Potencial dendrocronológico de 65 especies de la Serranía de los Yariguíes y el Cañón del Chicamocha

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Trabajo de Grado para Optar al Título de Magister en Biología

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Resúmen

Título: Potencial dendrocronológico de 65 especies de la Serranía de los Yariguíes y el Cañón del Chicamocha

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Palabras clave: Dendrocronología, Colombia, trópicos, anillos de crecimiento, radiocarbono, anatomía de la madera

Descripción: Los anillos de crecimiento de los árboles tropicales ofrecen información valiosa sobre sus patrones de crecimiento y las restricciones ambientales que enfrentan. Aunque históricamente debatida, la presencia de anillos de crecimiento en especies tropicales está ahora bien documentada. Sin embargo, la alta diversidad de especies y las complejas interacciones climáticas representan desafíos para su estudio. En Colombia, la investigación dendrocronológica se ha expandido progresivamente en diversas regiones geográficas, proporcionando información clave sobre el crecimiento arbóreo en distintos ecosistemas tropicales. No obstante, la región noreste sigue siendo en gran parte inexplorada, y es necesario evaluar el potencial dendrocronológico de sus especies arbóreas. En este estudio, demuestro que aproximadamente el 78 % de las especies analizadas presentan anillos de crecimiento distinguibles. La visibilidad de los anillos varía según la estructura de la madera: los anillos bien definidos suelen estar asociados con bandas de parénquima marginal y variaciones en el tamaño de los vasos, mientras que los anillos poco definidos se relacionan con la estructura de las fibras. El análisis con radiocarbono (^{14}C) confirma la formación anual de los anillos en la mayoría de las especies. No obstante, también revela discrepancias en algunas especies, probablemente debido a la presencia de anillos falsos, anillos ausentes o variaciones de crecimiento intra-anuales y supra-anuales, fenómenos comunes en árboles tropicales. Nuestros resultados reafirman que cerca del 80 % de las especies de árboles tropicales tienen potencial dendrocronológico. Estos hallazgos, obtenidos a partir de un marcado gradiente climático, abren nuevas oportunidades para la reconstrucción de condiciones ambientales pasadas, mejorando la comprensión de la dinámica de crecimiento arbóreo y proporcionando cronologías valiosas para estudios sobre el cambio climático en Colombia. Además, esta información puede contribuir a la gestión sostenible de los bosques al proporcionar datos sobre tasas de crecimiento de especies, estrategias de regeneración forestal y esfuerzos de conservación de la biodiversidad.

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*Trabajo de grado

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Abstract

Title: Dendrochronological potential of 65 trees from the Serranía de Los Yariguíes and the Chicamocha Canyon

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Key words: Dendrochronology, Colombia, tropics, growth rings, radiocarbon, wood anatomy

Description: Tropical tree rings offer valuable information about tree growth patterns and their environmental constraints. While historically debated, the presence of growth rings in tropical species is now well-documented, though high species diversity and complex climatic interactions pose challenges for their study. In Colombia, dendrochronological research has progressively expanded across different geographic regions, uncovering valuable insights into tree growth in various tropical ecosystems. However, the northeastern region remains largely unexplored and an evaluation of the dendrochronological potential of its tree species is needed. Here, I show that approximately 78% of the studied species exhibit distinguishable growth rings. Ring visibility varies depending on wood structure, with well-defined rings often associated with marginal parenchyma bands and vessel size variations, while poorly defined rings correlate with fiber structure. Radiocarbon (^{14}C) dating confirms the annual formation of growth rings in most species. However, it also reveals discrepancies in some species, likely due to false rings, missing rings, or intra-annual and supra-annual growth variations, which are common in tropical trees. Our results reaffirm that nearly 80% of tropical tree species have dendrochronological potential. These findings, derived from a steep climatic gradient, provide new opportunities for reconstructing past environmental conditions, enhancing our understanding of tree growth dynamics and providing valuable chronologies for climate change studies in Colombia. Additionally, this information can support sustainable forest management by informing species growth rates, forest regeneration strategies, and biodiversity conservation efforts.

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*Degree thesis

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Introduction

Patterns in tree ring width, wood density, elemental composition, and other characteristics that define growth rings serve as natural archives of past climate and form the foundation of dendrochronology (Worbes, 2004). Growth rings consist of layers of cells from the vascular cambium that differentiate due to physical constraints and variations in resource availability over time, typically on an annual basis. These layers generate temporal patterns in tree growth rates (Kaennel & Schweingruber, 1995; Worbes, 2004; Brienen et al., 2016).

Although dendrochronology in tropical regions dates back over a century (Worbes, 2002), the presence of annual growth rings in tropical regions was historically questioned (Lieberman & Lieberman, 1985; Turner, 2004). It was traditionally believed that only high-latitude regions experience sufficiently strong seasonal variations for trees to form distinct annual growth rings (Sánchez-Calderón et al., 2022). Even though not all tropical species form annual rings, some temperate and extratropical species also lack them. Variations in environmental factors, combined with genetic and endogenous influences, regulate the development of contrasting tissues in the secondary xylem, leading to different growth rhythms even among species within the same habitat (Silva et al., 2019). However, the high diversity of tropical trees presents an additional challenge for dendrochronology, making it essential to first identify species with dendrochronological potential (Worbes, 2002).

Once the notion that tropical species lack dendrochronological potential was challenged, numerous studies have demonstrated the presence of tree growth rings in tropical regions, emphasizing the role of environmental factors. For instance, in hyper-humid forests, growth rings are influenced by soil moisture, hypoxia, and solar radiation (Giraldo et al., 2023). In mangrove ecosystems, their formation is associated with precipitation, water salinity, rising sea levels, and interspecific competition (Menezes et al., 2003; Verheyden et al., 2004; Yu et al., 2004; Estrada et al., 2008; Ramírez et al., 2010). Meanwhile, in tropical dry forests, annual ring formation is linked to rainfall seasonality, ENSO events, and soil moisture (Ramírez & del Valle, 2011; 2012; Briceño et al., 2016; 2018). However, it still remains an enigma why most of the studied tropical growth rings are annual considering that the constraining environmental factors do not necessarily operate at an annual time scale.

Advances in methodologies, such as stable isotopes, gamma radiation, X-ray or high-frequency densitometry have further expanded the potential of dendrochronology in tropical regions, enabling its application in fields such as ecology, climatology, geomorphology, conservation, hydrology, and growth modeling (Giraldo, 2011; Brienen et al., 2016).

Most dendrochronological studies rely on anatomical criteria to classify growth rings, particularly using three main structural components: fibers, parenchyma, and pores (Worbes, 2004). The IAWA classification system (1989), that incorporates these three components, is one of the most widely used and categorizes rings as "distinct," "indistinct or absent." However, this approach may underestimate the presence of growth rings in tropical species (Giraldo et al., 2020), contributing to a lack of consensus on ring classification in these ecosystems (Tarelkin et al., 2016). As a result, researchers have proposed broader classification criteria that better reflect the diversity and variability of growth rings in tropical species. This expanded classification includes four categories: (i) highly defined, (ii) moderately defined, (iii) poorly defined, and (iv) indistinct or absent (Groenendijk et al., 2014; Tarelkin et al., 2016; Marcelo-Peña et al., 2020).

Colombia is one of the most biodiverse countries in the world, hosting a wide range of ecosystems due to its geographical position and topographic complexity (Etter et al., 2017). This environmental heterogeneity results in a mosaic of microclimates that influence tree growth and ecological dynamics. However, understanding past climate variability and ecosystem responses in these diverse landscapes is challenging due to the scarcity of long-term meteorological records and the limited spatial coverage of weather stations (Manton et al., 2010). Dendrochronology presents a valuable opportunity to address these challenges by providing high-resolution, annually resolved records of environmental variability (Sheppard, 2010; Groenendijk et al., 2025).

Over the past decade, dendrochronological research in Colombia has expanded across various ecosystems, exploring the influence of environmental factors on tree growth. In mangrove ecosystems, growth ring formation is primarily affected by water salinity (Ramírez et al., 2010). In the Amazonian Trapezium, a high percentage of studied species exhibit visible growth rings, whereas in tropical dry forests, ring formation is closely linked to rainfall seasonality and ENSO variability (Ramírez & del Valle, 2011; 2012; Rivera, 2013; Briceño et al., 2016; 2018). In the humid Chocó biogeographic region, tree growth rings are influenced by fluctuations in soil moisture, hypoxia, and solar radiation (Giraldo et al., 2020; Giraldo et al., 2023). Beyond tree growth dynamics, dendrochronology has also been applied to reconstruct past hydrological conditions in the Colombian Andes and to assess historical CO2 concentrations in Medellín (Noriega-Londoño et al., 2022; Vásquez et al., 2022). Broadening the geographic extent of dendrochronological studies would enhance the characterization of Colombia’s regional climate dynamics and provide valuable insights into forest responses to environmental stress, including anthropogenic impacts and climate change

(Giraldo et al., 2020; Pompa-García & Camarero, 2020; Sánchez-Calderón et al., 2022), thus expanding ecological knowledge in Colombia.

In Colombia the Andes splits into 3 mountain chains that are part of the tropical Andean system and are considered a biodiversity hotspot, hosting a rich diversity of flora and fauna across an area of approximately 280,000 km², which constitutes 24.52% of the national territory (Rangel, 1997a, b; Myers et al., 2000; Rodríguez et al., 2006). This region also experiences high levels of anthropogenic pressure, as it is the center of the country’s economic activity and home to the majority of Colombia's population (Armenteras et al., 2011; Rodríguez-Eraso et al., 2013). Within the Eastern Cordillera, the Serranía de los Yariguíes and the Chicamocha Canyon are of particular ecological significance. The Serranía de los Yariguíes harbors some of the most well-preserved forest remnants on the western slopes of the Eastern Cordillera, playing a critical role in regional water regulation, species diversification, and agricultural production (Donegan & Huertas, 2005; Donegan et al., 2010; Moreno & Tinjacá, 2018). Meanwhile, the Chicamocha Canyon is the second biggest Canyon in the world and therefore has a strong influence on the climate of the department of Santander. Because of its extreme dryness it is also a site of significant pre-Hispanic and fossil records still under exploration (Oviedo-Chavez, 2018) and home to unique biodiversity, including various endemic plant and animal species (Albesiano et al., 2003; Albesiano & Rangel, 2006; Díaz-Perez et al., 2011; Valencia-Duarte et al., 2012; Collazos-Gonzalez et al., 2020).

Despite the ecological and climatic significance of the Serranía de los Yariguíes and the Chicamocha Canyon, no dendrochronological studies have been conducted in this region to evaluate the potential of different species for climate reconstruction. Given the scarcity of weather records, such research could provide valuable climate insights and encourage further ecological studies. Therefore, an initial exploration is needed to evaluate the region's dendrochronological potential. This study aims to assess the dendrochronological potential of tree species along a steep climatic gradient from the Serranía de los Yariguíes to the Chicamocha Canyon through anatomical descriptions and the determination of tree ring formation frequency.

1. Objectives

1.1. Main objective

Evaluate the dendrochronological potential of tree species in the northern sector of the Serranía de los Yariguíes and the Chicamocha Canyon

1.2. Specific objectives

1. Identify dominant and widely distributed tree species in the study area.

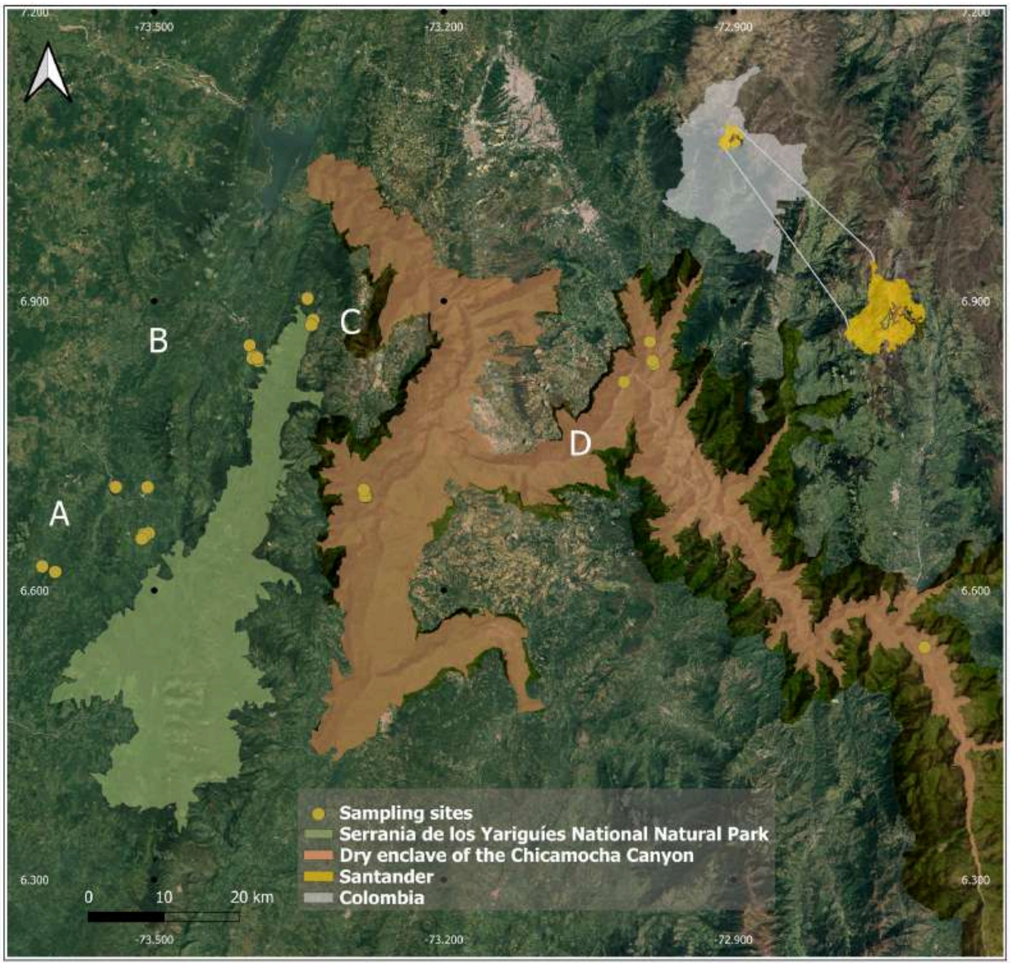
2. Describe the wood anatomy and its influence on growth ring formation in the selected species.

