	0,45 3,2 42 *	0,40 2,3 30	0,34 2,2 38	0,43 2,6 30	0,42 2,9 42	0,35 2,3 40	0,28 1,8 42 *	0,50 3,6 42	0,35 2,4 42 *		0,43 2,8 36
img634_l	37	0,59 4,3 36	0,49 3,2 35	0,31 1,9 36	0,44 2,8 36	0,24 1,5 36 *	0,39 2,3 32	0,30 1,9 36	0,42 2,7 36 *	0,44 2,8 36	0,37 2,3 36	0,43 2,8 36	
		Rest	img647_l	img631_l	img628_l	img626_l	img639_l	img619_l	img635_l	img633_l	img641me	img643me	img634_l
MinimumCorr 0,24		0,27	0,30	0,31	0,34	0,24	0,35	0,30	0,27	0,27	0,27	0,28	0,24

Correlation calculus based on P2YrsL: Proportion of last two years growth LIMITED Minimum overlap required: 30

Sorted by mean T-value of 3 best matches.

An "*" indicates that the best T-value selected anyhow has a lower corr coeff value than the next best available T-value (because of differences in overlap)

A 'T' indicates that a best matching point corresponds to the current offset within the collection.

Sum by stem is ON

"Rest" on a row or a column refers to the rest of the collection (comp. Test towards rest of collection).

Groups are: <Best corrCoeff value, Best T-test value, Overlap> RBAR (mean series intercorrelation based on NORMALIZED curves) for 11 series and 0 combinations.

RBAR= 0,00 when CC >= 0,5, T >= 7,0 and Overlap >= 20

Appendix 1.2. Dendrochronological characteristics of the tree ring chronology of *S. humilis* and *C. salvadorensis* from a seasonal tropical dry forest, Eastern Guatemala. Chronologies were built following the crossdating process described in appendix 1. No. cores: number of samples per tree; No. trees: number of analysed trees; n.tot: total number of tree-ring series used to construct the chronology; rbar.tot; mean interseries correlation; EPS: expression population signal; SNR: Signal-to-Noise Ratio.

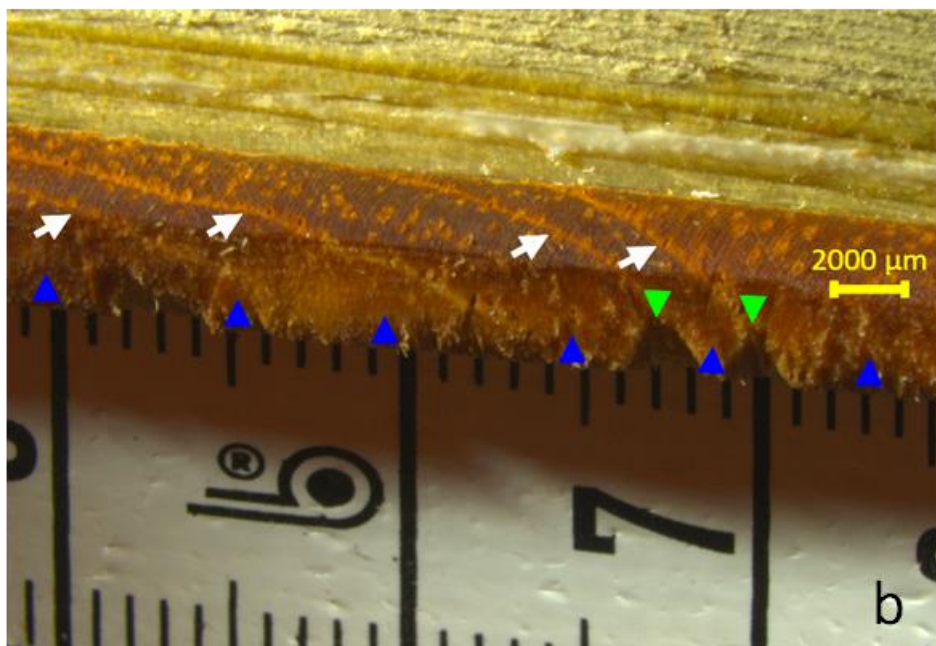
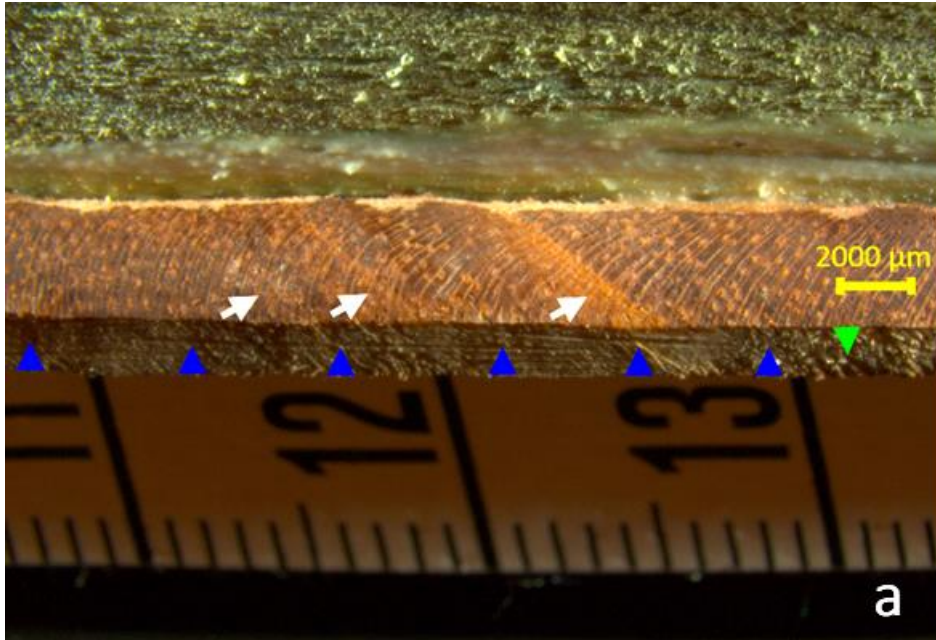
Species	No. cores	No. trees	n.tot	rbar.tot	EPS	SNR
<i>S. humilis</i>	16	16	114	0.115	0.676	2.083
<i>C. salvadorensis</i>	11	11	49	0.175	0.7	2.332