3. Dating of growth rings of species with dendrochronological potential.

2. Materials and methods

2.1. Study area

This study was conducted in the Eastern Cordillera of the Andes in the Department of Santander, spanning from the Serranía de los Yariguíes to the Chicamocha Canyon, where I sampled species in different localities within a climatic gradient (Figure 1). The higher humidity of localities in the western slope of the Serranìa de los Yariguíes (Figure 1A, 1B) originates from substantial evapotranspiration of the wetlands of the Magdalena river and orographic rainfall,cooling of humid air while pushed against the mountain ridge of the Serranía. The humidity gradient is formed because of this moisture source of the Magdalena valley on the one hand, and the Chicamocha Canyon on the other. The Canyon acts as a barrier, because ascending air heats up at its bottom. This upward air flow efficiently limits moist air passing from west to east (Figure 1C, 1D). The climatic characteristics of the different localities reflect the influence of this local atmospheric circulation pattern. As a consequence, el Carmen de Chucurí (Figure 1A) ranging from 300 to 1,000 m.a.s.l., exhibits high humidity levels, with an annual precipitation of 2,515 mm and an average temperature of 25.4 °C, experiencing no water limitations throughout the year. Further north, San Vicente de Chucurí (400–2,600 m.a.s.l.) records lower annual precipitation of 1,844 mm and a mean temperature of 21.7 °C, with water limitations at the beginning of the year (Figure 1B). Further east, Zapatoca (1,850–2,495 m.a.s.l.) transitions into a biannual precipitation regime, showing a dry period from December to February, an annual precipitation of 1,230 mm, and lower temperatures averaging 19.2 °C (Figure 1C). The Chicamocha Canyon (300–1,400 m.a.s.l.) experiences arid conditions, with low annual precipitation of 785 mm, a mean temperature of 25.7 °C, and pronounced dry periods within a biannual precipitation regime (Figure 1D).


7.200
-73.500
-73.200
-72.900
7.200
6.900
6.900
6.600
6.600
6.300
6.300
A
B
C
D
Sampling sites
Serrania de los Yariguíes National Natural Park
Dry enclave of the Chicamocha Canyon
Santander
Colombia
0
10
20 km
-73.500
-73.200
-72.900

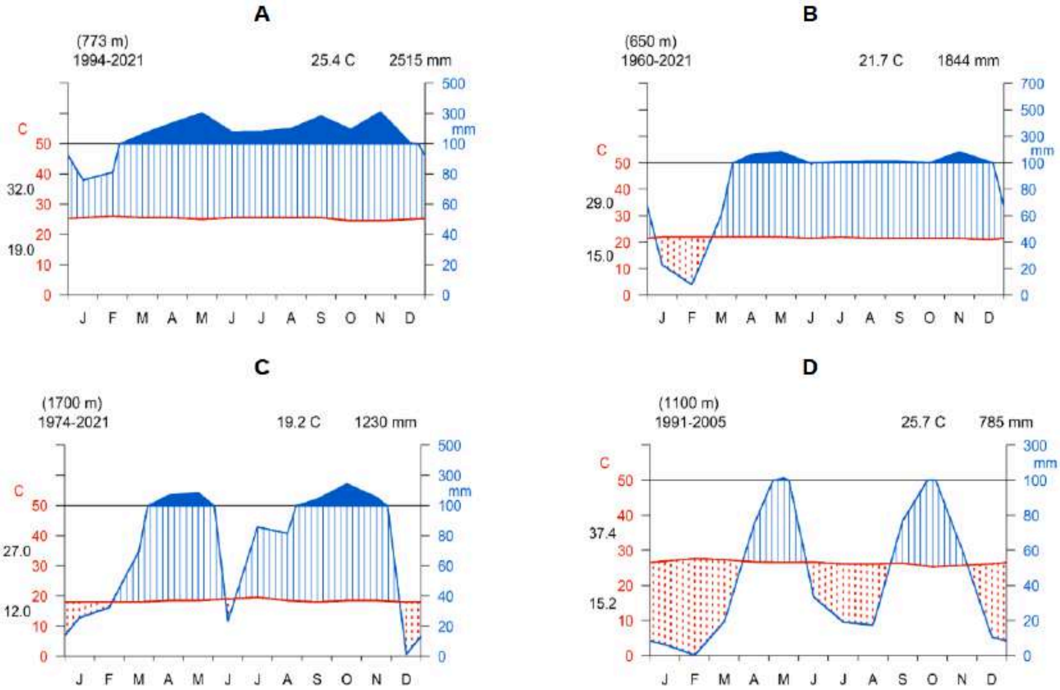

A
(773 m)
1994-2021
25.4 C
2515 mm
C
32.0
19.0
mm
J F M A M J J A S O N D
B
(650 m)
1960-2021
21.7 C
1844 mm
C
29.0
15.0
mm
J F M A M J J A S O N D
C
(1700 m)
1974-2021
19.2 C
1230 mm
C
27.0
12.0
mm
J F M A M J J A S O N D
D
(1100 m)
1991-2005
25.7 C
785 mm
C
37.4
15.2
mm
J F M A M J J A S O N D

Figure 1. Study area in the Serranía de los Yariguíes and the Chicamocha Canyon (upper) and climatic conditions of the sample sites (bottom). Walter and Lieth Conventions (1967).

2.2. Sampling and sample processing

I identified relatively frequent species across the study area as candidates using regional species lists (Fajardo-G et al., 2015), vegetation studies (Díaz-Rueda et al., 2025) and field surveys with local community members and researchers across diverse vegetation types—namely conserved forest, agroforestry systems, riparian forest, and dry forest—in four localities that span a broad altitudinal and climatic gradient (Figure 1 A-D). I collected two to three increment cores (5 mm diameter) from three healthy individuals of each of the selected species using a Pressler increment borer. Additionally, cross-sectional samples were collected from naturally fallen or felled individuals when available. A botanical sample was also collected for taxonomic identification when it was possible and necessary and deposited in the herbarium of the Industrial University of Santander in Bucaramanga.

The collected stem cross-sections and core samples were air-dried and only the core samples were subsequently mounted on wooden supports. To enhance wood anatomy visibility for growth ring identification, the samples were initially sanded using an orbital sander, followed by progressive sanding with grit sizes ranging from 60 to 1,000. For macroscopic characterization, the samples were digitized at 2,400 dpi using an Epson HP 5590 scanner. The samples were then analyzed at the Wood Laboratory of Universidad del Cauca, where histological sections were obtained using a microtome GSL1 (MIKROT L, Schenkung Dapples), and growth rings were examined at a microscopic level.

2.3. Wood classification and factor analysis

Growth rings were identified and classified based on their structural characteristics, which are easily recognizable in the transverse view of the wood, including fibers, parenchyma cells, and vessels (pores). Since tree species exhibit diverse anatomical features, a single sample may display multiple structural markers of growth ring formation. The classification considered three key features: (A) changes in fiber structure, including variations in fiber wall thickness and radial fiber diameter, (B) the presence of marginal axial parenchyma bands and differences in parenchyma cell density, and (C) variations in vessel characteristics, such as differences in vessel diameter, distribution patterns, and the degree of vessel grouping (Worbes, 2004).

Additionally, the degree of visibility of growth rings was categorized into four levels: Highly Defined, Moderately Defined, Poorly Defined, or Indistinct/Absent, following the recommendations of Marcelo-Peña et al. (2020) for tropical tree species. Highly defined rings have clear, easily distinguishable boundaries, while moderately and poorly defined rings show progressively weaker distinctions. In some cases, growth rings are indistinct or absent, making their identification more challenging.

A Factor Analysis for Mixed Data (FAMD) was conducted to investigate the relationships between wood anatomical traits and growth ring visibility levels (Audigier et al., 2016). This analysis incorporated a set of variables (Table 1) defined by the International Association of Wood Anatomists (IAWA), describing variations in each anatomical structure using the abbreviations established by Tarelkin et al. (2016). These traits were converted into binary values, where 1 indicated the presence of a given characteristic in the species and 0 indicated its absence. This approach enabled the simultaneous evaluation of both quantitative and qualitative data, facilitating the identification of key interactions between specific anatomical features and growth ring classification.

Table 1. Detailed anatomical features of growth-ring boundaries.

Abbreviation	**Feature**
AC_FW	Abrupt change in fibre wall thickness
GC_FD	Gradual change in radial fibre diameter
GC_VD	Gradual change in vessel diameter
VDV	Vessel density variation
MP	Marginal parenchyma present
PDV	Parenchyma bands density variation
DR	Distended rays

2.4. Tree rings frequency validation

To validate the frequency of growth rings, ^{14}C concentrations were measured in the rings of 12 different species with highly and moderately defined rings. For each sample, 50 mg of wood was extracted from three different growth rings. Calendar years were assigned by counting backward from the outermost ring (bark) toward the center, with cross-dating performed by matching tree growth patterns of the same tree and different individuals when a sufficient number of samples were available. I extracted alpha-cellulose following the methodology of Steinhof et al. (2017). ^{14}C analysis utilizes the increase in radiocarbon concentration in alpha-cellulose of wood as an effect of nuclear bomb testing (Hua et al., 2000). The resulting ^{14}C measurements were used in the CaliBomb application (Reimer et al., 2004) with the Northern Hemisphere Zone 2 calibration curve to obtain calendar years and establish the frequency of growth rings in the studied species. The radiocarbon analysis was conducted at the Max Planck Institute for Biogeochemistry in Jena, Germany, which has successfully supported various dendrochronological studies (Vásquez et al., 2022; Giraldo et al., 2020; 2023).

3. Results

3.1. Anatomical tree ring description

In this study, I examined the wood anatomy of 65 tree species from the Serranía de los Yariguíes and the Chicamocha Canyon (Table 2). These species belong to 31 different families with Fabaceae representing 11 species, Lauraceae 7 species, Clusiaceae 5 species, Burseraceae 5 species, and Meliaceae 3 species. The studied species exhibit varying degrees of growth ring visibility (Figure 2). Using macroscopic visualization (Figure 3) alongside microtome thin sections (Figure 4), I determined that 24 species displayed highly defined growth rings, 26 species exhibited moderately defined growth rings, and 15 species presented poorly defined growth rings (Figure 5).

Table 2. Tree ring anatomy of sampled species: **HD**= highly distinct; **MD** = moderately distinct; **PD** = poorly distinct; **A**= changes in fiber wall thickness or radial fiber diameter; **B**= the presence of marginal axial parenchyma bands and variations in parenchymal density; **C**= differences in vessel diameter, distribution, and grouping; **BD**= Banded; **PC**= Paratracheal confluent; **M**= Marginal; **AD**= Apotracheal diffuse; **ADA**= Apotracheal diffuse-in-aggregates; **SM**= Solitary and multiples; **S**= Solitary; **DP**= Diffuse-porous; **SRP**= Semi-ring-porous.

Family	Species	Type of sample	Visibility	Wood anatomy	Parenchyma anatomy	Vessels anatomy	Vessels arrangement	Previously reported	Type of study

Anacardiaceae	*Astronium graveolens* Jacq.	Cross section	MD	A, C	AD	SM	SRP	Enquist and Leffler, 2001; Lisi et al., 2008; Santos et al., 2011; León, 2014	Wood description; Dendrochronology
Annonaceae	*Guatteria amplifolia* Triana & Planch	Core	HD	B	BD	SM	DP	-	-
Burseraceae	*Bursera simaruba* (L.) Sarg.	Core	HD	A, C	M	SM	SRP	Enquist and Leffler, 2001; León, 2012; León, 2012	Wood description; Dendrochronology
Bignoniaceae	*Handroanthus chrysanthus* (Jacq.) S.O.Grose	Core	HD	B, C	PC	SM	SRP	León, 2014; Marcelo-Peña et al, 2020; Peña-Moreno et al., 2022; Betancourt and Pucha, 2024	Wood description; Dendrochronology
Boraginaceae	*Cordia alliodora* (Ruiz & Pav.) Oken	Core	HD	B, C	M	SM	SRP	Tschinkel 1966; Devall et al, 1995; Brienen et al., 2009; Worbes and Raschke, 2012; León, 2014; Bossu, 2015; Briceño-J et al., 2016; Mamani, 2018; Marcelo-Peña et al, 2020; Cahuana et al., 2021	Wood description; Dendrochronology
Burseraceae	*Protium cf cundinamarcensis* Cuatrec	Cross section	PD	A	AD	SM	DP	-	-
Burseraceae	*Protium* sp. Burm.f.	Cross section	PD	A	AD	SM	DP	-	-
Burseraceae	*Protium stevensonii* (Standl.) Daly	Core	PD	A	AD	SM	DP	-	-
Burseraceae	*Trattinnickia aspera* (Standl.) Swart	Core	PD	A	AD	SM	DP	-	-
Caryocaraceae	*Caryocar amygdaliferum* Mutis	Core	PD	A	AD	SM	DP	-	-
Clusiaceae	*Clusia* cf. *dixonii* Little	Cross section	MD	A, C	AD	SM	SRP	-	-

Clusiaceae	*Clusia schomburgkiana* (Planch. & Triana) Benth. ex Engl.	Cross section	MD	A, C	AD	SM	SRP	-	-
Clusiaceae	*Clusia* cf. *multiflora* Kunth	Cross section	MD	A, C	AD	SM	SRP	-	-
Clusiaceae	*Chrysochlamys sp.* Poepp. & Endl.	Core	MD	A, C	AD	SM	SRP	-	-
Clusiaceae	*Arawakia oblanceolata* (Rusby) L.Marinho	Core	MD	A, C	AD	SM	SRP	-	-
Elaeocarpaceae	*Sloanea tuerckheimii* Donn.Sm.	Core	MD	A, B	M	SM	DP	-	-
Euphorbiaceae	*Conceveiba pleiostemona* Donn.Sm.	Core	MD	A, B	M	SM	DP	Hayden and Hayden, 2000	Wood description
Euphorbiaceae	*Tetrorchidium andinum* Müll.Arg.	Core	PD	A	AD	SM	DP	-	-
Fabaceae	*Albizia niopoides* (Spruce ex Benth.) Burkart	Cross section	MD	A, B	M	SM	DP	Giraldo and del Valle, 2012; León, 2014	Wood description; Dendrochronology
Fabaceae	*Inga* sp. Mill.	Cross section	MD	B, C	PC	SM	SRP	-	-
Fabaceae	*Neltuma juliflora* (Sw.) Raf.	Cross section	HD	B, C	M	SM	SRP	Leavitt and Lone, 1991; Beramendi-Orosco et al., 2013; León, 2014; Nogueira et al., 2019	Wood description; Dendrochronology
Fagaceae	*Trigonobalanus excelsa* Lozano, Hern.Cam. & Henao	Core	PD	B, C	BD	SM	SRP	Mennega, 1980;	Wood description
Fabaceae	*Pterocarpus rohrii* Vahl	Core	HD	A, B	BD	S	DP	Brienen et al., 2009; Costa et al., 2015	Wood description; Dendrochronology

Fabaceae	*Diplotropis purpurea* (Rich.) Amshoff	Cross section	MD	B, C	PC	SM	SRP	Alves and Angyalossy-Alfonso, 2000; León, 2014; Soares et al., 2014	Wood description
Fabaceae	*Inga edulis* Mart.	Cross section	MD	B, C	PC	SM	SRP	Baretta-Kuipers, 1973; Shimamoto et al., 2016	Wood description
Fabaceae	*Schizolobium parahyba* (Vell.) S.F.Blake	Core	MD	A, C	AD	SM	SRP	Brienen et al., 2009; Costa et al., 2015	Wood description; Dendrochronology
Fabaceae	*Pseudosamanea carbonaria* (Britton) E.J.M.Koenen	Core	PD	A	AD	SM	DP	-	-
Fabaceae	*Lonchocarpus* sp. Kunth	Core	HD	B	BD	SM	DP	-	-
Fabaceae	*Macrolobium* sp. Schreb.	Core	HD	B	M	SM	DP	-	-
Fagaceae	*Quercus humboldtii* Bonpl.	Core	MD	B, C	BD	SM	SRP	-	-
Hypericaceae	*Vismia baccifera* (L.) Triana & Planch.	Core	HD	B, C	M	S	SRP	-	-
Juglandaceae	*Alfaroa williamsii* Ant.Molina	Cross section	HD	B, C	M	SM	SRP	-	-
Juglandaceae	*Oreomunnea munchiquensis* Lozano & F.González	Cross section	MD	B, C	BD	SM	SRP	-	-
Lamiaceae	*Vitex compressa* Turcz.	Core	MD	A, C	AD	SM	SRP	-	-
Lauraceae	*Nectandra cf laurel* Klotzsch ex Nees	Cross section	HD	A, C	AD	SM	SRP	-	-
Lauraceae	*Lauraceae* sp2	Cross section	HD	A, C	AD	SM	SRP	-	-
Lauraceae	*Lauraceae* sp1	Core	MD	A, C	AD	SM	SRP	-	-

Lauraceae	cf. *Aniba* sp. Aubl.	Core	HD	B	M	SM	DP	-	-
Lauraceae	*Licaria cannella* (Meisn.) Kosterm.	Core	PD	A, C	AD	SM	SRP	Alves and Angyalossy-Alfonso, 2000; Reis-Avila y Oliveira, 2017	Wood description
Lauraceae	*Caryodaphnopsis carmensis* Airy Shaw	Cross section	MD	B, C	M	SM	SRP	-	-
Lauraceae	*Caryodaphnopsis cogolloi* van der Werff	Cross section	MD	B, C	M	SM	SRP	-	-
Lecythidaceae	*Lecythis mesophylla* S.A.Mori	Core	HD	B	BD	SM	DP	-	-
Magnoliaceae	*Magnolia* sp1	Core	HD	B	M	SM	DP	-	-
Magnoliaceae	*Magnolia* sp2	Core	HD	B	M	SM	DP	-	-
Malpighiaceae	*Byrsonima crispa* A.Juss.	Core	PD	A, C	AD	SM	SRP	Aparecido et al., 2019	Wood description
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Core	HD	B	M	SM	DP	Heyden, 2008; León, 2014; Nordahlia et al., 2016; Marcelo-Peña et al., 2020	Wood description
Melastomataceae	*Miconia prasina* (Sw.) DC.	Cross section	MD	B	ADA	SM	DP	-	-
Melastomataceae	*Miconia* sp. Ruiz & Pav.	Cross section	HD	B, C	M	SM	SRP	-	-
Meliaceae	*Carapa cedrotagua* Londoño-Ech., A.M. Trujillo & Jiménez-Mont.	Cross section	PD	C	AD	SM	SRP	-	-

Meliaceae	*Cedrela odorata* L.	Core	HD	B	M	SM	DP	Worbes, 1999; Alves and Angyalossy-Alfonso, 2000; Dünisch et al., 2003; Roig et al., 2005; Brienen and Zuidema, 2005; Boninsegna et al., 2009; Lobão, 2011; Schipper, 2011; Beltrán-Gutiérrez and Valencia-Ramos, 2013; Leon, 2013; Pereyra et al., 2014; Mendivelso et al, 2016; Inga and del Valle, 2017; Lisi et al., 2020; Alves-Ferrerira et al., 2021	Wood description; Dendrochronology
Meliaceae	*Cedrela fissilis* Vell.	Cross section	HD	B	M	SM	DP	Paredes-Villanueva et al., 2016; Pereira et al., 2018; Rodríguez et al., 2023; Fontana et al., 2024	Wood description; Dendrochronology
Metteniusaceae	*Metteniusa* sp. H.Karst.	Core	PD	A	AD	SM	DP	-	-
Moraceae	*Ficus americana* subsp. *greiffiana* Aubl.	Cross section	MD	B, C	BD	SM	SRP	Sato, 2011	Wood description
Moraceae	*Ficus crocata* (Miq.) Mart. ex Miq.	Core	MD	B, C	BD	SM	SRP	-	-
Moraceae	*Maclura tinctoria* (L.) D.Don ex Steud.	Core	HD	B	M	SM	SRP	León, 2014; Pucha-Cofrep et al., 2015; Lanzarin, 2016; Marcelo-Peña et al., 2020; García-Cervigón et al., 2020; Bauer et al., 2021	Wood description; Dendrochronology
Myristicaceae	*Compsoneura atopa* (A.C.Sm.) A.C.Sm.	Core	MD	B	M	SM	DP	-	-
Myrsinaceae	*Myrsine pellucida* (Ruiz & Pav.) Spreng.	Core	PD	A	AD	SM	DP	-	-
Myrtaceae	*cf Myrcia* DC. ex Guill.	Cross section	MD	B, C	BD	S	SRP	-	-

Olacaceae	*Minquartia guianensis* Aubl.	Core	PD	A	AD	SM	DP	Fichtler et al., 2003; Giraldo et al., 2020	Wood description
Phyllanthaceae	*Hieronyma* sp. Allemão	Core	MD	A	AD	SM	DP	-	-
Polygonaceae	*Triplaris* sp Loefl. ex L..	Core	HD	B, C	BD	SM	SRP	-	-
Rubiaceae	*Ladenbergia undata* Klotzsch	Cross section	MD	B, C	M	SM	SRP	-	-
Rubiaceae	*Elaeagia pastoensis* L.E.Mora	Core	PD	A, C	AD	SM	SRP	-	-
Sapindaceae	*Billia rosea* (Planch. & Linden) C.Ulloa & P.M.Jørg.	Core	HD	B	M	SM	DP	-	-
Sapindaceae	*Cupania americana* L.	Core	HD	B, C	BD	C	SRP	-	-

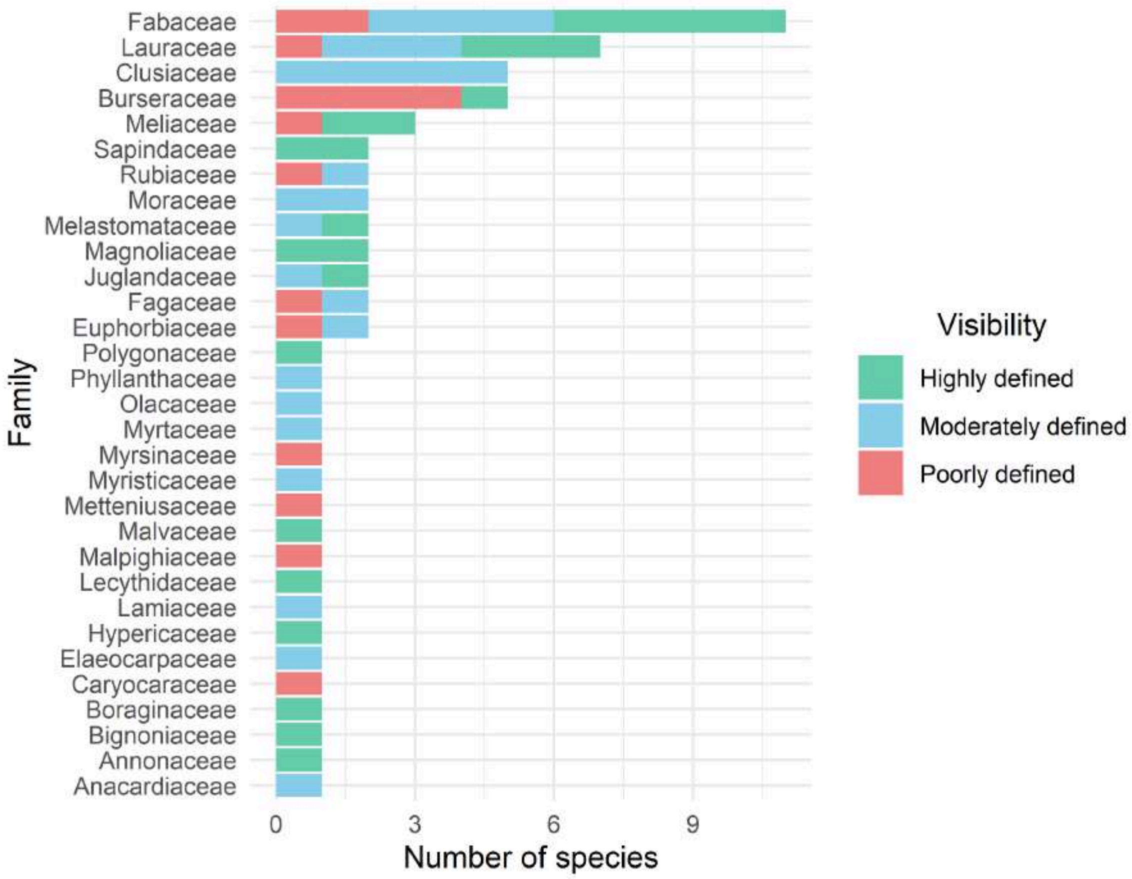


Figure 2. Number of species per family and growth ring visibility.