The low rbar.tot values for both chronologies suggest that trees are not responding similarly to external environmental factors. The EPS value for both chronologies is lower than the threshold ≥ 0.85 used in tree-ring studies. This suggests that the variation in the chronologies is mainly attributable to individual differences among tree-ring series rather than a shared signal, pointing to potential data quality issues or the influence of non-climatic factors on tree growth. This coincides with the low SNR values (ranges from 0 to positive infinity), indicating that the variability in the data is relatively high compared to the common signal (Fritts, 1976, Briffa, 1995; Cook and Petersen, 2011).

Appendix 2. Prior sampling processing

Firstly, I treated the surface of the samples with a scalpel, instead of a sander tool to improve the visibility of anatomical structures. Nevertheless, this method created artifact structures in the samples linked to the use of a scalpel, especially in *C. salvadorensis*. Moreover, during the macroscopic observation of the ring boundaries, I confirmed that the samples were glued in a non-optimal orientation (Appendix 2.1). Thus, it was necessary to detach all samples and reposition them to enable observation of the transverse section. To do that, I immersed them in boiling water for 40 minutes (some samples needed less time to unglue) and then I carefully loosened them with the help of a scalpel. Some of the samples were twisted and the orientation changed along the sample. For the samples where the twisting was very strong, I cut the twisted section into pieces to be able to glue each piece with the right orientation. However, for some samples this process damaged the tissues as seen in Appendix 3.