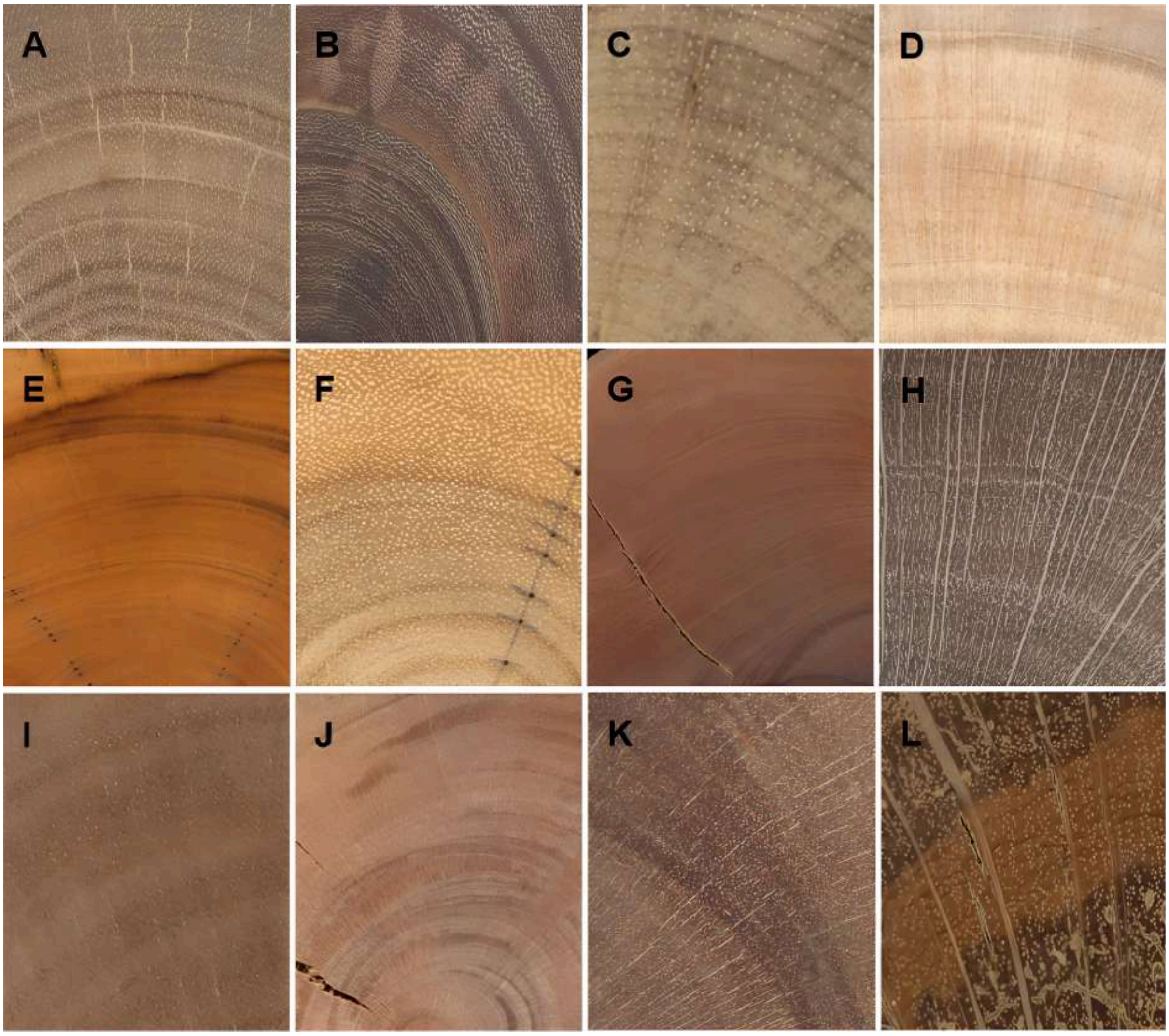


Figure 3. Images of tree rings visibility of selected species at macroscopic level. Highly defined: (A) *Nectandra cf laurel*, (B) *Maclura tinctoria*, (C) *Alfaroa williamsii* and (D) *Billia rosea*. Moderately defined: (E) *Astronium graveolens*. (F) *Albizia niopoides*, (G) *Clusia cf multiflora* and (H) *Quercus humboldtii*. Poorly defined growth rings: (I) *Carapa cedrotagua*, (J) *Protium cf cundinamarcensis*, (K) *Protium* sp and (L) *Trigonobalanus excelsa*.

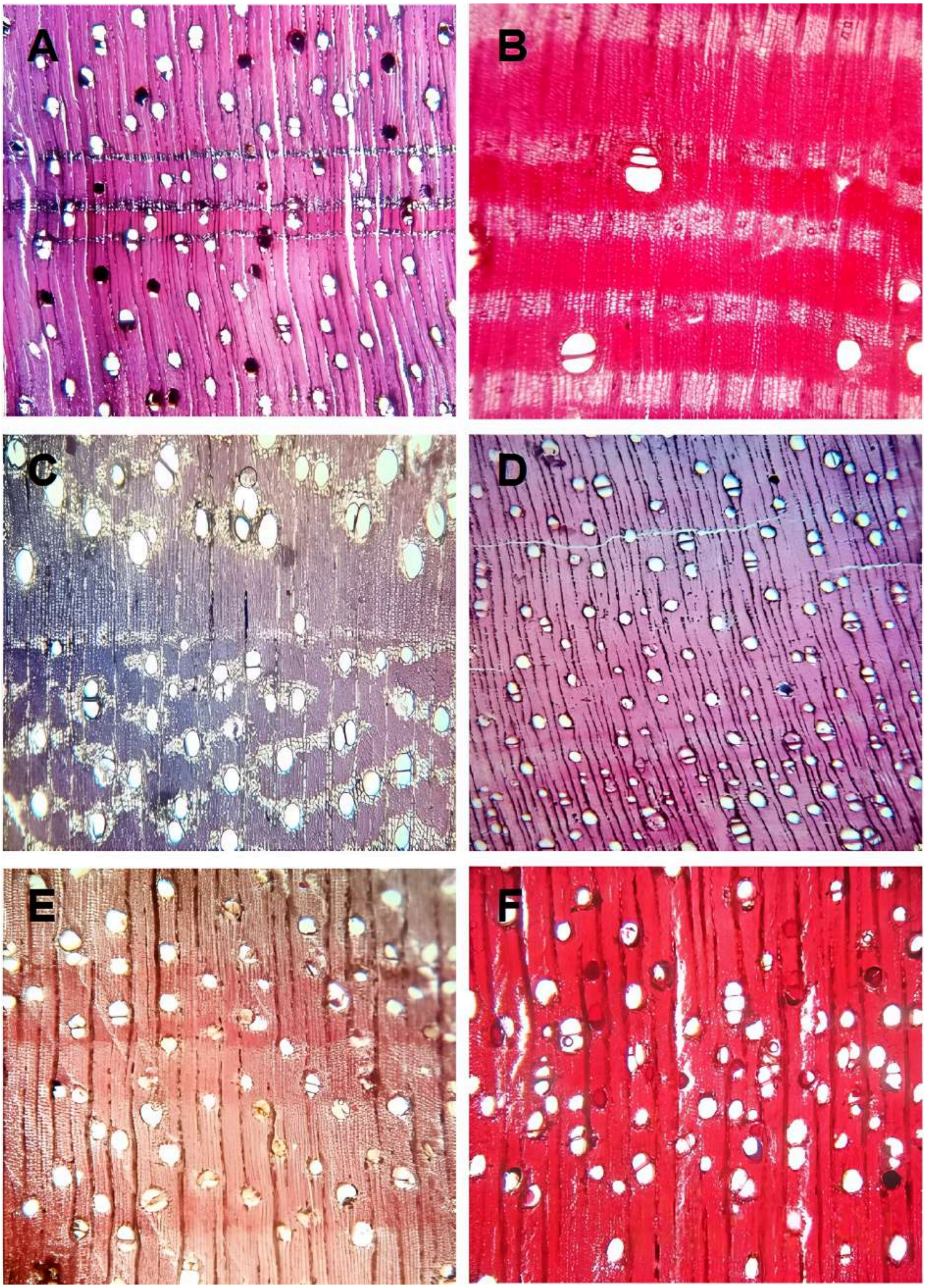


Figure 4. Images of tree ring boundaries of different species at microscopic level. A: boundary layer delimited by marginal parenchyma (e.g. *Billia rosea*). B: variations in

parenchymal density (e.g. *Ficus crocata*). C: marginal parenchyma and differences in vessel distribution (e.g. *Handroanthus chrysanthus*). D: changes in fiber wall thickness and differences in vessel diameter (e.g. *Quercus humboldtii*). E: changes in fiber wall thickness (e.g. *Pterocarpus rohrii*). F: poorly defined tree rings (e.g. *Carapa cedrotagua*).

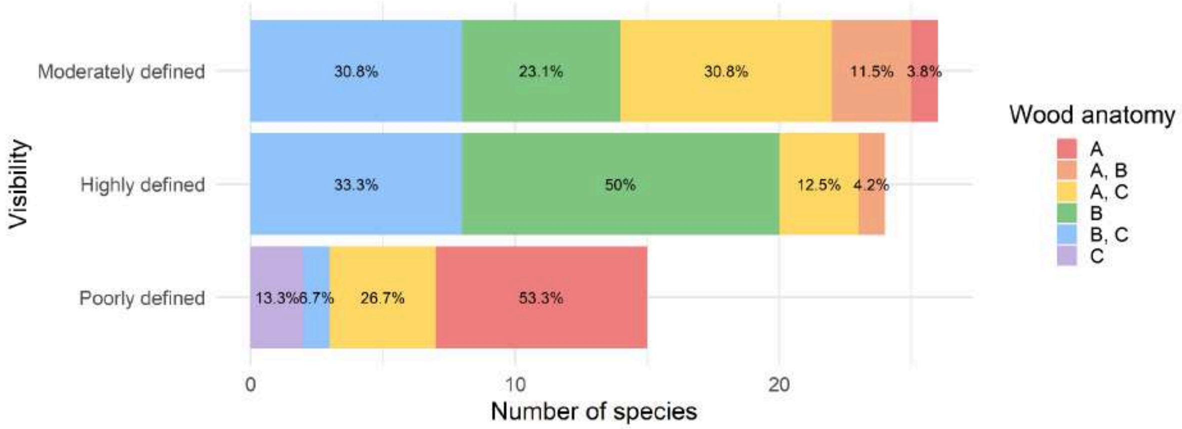


Figure 5. Number of species at each visibility level and their wood anatomy.

Regarding parenchyma types, diffuse apotracheal parenchyma was the most prevalent, found in 26 species, followed by marginal parenchyma (22 species) and banded parenchyma (12 species). Confluent apotracheal parenchyma and aggregated diffuse apotracheal parenchyma were less common, occurring in only 4 and 1 species, respectively.

In terms of vessel anatomy and distribution, the vast majority of species (61 species) exhibited vessels occurring both solitarily and in multiples. A diffuse porous arrangement was observed in 28 species, while 37 species displayed semi-ring porous growth rings (Figure 6). Moreover, a higher distribution of species with semi-ring porous rings was noted in the localities of Zapatoca and Capitanejo, which are characterized by drier climate (compare Fig 1.) compared to El Carmen and San Vicente de Chucurí (Figure 6).

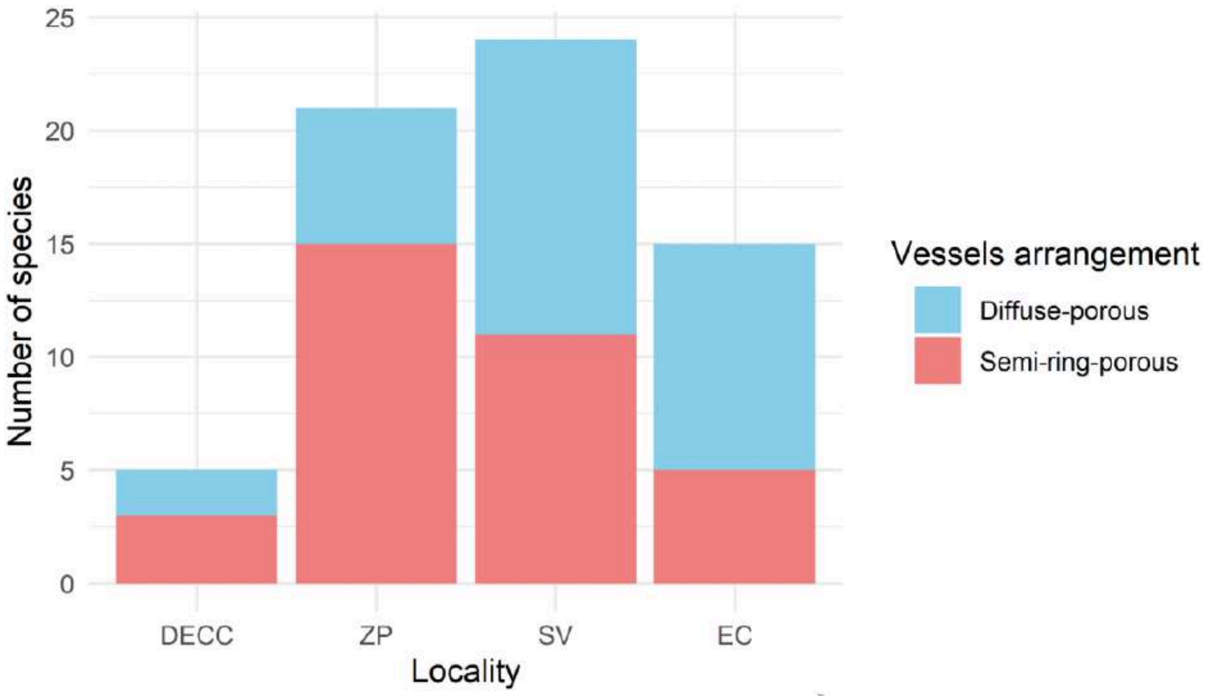


Figure 6. Distribution of pore arrangement across species along a humidity gradient in different locations: DECC: Dry enclave of the Chicamocha Canyon (D, Fig. 1); ZP: Zapatoca (C, Fig. 1); SV: San Vicente de Chucurí (B, Fig. 1) and EC: El Carmen de Chucurí (A, Fig. 1). Humidity of the localities increases from left to right.

3.2. Anatomical Traits Shaping Growth Ring Visibility

The results of the FAMD reveal that the first two principal axes accounted for approximately 43% of the total variation of anatomical structure across species (Figure 7). Species exhibiting highly and moderately defined growth rings tend to cluster together, driven primarily by traits related to axial parenchyma and variations in pore size. These findings suggest that these anatomical characteristics play a central role in the formation of clearly delineated growth rings. In contrast, species with poorly defined rings were mainly characterized by fiber-related traits. Additionally, some species with moderately defined rings occupied intermediate positions in the multivariate space, displaying a blend of features common to both highly defined and poorly defined groups.

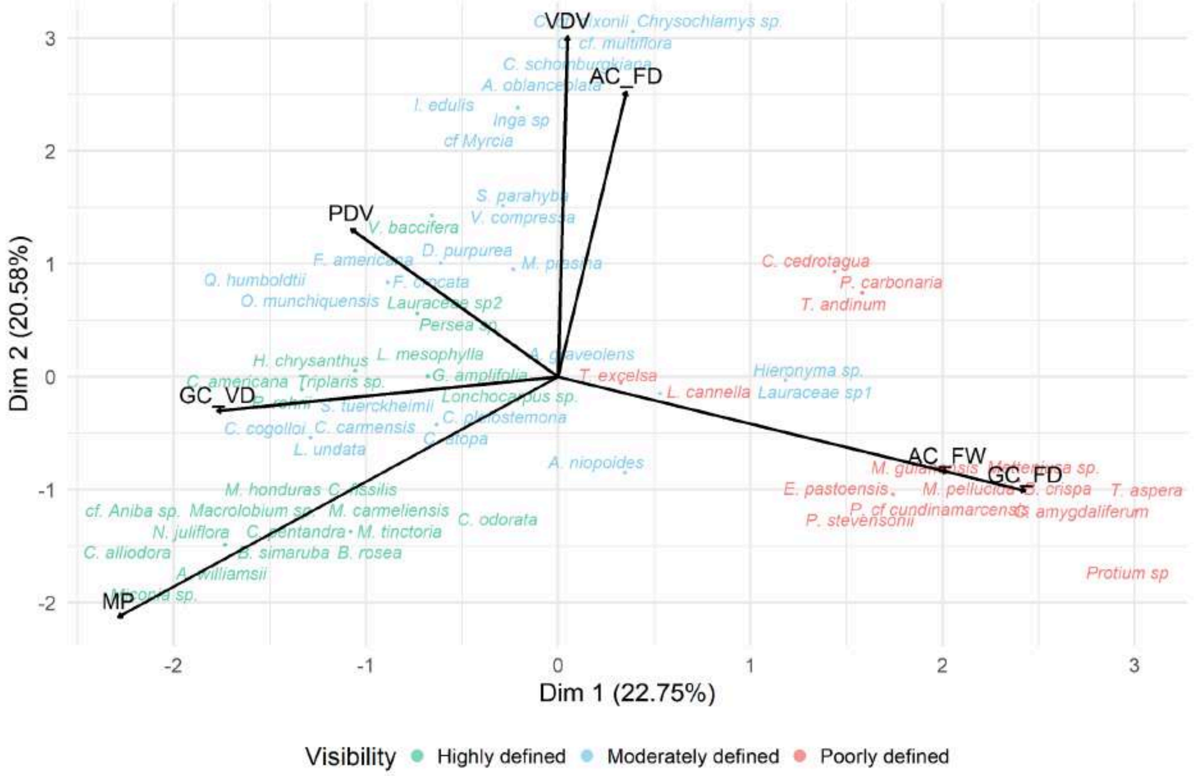


Figure 7. Factor Analysis of Mixed Data (FAMD) on growth ring visibility and the structures that define growth rings. AC_FW: Abrupt change in fibre wall thickness; GC_FD: Gradual change in radial fibre diameter; GC_VD: Gradual change in vessel diameter; VDV: Vessel density variation; MP: Marginal parenchyma present; PDV: Parenchyma bands density variation.

3.3. Validation of Annual Growth Rings Using ^{14}C Dating

Radiocarbon (^{14}C) dating confirmed the annual formation of growth rings in several species (Figure 8). A total of 12 species were dated, resulting in 30 samples corresponding to three distinct growth rings, except for *Cedrela odorata*, *Ceiba pentandra*, and *Cupania americana*, where only two rings were analyzed. For species such as *Maclura tinctoria*, *Cedrela odorata*, *Ceiba pentandra*, and *Cupania americana*, the ages obtained from ^{14}C

dating were consistent with those estimated by backwards ring counting under the assumption of annual ring formation. However, in species such as *Inga edulis*, *Astronium graveolens* and *Oreomunnea munchiquensis*, agreement between the two methods was observed for some rings only, with discrepancies of 1 to 3 years in others (appendix 1), possibly due to the inadvertent inclusion of wood material from adjacent rings. Moreover, species such as *Alfaroa williamsii* and *Neltuma juliflora* exhibited substantial differences between the ages estimated by ring counting and those determined by radiocarbon dating, with discrepancies ranging from 30 to 40 years. These results suggest that the growth rings in these species may not form annually.

Radiocarbon dating of all *Albizia niopoides* samples, as well as some rings from *Alfaroa williamsii*, *Quercus humboldtii*, and *Nectandra cf laurel*, yielded dates ranging from 1954 to as early as 1910 due to low ^{14}C concentrations. This suggests that some rings may correspond to periods predating 1956 but were miscounted and erroneously assigned to post-1956 dates. Additionally, two rings of *Quercus humboldtii* exhibited ^{14}C-derived ages approximately twice those estimated through ring counting, indicating the possibility that a single growth ring may have formed over a period longer than one year.

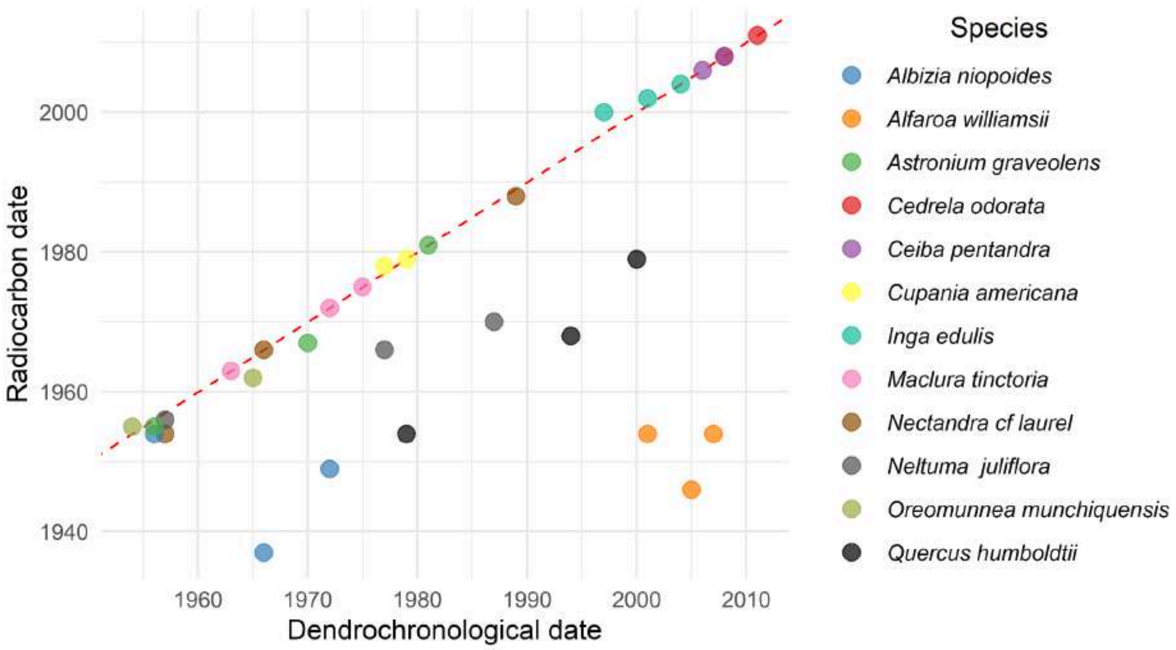


Figure 8. Correspondence between dendrochronological date and radiocarbon (^{14}C) results for 12 species.

4. Discussion

The anatomical examination of 65 tree species distributed along a climatic gradient from the forests of the Serranía de Los Yariguíes to the Chicamocha Dry Canyon confirmed that all species develop growth rings, though with varying degrees of visibility. This variability in growth ring visibility is primarily driven by differences in wood structure, including fiber arrangement, parenchyma distribution, and vessel organization. Species with highly defined growth rings were often associated with distinct anatomical markers, such as marginal parenchyma bands and variations in vessel size, whereas poorly defined rings were linked to more diffuse anatomical features in fiber cells. I validate the periodicity of ring formation performing radiocarbon (^{14}C) dating, confirming the annual nature of growth rings in the majority of the species. However, discrepancies in age estimations between ring counts and radiocarbon dating in certain species suggest the influence of factors such as false rings, missing rings, or intra-annual growth variations which has been frequently reported for tropical species (Silva et al., 2019). In the following I will discuss how these factor might affect our results:

4.1. Tree rings distinction

The anatomical analysis of growth rings reveals that 78% of the species exhibit distinguishable rings. Although many dendrochronological investigations have traditionally focused on well-documented species in different ecosystems, our results—and those of other studies in the tropics—demonstrate that dendrochronological studies can be extended to all parts of the tropics (Fichtler et al. 2003). This is attributable not only to the presence of a few extensively studied species but also to the substantial proportion of tropical taxa that inherently possess dendrochronological potential based on their anatomical features.

Expanding dendrochronological studies into our research area introduces a new geographic and climatic region with unique characteristics that call for further exploration. Establishing an initial assessment of the area's dendrochronological potential is essential to complement existing studies across the tropics, particularly in Colombia. However, evaluating dendrochronological potential in diverse tropical regions with varying climatic conditions presents challenges, and even contrasting conclusions may arise in similar environments. Recent findings by Giraldo et al. (2020; 2023) in the highly diverse and humid Chocó region revealed that approximately 82% of 81 species exhibited growth rings with varying degrees of visibility. Similarly, in regions with high vascular plant diversity such as Brazil, numerous species with discernible rings have been documented (Alves and Angyalossy-Alfonso 2000; Schöngart et al., 2011; de Arruda et al., 2017). In the Colombian Amazon, Rivera (2013) reported that about 87% of the species studied possessed easily distinguishable rings, while Marcelo-Peña et al. (2020) found that 53% of 183 species in

Peruvian forests displayed clearly to moderately defined rings. Studies conducted in Costa Rica (Fichtler et al. 2003; Worbes and Raschke, 2012), Venezuela (Worbes 1999), India (Nath et al. 2016), and a deciduous dry forest in Mexico (Ramírez-Martínez et al. 2017) further illustrate the variability in ring visibility across tropical regions, with proportions ranging from 50% to 100%. Conversely, some investigations have reported a lower proportion of species with distinct growth rings in the same tropical regions in certain tropical areas previously mentioned (Tomazello-Filho et al. 2004; Roig et al. 2005; Brienen et al. 2009; Beltrán-Gutiérrez and Valencia-Ramos, 2013; Tarelkin et al. 2016). Indeed, Giraldo et al. (2020) highlighted that ring visibility can vary dramatically—from as low as 3% to as high as 100%—across 60 pantropical study sites with differing degrees of seasonality.

These findings underscore the subjective nature of defining a species' dendrochronological potential, which can be influenced by the visual criteria and identification scales (macroscopic versus microscopic) employed by researchers (IAWA, 1989; Nath et al., 2016). Moreover, the reliance on somewhat vague IAWA definitions for visibility in the early years may lead to an underestimation of tropical species with visible rings (Tarelkin et al. 2016), whereas adopting broader classifications of ring visibility could enhance the accuracy of growth ring assessments in the tropics (Marcelo-Peña et al., 2020).

4.2. Taxonomy and species

This study successfully describes the wood anatomy of 65 tree species for northeast Colombia where dendrochronology has been scarcely explored. This is approximately half of the families and around 30% of the identified species recorded for the municipalities of the northern part of the Serranía de los Yariguíes (Díaz-Rueda et al., 2025). Among these families, Fabaceae, Lauraceae, Clusiaceae, and Burseraceae are the ecologically most important (Díaz-Rueda et al., 2025). Notably, the diversity and abundance of Lauraceae family in the study area provides an opportunity for the representativity of species with dendrochronological potential, as this family is known to include species with highly defined, annual, and climate-sensitive growth rings (Reis-Avila and Oliveira, 2017).

Of the 65 species analyzed, 51 are identified at the species level. Among these, 32 species are reported and its wood anatomy is described for the first time, suggesting that at least half of the species had not been previously explored in dendrochronological works. In contrast, at least 19 species have been previously studied and described in studies related to wood anatomy or dendrochronological applications (Table 2). Certain species, such as *Cordia alliodora* (Tschinkel, 1966; Devall et al., 1995; Brienen et al., 2009; Worbes & Raschke, 2012; Leon, 2014; Bossu, 2015; Briceño-J et al., 2016; Mamani, 2019; Marcelo-Peña et al., 2020; Cahuana et al., 2021) and *Cedrela odorata* (Worbes, 1999; Alves & Angyalossy-Alfonso 2000; Dünisch et al., 2003; Roig et al., 2005; Brienen & Zuidema, 2005; Boninsegna et al., 2009; Lobão, 2011; Schipper, 2011; Beltrán-Gutiérrez & Valencia-Ramos, 2013; Leon, 2013; Pereyra et al., 2014; Mendivelso et al., 2016; Inga and del Valle, 2017; Lisi et al., 2020; Alves-Ferrerira et al., 2021), have been disproportionately represented in the literature. This trend is likely attributable to the distinctiveness and annuality of their tree rings, as well as their wide distribution, making them particularly valuable for dendrochronological research.

While several species previously reported in other studies exhibit similar anatomical characteristics and ring visibility—such as *Trigonobalanus excelsa* (Mennega, 1980), *Diplotropis purpurea* (Alves & Angyalossy-Alfonso, 2000; León, 2014; Soares et al., 2014), *Licaria cannella* (Alves and Angyalossy-Alfonso, 2000; Reis-Avila and Oliveira, 2017), *Minquartia guianensis* (Fichtler et al., 2003; Giraldo et al., 2020), *Astronium graveolens* (Enquist and Leffler, 2001; Lisi et al., 2008; Santos et al., 2011; León, 2014), and *Bursera simaruba* (Enquist and Leffler, 2001; León, 2012; León, 2014)—this study presents significant discrepancies in ring visibility compared to previous works for species such as *Handroanthus chrysanthus* (León, 2014; Marcelo-Peña et al., 2020). While earlier studies describe these species as having poorly defined rings, our findings indicate highly defined rings, making them suitable for dendrochronological studies (Peña-Moreno et al., 2022; Betancourt and Pucha, 2024). While our dating results confirmed the annual nature of *Maclura tinctoria* and different studies have employed this specie en dendrochronological applications (Pucha-Cofrep et al., 2015; Lanzarin, 2016; García-Cervigón et al., 2020; Bauer et al., 2021), some descriptions described their growth rings as indistinct (León, 2014; Marcelo-Peña et al., 2020). Additional differences in ring visibility and pore arrangement are observed in species such as *Ceiba pentandra* (Heyden, 2008; León, 2014; Nordahlia et al., 2016; Marcelo-Peña et al., 2020), *Inga edulis* (Baretta-Kuipers, 1973; Shimamoto et al., 2016), *Ficus americana* (Sato, 2011), and *Byrsonima crispa* (Aparecido et al., 2019), which may be attributed to climatic constraints influencing their growth.