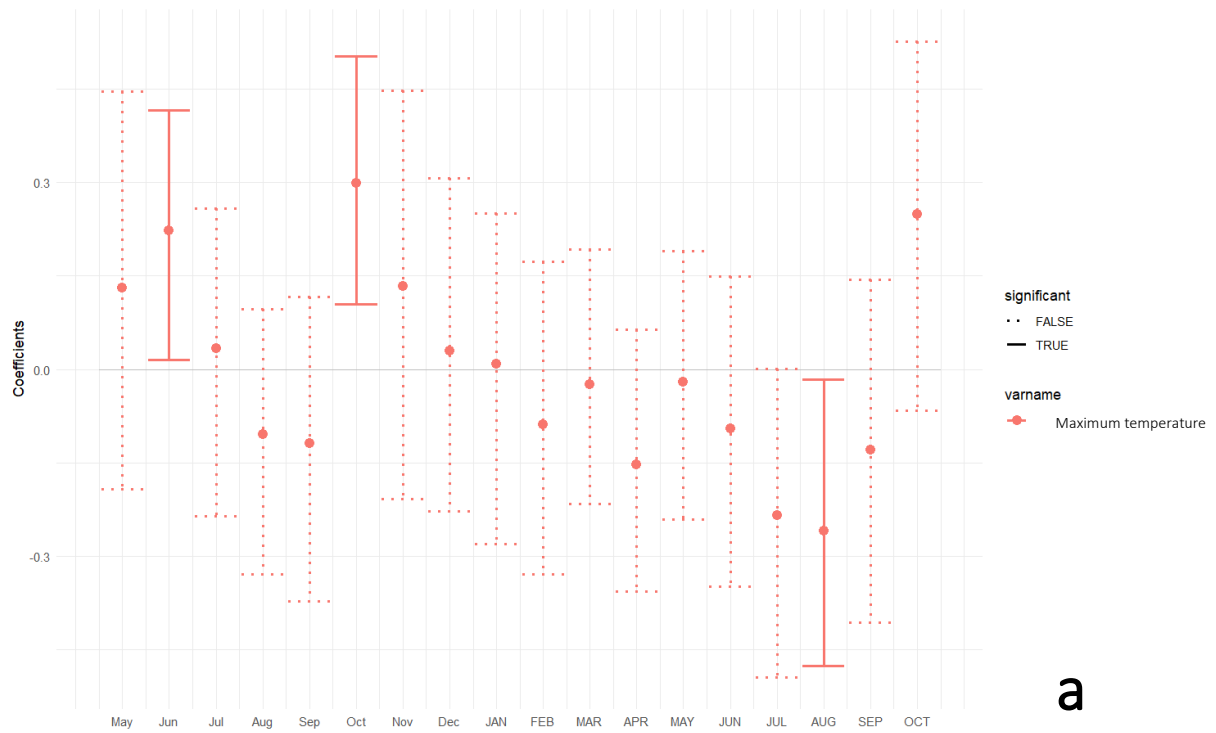
Appendix 2.1. Wood samples from *S. humilis* (a) and *C. salvadorensis* (b). White arrows indicate growing ring boundaries; Blue arrows show the surface where the treatment with the scalpel was done; Green arrows indicate the artifact structures in the samples linked to the use of a scalpel. The non optimal orientation of the tree rings can be observed in both samples.



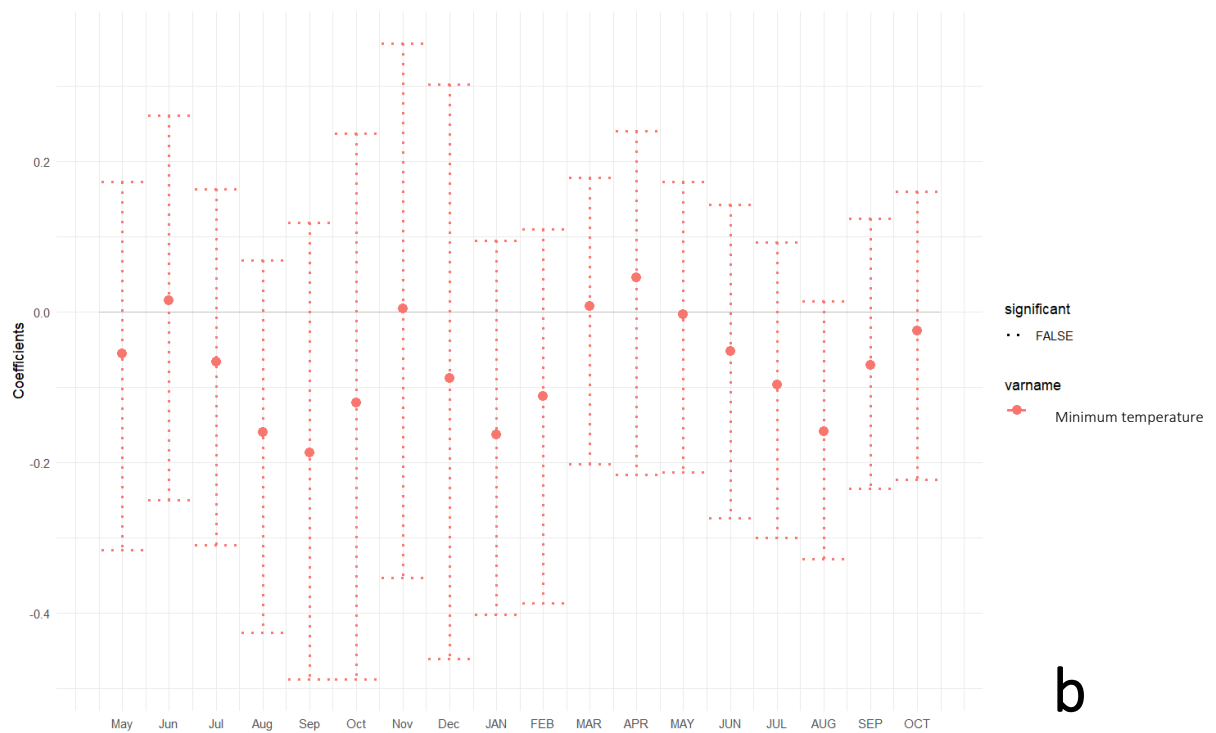
Appendix 3. Sections of damaged wood samples from *S. humilis* (a) and *C. salvadorensis* (b) following treatment to unmount the samples with suboptimal orientation.