4.3. Structural tree ring diversity

I observed considerable diversity in the structural patterns of growth ring structure among the studied species, which play a critical role in determining the visibility of these rings. The variation in ring definition and structure may stem from taxonomic and phytogeographic factors, with boreal-origin species often exhibiting distinctly defined rings (Rodríguez &Morales, 2005); however, this hypothesis remains unconfirmed (Nath et al., 2016; Giraldo et al., 2020). Although our data do not reveal a clear relationship among anatomical structure, ring visibility, and taxonomic affiliation, previous studies have noted distinctions at the family and genus levels (Nath et al., 2016; Marcelo-Peña et al., 2020). It is also possible that these variations represent species-specific behaviour (Detienne, 1989).

The structural patterns of fibers, parenchyma, and vessels—which together define the visibility of growth rings—typically occur in combination across most species. In many cases, a fiber pattern is accompanied by a corresponding vessel pattern, or a distinct parenchyma pattern co-occurs with vessel characteristics. This degree of anatomical variability, characterized by diverse combinations of parenchyma, fibers, and vessels, suggests the existence of multiple adaptive functional strategies within the arboreal communities of the Serranía de los Yariguíes and the Chicamocha Canyon. Notably, the presence and variation of parenchyma are primarily associated with the clear demarcation of growth rings and serve as a potential marker delineating the cessation of growth caused by climatic constraints—a feature frequently observed in the growth rings of various tropical species (Baas, 1983; León and Espinoza, 2001; Brienen and Zuidema, 2005; Roig et al., 2005; Lisi et al., 2008; Rivera, 2013; Tarelkin et al., 2016). Given that parenchyma functions are mainly related to mechanical support, conduction, and storage (Esteban et al., 2024), it may indicate the transition between growth periods in response to exogenous or endogenous factors (Tomlinson and Longman; Nath et al., 2016) and thus serve as an annual marker for ring determination and counting.

Although fibers have been recognized as a predominant anatomical marker of growth rings in various tropical species (Aguilar-Rodríguez and Barajas-Morales, 2005; Beltrán-Gutiérrez and Valencia-Ramos, 2012; Reis-Avila and Moreno et al., 2017; Marcelo-Peña et al., 2020), our findings indicate that fiber patterns were not sufficiently distinct to aid in ring identification; they were mainly associated with species exhibiting a high degree of ring indistinctness.

Furthermore, variations in the grouping and size of vessels emerged as key characteristics influencing ring visibility determining species with highly or moderately defined rings. Although tropical forest species generally display a predominance of diffuse porosity—especially in humid regions (Aguilar-Rodríguez and Barajas-Morales, 2005; Roig et al., 2005; Beltrán-Gutiérrez and Valencia-Ramos, 2013; Rivera, 2013; Esteban et al., 2024)—our observations reveal that the distribution of species with diffuse versus semi-ring porosity differed among the sampled localities. More humid areas, such as El Carmen de Chucurí and San Vicente de Chucurí, were primarily composed of species with diffuse porous rings, whereas Zapatoca—located in the same mountainous region but under drier conditions—and the predominantly arid Chicamocha Canyon exhibited a higher prevalence of species with semi-ring diffuse porosity.

The occurrence of vessel grouping, particularly diffuse versus semi-ring porosity, has been associated with seasonal environments, particularly at higher latitudes and in regions with pronounced seasonality, potentially serving as a strategy to enhance hydraulic safety (Zimmermann, 1983). In this context, studies have documented that, in dry environments, vessels tend to group (Carlquist, 1966; Bissing, 1982; Carlquist and Hoekman, 1985; Barajas-Morales, 1985; Fahn et al., 1986; Lindorf, 1994), while in highly humid conditions, vessel grouping is less common. Nonetheless, inverse relationships have also been reported in arid and humid zones (Baas et al., 1988; Xinying and Baas, 1988; Baas and Schweingruber, 1987), underscoring the complexity of these patterns. The remarkable functional plasticity of xylem is further evidenced by the ability of some species to modify the type of ring porosity in response to environmental conditions (Chowdhury, 1953; Carlquist, 1988). In this regard, water transport efficiency in “earlywood” is associated with the presence of large-diameter, short-length vessels, which facilitate rapid water conduction. In contrast, “latewood” is characterized by smaller-diameter, longer vessels, which help prevent embolisms during drought periods, reflecting key adaptation strategies to seasonal water availability (López-Ayala et al., 2006; León & Espinoza, 2001; Nath et al., 2016).

4.4. Annual Growth patterns

I used radiocarbon analysis in combination with dendrochronological techniques, such as cross-dating, to confirm the annual periodicity of the studied species (Speer, 2010; Santos et al., 2020). For most species, there was a strong agreement between the estimated growth ring years and the calendar years obtained through radiocarbon dating, with differences of only one or two years in some cases. These minor discrepancies may be influenced by the presence of false rings or the loss of rings in specific years. However, the selection of the calibration curve for the bomb-spike period can introduce additional variability, as atmospheric calibration data and growth rings are not evenly distributed, with most calibration data derived from regions outside the tropics (Hua et al., 2022). Despite this, the radiocarbon method provides good resolution from 1955 onward (Hua and Barbetti, 2004; Hua, 2009) and agreement with age estimation of ring counting of 12 selected species.

The presence of a higher frequency of rings that are difficult to identify in species such as *Quercus humboldtii, Neltuma juliflora*, *Alfaroa williamsii and Albizia niopoides* introduced uncertainties regarding the annual periodicity of their rings. This limitation challenges the reliability of cross-dating and reduces the suitability of these species for classical dendrochronological studies, however, this should not be a reason to exclude these species from dendro-ecological studies, as they can provide valuable insights into non-annual growth rhythms in the tropics (Silva et al., 2019). Our results indicate that *Neltuma juliflora* does not develop annual growth rings in our study area, despite previous reports of annual ring formation in tropical studies (Leavitt & Lone, 1991; Beramendi-Orosco et al., 2013; Nogueira et al., 2019) and that *Quercus humboldtii* may form supra-annual rings, an uncommon growth pattern characterized by the development of a single ring over multiple years (Silva et al., 2019). And, although I aimed to select samples from rings formed after the bomb period, the possible presence of missing rings could have led to sampling of rings formed before the 1950s resulting in $F^{14}C$ values below 1. This means that radiocarbon dating using the IntCal20 calibration curve (Reimer et al., 2020) is problematic due to fluctuations in ^{14}C levels. Specifically, between 1900 and 1950, ^{14}C values exhibit minimal variation, resulting in wide age ranges and increased uncertainty in the estimated calendar years (Hua, 2009).

5. Conclusions

Our results reaffirm that in the tropics, close to 80% of tree species have potential for dendrochronological studies. The anatomical description of the 65 species presented here reveals a high diversity of anatomical patterns defining annually formed growth rings. We highlight species such as *Maclura tinctoria*, *Cedrela odorata*, *Ceiba pentandra*, *Cupania americana*, *Oreomunnea munchiquensis*, and *Inga edulis*, which exhibit highly defined growth rings and annual periodicity, making them strong candidates for future dendrochronological studies. However, this does not exclude non-annual species, as they can also provide valuable insights into tree growth dynamics in tropical ecosystems. These findings, obtained from a steep climatic gradient, offer new opportunities to reconstruct past environmental conditions, enhance our understanding of tree growth dynamics in tropical ecosystems, and can generate valuable data (e.g., chronologies) for climate change studies (Groenendijk et al., 2025). This is especially relevant for the Colombian Andes, a region experiencing continuous change and facing critical challenges related to climate change, as well as the management of protected and agricultural areas. Furthermore, this information could be locally valuable for supporting and guiding sustainable forest management programs, for example, by establishing species growth rates for e.g. regeneration of forest ecosystems and projects for biodiversity conservation.

References

1. Albesiano, S., Rangel-Churio, J. O., & Cadena, A. (2003). La vegetación del cañón del río Chicamocha (Santander, Colombia). *Caldasia*, 25(1), 73-99.

2. Albesiano Hoyos, A. S., & Rangel Churio, J. O. Estructura de la vegetación del canón del río chicamocha, 500-1200 m; santandercolombia: una herramienta para la conservación. *Caldasia*.

3. Alves, E. S., & Angyalossy-Alfonso, V. (2000). Ecological trends in the wood anatomy of some Brazilian species. 1. Growth rings and vessels. *IAWA journal*, 21(1), 3-30. https://doi.org/10.1163/22941932-90000233

4. Aparecido, L. M. T., Santos, J. D., Higuchi, N., & Kunert, N. (2019). Relevance of wood anatomy and size of Amazonian trees in the determination and allometry of sapwood area. *Acta Amazonica*, 49(1), 1-10.

5. Armenteras D., Rodríguez N., Retana J., & Morales M. (2011). Understanding deforestation in upper montane and lower montane areas of the Colombian Andes. *Regional Environmental Change*. 1,693–705. https://doi.org/10.1007/s10113-010-0200-y

6. Arruda, É. C. D., Santos, E. C. D. P. R. D., Nunes da Cunha, C., & Schongart, J. (2017). Methodological baseline for dendrochronological studies in the Pantanal. Natural resources in wetlands: from Pantanal to Amazonia, pgs. 90-114.

7. Audigier, V., Husson, F., & Josse, J. (2016). A principal component method to impute missing values for mixed data. Advances in Data Analysis and Classification, 10, 5-26. https://doi.org/10.1007/s11634-014-0195-1

8. Baas P. 1983. Ecological patterns in xylem anatomy. En: Givnish T.J. Ed. On the Economy of Plant Form and Function, pp. 327-352, Cambridge University Press, Cambridge.

9. Baas, P., & Schweingruber, F. H. (1987). Ecological trends in the wood anatomy of trees, shrubs and climbers from Europe. *IAWA journal*, 8(3), 245-274.

10. Barajas-Morales, J. (1985). Wood structural differences between trees of two tropical forests in Mexico. *IAWA journal*, 6(4), 355-364.

11. Baretta-Kuipers, T. (1973). Some aspects of wood-anatomical research in the genus Inga (Mimosaceae) from the Guianas and especially Suriname. Acta botanica neerlandica, 22(3), 193-205.

12. Bauer, D., Schmitt, J. L., & Oliveira, J. M. (2020). Xylem growth rings and leaf phenological patterns in tree species of a subtropical seasonal forest. *Acta Botanica Brasilica*, 34(4), 680-693. https://doi.org/10.1590/0102-33062019abb0395

13. Beltrán Gutiérrez, L. A., & Valencia Ramos, G. M. (2013). Anatomic characterization of growth-rings in 80 potential tree species for dendrocronological studies in the Central forest, Perú. *Revista de Biología Tropical*, 61(3), 1025-1037.

14. Beramendi-Orosco, L. E., Rodriguez-Estrada, M. L., Morton-Bermea, O., Romero, F. M., Gonzalez-Hernandez, G., & Hernandez-Alvarez, E. (2013). Correlations between metals in tree-rings of *Prosopis julifora* as indicators of sources of heavy metal contamination. *Applied geochemistry*, 39, 78-84. https://doi.org/10.1016/j.apgeochem.2013.10.003

15. Betancourt, V. M., & Pucha, D. (2024). Dinámica de Crecimiento de Handroanthus chrysanthus (Jacq.) SO Grose al sur de Ecuador. *Bosques Latitud Cero,* 14(2), 73-81.

16. Bissing, D. R. (1982). Variation in qualitative anatomical features of the xylem of selected dicotyledonous woods in relation to water availability. Bulletin of the *Torrey Botanical Club*, 371-384.

17. Boninsegna, J. A., Argollo, J., Aravena, J. C., Barichivich, J., Christie, D., Ferrero, M. E., ... & Villalba, R. (2009). Dendroclimatological reconstructions in South America: A review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 281(3-4), 210-228. https://doi.org/10.1016/j.palaeo.2009.07.020

18. Bossu, J. (2015). Potentiel de *Bagassa guianensis* et *Cordia alliodora* pour la plantation en zone tropicale (Doctoral dissertation, Université de Guyane).

19. Briceño, A. M., Rangel-Ch, J. O., y Bogino, S. M. (2016). Estudio de los anillos de crecimiento de *Cordia alliodora* (Ruiz & Pav.) en Colombia. *Colombia Forestal*, 19(2), 219-232. https://doi.org/10.14483/udistrital.jour.colomb.for.2016.2.a07.

20. Briceño-J, A. M., Rangel-Ch, J. O., & Bogino, S. M. (2016). Tree rings study of *Cordia alliodora* (Ruiz & Pav.) Oken in Colombia. https://doi.org/10.14483/udistrital.jour.colomb.for.2016.2.a07

21. Briceño, A. M., Rangel-Ch, J. O., y Bogino, S. M. (2018). Anatomía y anualidad de los anillos de crecimiento de tres especies del bosque seco tropical del Caribe de Colombia. *Polibotánica*, (46), 169-178. https://doi.org/10.18387/polibotanica.46.10.