Appendix 4. Correlation between detrended and standardised annual growth increments of the “best” *S. humilis* sample and monthly maximum (a) and minimum (b) temperatures at Pasabien (months of the current year given in capital letters and in lower case letters for the previous year). Shown is the mean correlation over the entire life span of the sample, where solid lines indicate significance ($p < 0.05$).

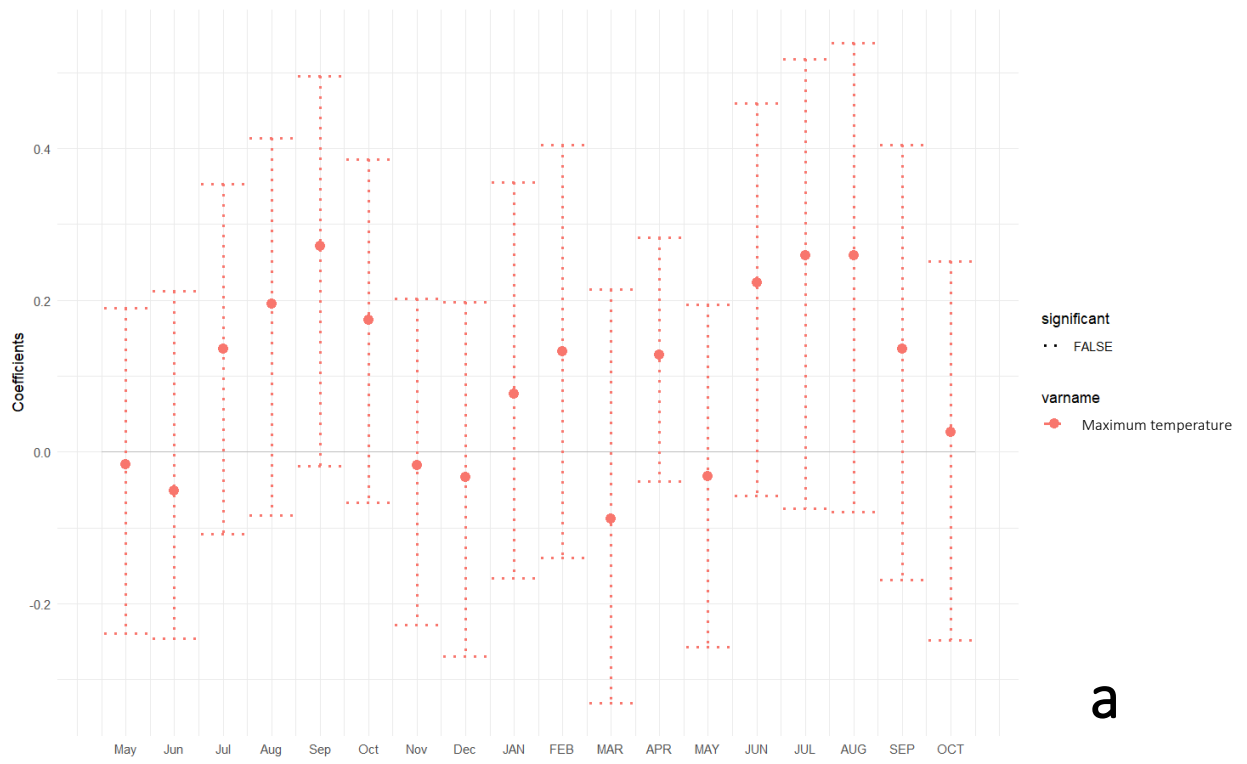


a

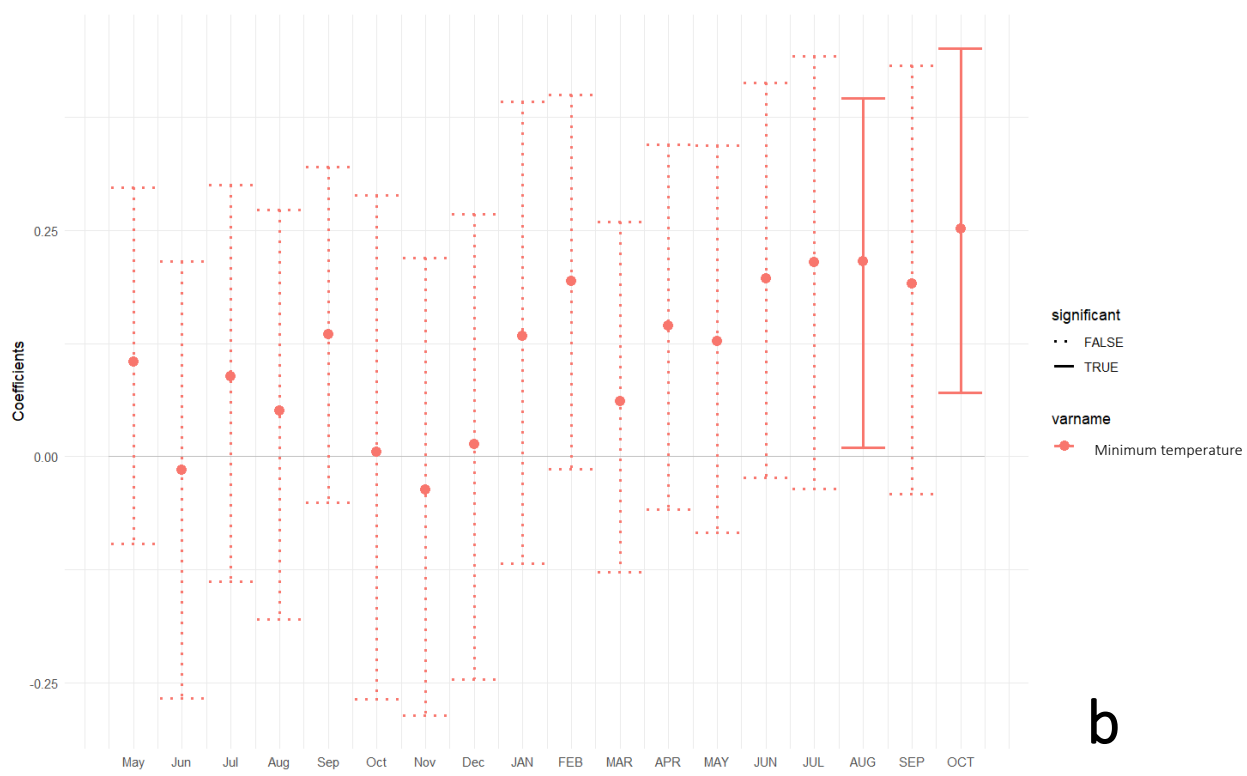


b

Appendix 5. Correlation between detrended and standardised annual growth increments of the “best” *C. salvadorensis* sample and monthly maximum (a) and minimum (b) temperatures at Pasabien (months of the current year given in capital letters and in lower case letters for the previous year). Shown is the mean correlation over the entire life span of the sample, where solid lines indicate significance ($p < 0.05$).



a



b