22. Brienen, R. J., & Zuidema, P. A. (2005). Relating tree growth to rainfall in Bolivian rain forests: a test for six species using tree ring analysis. *Oecologia*, 146, 1-12. https://doi.org/10.1007/s00442-005-0160-y

23. Brienen, R. J., Lebrija‐Trejos, E., Van Breugel, M., Pérez‐García, E. A., Bongers, F., Meave, J. A., & Martínez‐Ramos, M. (2009). The potential of tree rings for the study of forest succession in southern Mexico. *Biotropica*, 41(2), 186-195. https://doi.org/10.1111/j.1744-7429.2008.00462.x

24. Brienen, R. J. W., Schöngart, J., & Zuidema, P. A. (2016). Tree Rings in the Tropics: Insights into the Ecology and Climate Sensitivity of Tropical Trees. *Tropical Tree Physiology*. https://doi.org/10.1007/978-3-319-27422-5_20

25. Cahuana, L. A. P., Guevara, B. A. H., Luque, E. M. M., Palermo, G. P. D. M., & Latorraca, J. V. D. F. (2021). Dendrochronology of two forest species in the urban area of the city of Puerto Maldonado, Peru. https://doi.org/10.5380/rf.v51i3.72410

26. Carlquist, S. (1966). Wood anatomy of Compositae: a summary, with comments on factors controlling wood evolution. Aliso: *A Journal of Systematic and Floristic Botany,* 6(2), 25-44.

27. Carlquist, S., & Hoekman, D. A. (1985). Ecological wood anatomy of the woody southern Californian flora. *Iawa Journal*, 6(4), 319-347.

28. Carlquist, S. (1988). Comparative wood anatomy: Systematic, ecological and evolutionary aspects of dicotyledon wood. Springer-Verlag, Berlin.

29. Chowdhury, K. A. (1953). The role of initial parenchyma in the transformation of the structure diffuse-porous to ring-porous in the secondary xylem of the genus Gmelina Linn.

30. Collazos-González, S. A., Zuluaga-Carrero, J., & Cortés-Herrera, J. O. (2020). Aves del Cañón del Chicamocha, Colombia: un llamado para su conservación. *Biota colombiana*, 21(1), 58-85. https://doi.org/10.21068/c2020.v21n01a05

31. de Arruda EC, Paixão E, Nunes da Cunha C & Schöngart J. (2017) Methodological baseline for dendrochronological studies in the Pantanal. In: Soares M, Gonçalves M (eds) Natural resources in wetlands: from Pantanal to Amazonia. Museu Paraense Emílio Goeldi, Belem, pp 90–114

32. Detienne P .(1989). Appearance and periodicity of growth rings in some tropical woods. *IAWA Bul*l 10:123–132

33. Devall, M. S., Parresol, B. R., & Wright, S. J. (1995). Dendroecological analysis of *Cordia alliodora, Pseudobombax septenatum* and *Annona spraguei* in central Panama. *Iawa Journal*, 16(4), 411-424.

34. Donegan, T. M., & Huertas, B. C. (2005). Threatened species of Serranía de los Yariguíes: final report. *Colombian EBA Project Report Series*, 5, 27-35.

35. Donegan, T. M., Avendaño, J. E., Briceño-L, E. R., Luna, J. C., Roa, C., Parra, R., ... and Huertas, B. (2010). Aves de la Serranía de los Yariguíes y tierras bajas circundantes, Santander, Colombia. *Cotinga*, 32, 72-89.

36. Díaz-Pérez, C. N., Puerto-Hurtado, M. A., & Fernández-Alonso, J. L. (2011). Evaluación del hábitat, las poblaciones y el estatus de conservación del Barrigón (*Cavanillesia chicamochae, Malvaceae-Bombacoideae*). *Caldasia*, 33(1), 105-119.

37. Díaz-Rueda, D. M., Herrera-Pacheco, M. A., Plata-Castro, A. D., Ardila-Hurtado, S. F., & Reu, B. (2025). Composición y diversidad florísticas de tres coberturas en la Serranía de Los Yariguíes (Santander, Colombia). *Colombia forestal*, 28(1), e22659-e22659. https://doi.org/10.14483/2256201X.22659

38. Dünisch, O., Montóia, V. R., & Bauch, J. (2003). Dendroecological investigations on *Swietenia macrophylla* King and *Cedrela odorata* L.(Meliaceae) in the central Amazon. *Trees*, 17, 244-250. https://doi.org/10.1007/s00468-002-0230-2

39. Enquist, B. J., & Leffler, A. J. (2001). Long-term tree ring chronologies from sympatric tropical dry-forest trees: individualistic responses to climatic variation. *Journal of Tropical Ecology*, 17(1), 41-60. https://doi.org/10.1017/S0266467401001031

40. Esteban, L. G., de Palacios, P., Gasson, P., García-Iruela, A., García-Fernández, F., & García-Esteban, L. (2024). Hardwoods: Anatomy and functionality of their elements—a short review. *Forests*, 15(7), 1162. https://doi.org/10.3390/f15071162

41. Estrada, G. C. D., Callado, C. H., Soares, M. L. G., & Lisi, C. S. (2008). Annual growth rings in the mangrove *Laguncularia racemosa* (Combretaceae). *Trees*, 22(5), 663-670. https://doi.org/10.1007/s00468-008-0224-9

42. Etter, A., Andrade, Á., Saavedra, K., Amaya, P., & Arévalo, P. (2017). Risk assessment of Colombian continental ecosystems: An application of the Red List of Ecosystems methodology (v2. 0). Bogotá DC, Colombia. Available at: The Colombian Red List of Ecosystems (version 2.0).

43. Fahn, A., Werker, E., & Baas, P. (1986). Wood anatomy and identification of trees and shrubs from Israel and adjacent regions (pp. iv+-221pp).

44. Fajardo-G, F., Montealegre, C., & Pardo-P, M. (2015). ZOCAMATA. Guía de plantas del Cañón del Chicamocha.

45. Alves-Ferrerira, C., Inga Guillen, J. G., Vidal Alanya, O. D., Goytendia Centeno, W., Moya Mateo, S. M., Centeno Utos, T., ... & Tomazello-Filho, M. (2021). Identification of tree species from the peruvian tropical amazon "selva central" forests according to wood anatomy. *BioResources*.

46. Fichtler, E., Clark, D. A., & Worbes, M. (2003). Age and long‐term growth of trees in an old‐growth tropical rain forest, based on analyses of tree rings and 14C1. *Biotropica*, 35(3), 306-317. https://doi.org/10.1111/j.1744-7429.2003.tb00585.x

47. García‐Cervigón, A. I., Camarero, J. J., Cueva, E., Espinosa, C. I., & Escudero, A. (2020). Climate seasonality and tree growth strategies in a tropical dry forest. *Journal of Vegetation Science*, 31(2), 266-280. https://doi.org/10.1111/jvs.12840

48. Giraldo, J. A. (2011). Dendrocronología en el trópico: aplicaciones actuales y potenciales. *Colombia Forestal*, 14 14(1), 97–111. https://doi.org/10.14483/udistrital.jour.colomb.for.2011.1.a08.

49. Giraldo, J. A., del Valle, J. I., Sierra, C. A., & Melo, O. (2020). Dendrochronological potential of trees from America's rainiest region. *Latin American Dendroecology: Combining Tree-Ring Sciences and Ecology in a Megadiverse Territory*, 79-119. https://doi.org/10.1007/978-3-030-36930-9_5

50. Giraldo, J. A., del Valle, J. I., González‐Caro, S., David, D. A., Taylor, T., Tobón, C., & Sierra, C. A. (2023). Tree growth periodicity in the ever‐wet tropical forest of the Americas. *Journal of Ecology*, 111(4), 889-902. https://doi.org/10.1111/1365-2745.14069

51. Groenendijk, P., Sass-Klaassen, U., Bongers, F., & Zuidema, P. A. (2014). Potential of tree-ring analysis in a wet tropical forest: a case study on 22 commercial tree species in Central Africa. *Forest Ecology and Management,* 323, 65-78. https://doi.org/10.1016/j.foreco.2014.03.037

52. Groenendijk, P., Babst, F., Trouet, V., Fan, Z. X., Granato-Souza, D., Locosselli, G. M., ... & Wils, T. (2025). The importance of tropical tree-ring chronologies for global change research. *Quaternary Science Reviews*, 355, 109233. https://doi.org/10.1016/j.quascirev.2025.109233

53. Hayden, B. (2008). Annual growth rings in dry tropical forest trees (Doctoral dissertation, Concordia University).

54. Hua, Q., Barbetti, M., Jacobsen, G. E., Zoppi, U., & Lawson, E. M. (2000). Bomb radiocarbon in annual tree rings from Thailand and Australia. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 172(1-4), 359-365. https://doi.org/10.1016/S0168-583X(00)00147-6

55. Hua, Q. (2009). Radiocarbon: a chronological tool for the recent past. *Quaternary Geochronology*, 4(5), 378-390. https://doi.org/10.1016/j.quageo.2009.03.006

56. Hua, Q., Turnbull, J. C., Santos, G. M., Rakowski, A. Z., Ancapichún, S., De Pol-Holz, R., ... & Turney, C. S. (2022). Atmospheric radiocarbon for the period 1950–2019. *Radiocarbon*, 64(4), 723-745. https://doi.org/10.1017/RDC.2021.95

57. Inga, J. G., & del Valle, J. I. (2017). Log-relative growth: A new dendrochronological approach to study diameter growth in *Cedrela odorata* and *Juglans neotropica*, Central Forest, Peru. *Dendrochronologia*, 44, 117-129. https://doi.org/10.1016/j.dendro.2017.03.009

58. Kaennel, M., y Schweingruber, F. H. (1995). Multilingual glossary of dendrochronology. WSL FNP, Haupt, 133,162-184.

59. Lanzarin, K. (2016). Relações morfométricas e potencial de manejo de Maclura tinctoria (L.) D. Don Ex. Steud em formações secundárias no noroeste do Rio Grande do Sul.

60. Leavitt, S. W., & Lone, A. (1991). Seasonal stable-carbon isotope variability in tree rings: possible paleoenvironmental signals. *Chemical Geology: Isotope Geoscience section*, 87(1), 59-70.

61. León, W. & N. Espinoza. (2001). Anatomía de la Madera. Consejo de Publicaciones, Mérida, Venezuela.

62. Leon H, W. J. (2013). Wood anatomy of 27 species from Sapindales from Barinas state (Venezuela). Taxonomic aspects.

63. León, H. W. J. (2014). Anatomía de maderas de 108 especies de Venezuela. Pittieria, 66p.

64. Lieberman, M., y Lieberman, D. (1985). Simulation of growth curves from periodic increment data. *Ecology*, 66(2), 632-635.

65. Lindorf, H. (1994). Eco-anatomical wood features of species from a very dry tropical forest. *Iawa Journal*, 15(4), 361-376.

66. Lisi, C. S., Fo, M. T., Botosso, P. C., Roig, F. A., Maria, V. R., Ferreira-Fedele, L., & Voigt, A. R. (2008). Tree-ring formation, radial increment periodicity, and phenology of tree species from a seasonal semi-deciduous forest in southeast Brazil. *Iawa Journal*, 29(2), 189-207.

67. Lisi, C. S., Pagotto, M. A., Anholetto, C. R., Nogueira, F. C., Santos, H. L., Costa, C. M., ... & Tommasiello Filho, M. (2020). Dendroecological studies with *Cedrela odorata* L., northeastern Brazil. *Latin American Dendroecology: Combining Tree-Ring Sciences and Ecology in a Megadiverse Territory,* 37-59.

68. Lobão, M. S. (2011). Dendrocronologia, fenologia, atividade cambial e qualidade do lenho de árvores de *Cedrela odorata L., Cedrela fissilis* Vell. e *Schizolobium parahyba* var. amazonicum Hub. ex Ducke, no estado do Acre, Brasil (Doctoral dissertation, Universidade de São Paulo).

69. López-Ayala, J. L., Valdez-Hernández, J. I., Terrazas, T., & Valdez-Lazalde, J. R. (2006). Anillos de crecimiento y su periodicidad en tres especies tropicales del Estado de Colima, México. *Agrociencia*, 40(4), 533-544.

70. Mamani Luque, E. M. (2019). Dendrocronología en Árboles de *Cordia alliodora* (Ruiz & Pav.) Oken., en el Sector La Joya–Tambopata–Madre de Dios.

71. Manton, M. J., Belward, A., Harrison, D. E., Kuhn, A., Lefale, P., Rösner, S., ... & Zillman, J. (2010). Observation needs for climate services and research. *Procedia Environmental Sciences*, 1, 184-191. https://doi.org/10.1016/j.proenv.2010.09.012

72. Marcelo-Peña, J. L., Roig, F. A., Goodwin, Z. A., & Tomazello-Filho, M. (2020). Characterizing growth rings in the trees of Perú: A wood anatomical overview for potential applications in dendroecological-related fields. *Dendrochronologia*, 62, 125728. https://doi.org/10.1016/j.dendro.2020.125728

73. Mendivelso, H. A., Camarero, J. J., & Gutiérrez, E. (2016). Dendrocronología en bosques neotropicales secos: métodos, avances y aplicaciones. *Ecosistemas*, 25(2), 66-75. https://doi.org/10.7818/ECOS.2016.25-2.08

74. Menezes, M., Berger, U., & Worbes, M. (2003). Annual growth rings and long-term growth patterns of mangrove trees from the Bragança peninsula, North Brazil. *Wetlands Ecology and Management*, 11, 233-242. https://doi.org/10.1023/A:1025059315146

75. Mennega, A. M. (1980). Wood structure of *Trigonobalanus Excelsa* G. Lozano-c., HDZ-C. & Henao (Fagaceae). *Caldasia*, 97-101.

76. Moreno, H., & Tinjaca, Z. (2018). Plan de Manejo del Parque Nacional Natural Serranía de los Yariguíes. *Parques Nacionales Naturales de Colombia*, 152.

77. Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), 853-858. https://doi.org/10.1038/35002501

78. Nath, C. D., Munoz, F., Pélissier, R., Burslem, D. F., & Muthusankar, G. (2016). Growth rings in tropical trees: role of functional traits, environment, and phylogeny. *Trees*, 30, 2153-2175. https://doi.org/10.1007/s00468-016-1442-1

79. Nogueira, F. D. C., Pagotto, M. A., Aragão, J. R. V., Roig, F. A., Ribeiro, A. D. S., & Lisi, C. S. (2019). The hydrological performance of Prosopis juliflora (Sw.) growth as an invasive alien tree species in the semiarid tropics of northeastern Brazil. *Biological Invasions*, 21, 2561-2575. https://doi.org/10.1007/s10530-019-01994-y

80. Nordahlia, A. S., Noraini, T., Chung, R. C. K., Lim, S. C., Nadiah, I., Azahana, N. A., & Solihani, N. S. (2016). Comparative wood anatomy of three Bombax species and Ceiba pentandra (Malvaceae: Bombacoideae) in Malaysia. *Mal Nat J*, 68, 203-216.

81. Noriega-Londoño, S., Yepes-Bonilla, S., Urueña-Ramírez D., Quesada-Román, A., del Valle, J. I., Giraldo, J.,Restrepo-Moreno, S. A., y Marín-Carón, M. I. (2022). Debris Flow

Peak Discharge Reconstruction Using Geological, Historical, and Dendrogeomorphic Analyses in the Cauca River Canyon, Northern Andes, Colombia. *Historical, and Dendrogeomorphic Analyses in the Cauca River Canyon, Northern Andes, Colombia.* http://dx.doi.org/10.2139/ssrn.4088211.

82. Oviedo-Chavez, G. (2018). Criterios de valoración para la declaratoria del Cañón del Chicamocha como Patrimonio Mundial. *Revista Santander,* (10), 48–59.

83. Pereyra Espinoza, M. J., Inga Guillen, G. J., Santos Morales, M., & Arisméndiz, R. (2014). Potencialidad de Cedrela odorata (Meliaceae) para estudios dendrocronológicos en la selva central del Perú. *Revista de Biología Tropical*, 62(2), 783-793.

84. Peña-Moreno, K. Y., & González Narváez, M. (2022). Reconstrucción de datos climáticos e hidrológicos a través de la dendrocronología en el sur del Ecuador (Doctoral dissertation, ESPOL. FCNM).

85. Pompa-García, M., & Camarero, J. (2020). Latin American Dendroecology. *Latin American Dendroecology.*

86. Pucha-Cofrep, D., Peters, T., & Bräuning, A. (2015). Wet season precipitation during the past century reconstructed from tree-rings of a tropical dry forest in Southern Ecuador. *Global and Planetary Change*, 133, 65-78. https://doi.org/10.1016/j.gloplacha.2015.08.003

87. Ramírez Correa, J. A., Molina Grajales, E. C., & Bernal Escobar, M. (2010). Anillos anuales y clima en *Rhizophora mangle* L. de la Bahía de Cispatá, Colombia. *Revista Facultad Nacional de Agronomía Medellín*, 63(2), 5639-5650.

88. Ramírez, J. A., & del Valle, J. I. (2011). Paleoclima de La Guajira, Colombia; según los anillos de crecimiento de *Capparis odoratissima* (Capparidaceae). *Revista de biologia tropical*, 59(3), 1389-1405. 10.15517/rbt.v0i0.3406

89. Ramķrez, J. A., & del Valle, J. (2012). Local and global climate signals from tree rings of *Parkinsonia praecox in La Guajira*, Colombia. *International Journal of Climatology*, 32, 1077-1088. https://doi.org/10.1002/joc.2335.

90. Ramírez-Martínez, M., Terrazas, T., Aguilar-Rodríguez, S., & Martínez-Ávalos, J. G. (2017). Anatomía de la madera de especies de la selva baja caducifolia de Tamaulipas, México. Madera y bosques, 23(2), 21-41. https://doi.org/10.21829/myb.2017.2321126

91. Rangel, J.O. (1997a). Diversidad de la flora de Colombia. *Informe Nacional sobre el estado de la biodiversidad*, tomo I, 323–336.

92. Rangel, J.O. (1997b). Diversidad de la fauna de Colombia. *Informe Nacional sobre el estado de la biodiversidad*, tomo I, 337–365.

93. Reimer, P. J., Brown, T. A., & Reimer, R. W. (2004). Discussion: reporting and calibration of post-bomb 14C data. *Radiocarbon*, 46(3), 1299-1304. https://doi.org/10.1017/S0033822200033154

94. Reimer, P. J., Austin, W. E., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., ... & Talamo, S. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, 62(4), 725-757. https://doi.org/10.1017/RDC.2020.41

95. Reis-Avila, G., & Oliveira, J. M. (2017). Lauraceae: A promising family for the advance of neotropical dendrochronology. *Dendrochronologia*, 44, 103-116. https://doi.org/10.1016/j.dendro.2017.04.002

96. Rivera Builes, C. (2013). Potencial dendrocronológico de árboles de la Amazonia colombiana (Doctoral dissertation, Universidad Nacional de Colombia-Sede Amazonas).

97. Rodríguez, S. A., & Morales, J. B. (2005). Anatomía de la madera de especies arbóreas de un bosque mesófilo de montaña: un enfoque ecológico-evolutivo. *Boletín de la Sociedad Botánica de México*, (77), 51-58.

98. Rodríguez, N., Armenteras D., Morales, M., & Romero M. (2006). Ecosistemas de los Andes colombianos. (2da ed). Instituto de Investigación de Recursos Biológicos Alexander von Humboldt. Bogotá, Colombia.

99. Rodríguez Eraso, N., Armenteras-Pascual, D., & Alumbreros, J. R. (2013). Land use and land cover change in the Colombian Andes: dynamics and future scenarios. *Journal of Land Use Science*, 8(2), 154-174. https://doi.org/10.1080/1747423X.2011.650228

100. Roig, F. A., Osornio, J. J. J., Diaz, J. V., Luckman, B., Tiessen, H., Medina, A., & Noellemeyer, E. J. (2005). Anatomy of growth rings at the Yucatán Peninsula. *Dendrochronologia*, 22(3), 187-193. https://doi.org/10.1016/j.dendro.2005.05.007

101. Sato Tokashiki, D. C. (2011). Estructura anatómica del leño de cinco especies forestales provenientes de Loreto y Junin.

102. Santos, C. M., de Lima, I. L., Longui, E. L., Romeiro, D., Zanatto, A. C. S., Morais, E., ... & Florsheim, S. M. B. (2011). A densidade básica e características anatômicas variam radialmente na madeira de *Astronium graveolens* Jacq.(Anacardiaceae). *Revista do Instituto Florestal*, 23(2), 191-201. https://doi.org/10.24278/2178-5031.2011232294

103. Santos, G. M., Granato-Souza, D., Barbosa, A. C., Oelkers, R., & Andreu-Hayles, L. (2020). Radiocarbon analysis confirms annual periodicity in *Cedrela odorata* tree rings from the equatorial Amazon. *Quaternary Geochronology*, 58, 101079. https://doi.org/10.1016/j.quageo.2020.101079

104. Schipper, A. (2011). Dendrocronología del cedro *Cedrela odorata* L.(meliaceae) de la Amazonia Sur del Perú, la región Madre de Dios (tesis de maestría). Universidad Nacional Agraria la Molina, Lima, Perú.

105. Schöngart, J., Arieira, J., Felfili Fortes, C., Cezarine de Arruda, E., & Nunes da Cunha, C. (2011). Age-related and stand-wise estimates of carbon stocks and sequestration in the aboveground coarse wood biomass of wetland forests in the northern Pantanal, Brazil. *Biogeosciences*, 8(11), 3407-3421. https://doi.org/10.5194/bg-8-3407-2011, 2011.

106. Sheppard, P. R. (2010). Dendroclimatology: extracting climate from trees. Wiley Interdisciplinary Reviews: *Climate Change*, 1(3), 343-352. https://doi.org/10.1002/wcc.42

107. Shimamoto, C. Y., Botosso, P. C., Amano, E., & Marques, M. C. (2016). Stem growth rhythms in trees of a tropical rainforest in Southern Brazil. *Trees*, 30, 99-111. https://doi.org/10.1007/s00468-015-1279-z

108. Silva, M. D. S., Funch, L. S., & da Silva, L. B. (2019). The growth ring concept: seeking a broader and unambiguous approach covering tropical species. *Biological Reviews,* 94(3), 1161-1178. https://doi.org/10.1111/brv.12495

109. Speer, J. H. (2010). Fundamentals of tree-ring research. University of Arizona Press.

110. Steinhof, A., Altenburg, M., & Machts, H. (2017). Sample Preparation at the Jena 14C Laboratory. *Radiocarbon*, 59(3), 815–830. https://doi.org/10.1017/RDC.2017.50

111. Sánchez-Calderón, O. D., Carlón-Allende, T., Mendoza, M. E., & Villanueva-Díaz, J. (2022). *Dendroclimatology in Latin America: a review of the state of the art. Atmosphere*, 13(5), 748. https://doi.org/10.3390/atmos13050748

112. Soares, W. F., Melo, L. E. D. L., & Lisboa, P. L. B. (2014). Anatomy of five wood species marketed as' Sucupira'. *Floresta e ambiente*, 21, 114-125.

113. Tarelkin, Y., Delvaux, C., De Ridder, M., El Berkani, T., De Cannière, C., & Beeckman, H. (2016). Growth-ring distinctness and boundary anatomy variability in tropical trees. *IAWA journal*, 37(2), 275-S7. 10.1163/22941932-20160134

114. Tomazello-Filho, M., Lisi, C. S., Hansen, N., & Cury, G. (2004). Anatomical features of increment zones in different tree species in the State of São Paulo, Brazil. *Scientia Forestalis*, 66, 46-55.

115. Tomlinson PB, Longman KA .(1981) Growth phenology of tropical trees in relation to cambial activity. In: Bormann FH, Berlyn G (eds) Age and growth rate of tropical trees: New dimensions for research. Yale University, New Haven, pp 7–19

116. Tschinkel, H. M. (1966). Annual growth rings in *Cordia alliodora*.

117. Turner, I. M. (2004). The Ecology of trees in the tropical rain forest. *Cambridge University Press*.

118. Valencia-Duarte, J., Ortiz, L. N. T., & Ríos, O. V. (2012). Dinámica de la vegetación en un enclave semiárido del río Chicamocha, Colombia. *Biota Colombiana*, 13(2).

119. Verheyden, A., Kairo, J. G., Beeckman, H., & Koedam, N. (2004). Growth rings, growth ring formation and age determination in the mangrove *Rhizophora mucronata*. *Annals of botany*, 94(1), 59-66.. https://doi.org/10.1093/aob/mch115

120. Vasquez, M., Lara, W., del Valle, J. I., & Sierra, C. A. (2022). Reconstructing past fossil-fuel CO2 concentrations using tree rings and radiocarbon in the urban area of Medellín, Colombia. *Environmental Research Letters*, 17(5), 055008. https://doi.org/10.1088/1748-9326/ac63d4

121. Walter, H., & Lieth, H. (1967). Klimadiagramamm‐Weltatlos [Atlas of climate diagrams of the world]. Gustav Fischer, Jena.

122. Wheeler, E. A., Baas, P., & Gasson, P. E. (Eds.). (1989). IAWA list of microscopic features for hardwood identification (Vol. 10, pp. 219-332). Leiden: IAWA.

123. Worbes, M. (1999). Annual growth rings, rainfall‐dependent growth and long‐term growth patterns of tropical trees from the Caparo Forest Reserve in Venezuela. *Journal of ecology*, 87(3), 391-403. https://doi.org/10.1046/j.1365-2745.1999.00361.x

124. Worbes, M. (2002). One hundred years of tree-ring research in the tropics–a brief history and an outlook to future challenges. *Dendrochronologia*, 20(1-2), 217-231. https://doi.org/10.1078/1125-7865-00018

125. Worbes, M. (2004). Tree-ring analysis. En Encyclopedia of Forest Sciences. *Academic Press*, Amsterdam, 586-599.

126. Worbes, M., & Raschke, N. (2012). Carbon allocation in a Costa Rican dry forest derived from tree ring analysis. *Dendrochronologia*, 30(3), 231-238. https://doi.org/10.1016/j.dendro.2011.11.001

127. Xinying, Z., Liang, D., & Baas, P. (1988). The Ecological Wood Anatomy of the Lilacs (*Syringa Oblata* Var. GlraldII) on Mount Taibei in Northwestern China. *IAWA Journal*, 9(1), 24-30.

128. Yu, K. F., Zhao, J. X., Liu, T. S., Wang, P. X., Qian, J. L., y Chen, T. G. (2004). Alpha‐cellulose δ13C variation in mangrove tree rings correlates well with annual sea level trend between 1982 and 1999. *Geophysical research letters*, 31(11). https://doi.org/10.1029/2004GL019450

129. Zimmermann, M. H. (2013). Xylem structure and the ascent of sap. Springer Science & Business Media.

Appendices

Appendix 1. Age determination of 12 species using ^{14}C measurements. Calendar years were calculated with the CaliBomb software (Reimer et al., 2004) using the Northern Hemisphere Zone 2 calibration curve. **F14C:** modern fraction of ^{14}C (Postbomb); **err (%):** error percentage.

Family	**Species**	**Sample code**	**Dendrochronological year**	**F14C**	**err (‰)**	**Radiocarbon calendar year**
Anacardiaceae	*Albizia niopoides*	An1	1956	0.9887	2.8	1954
		An2	1966	0.9771	2.8	1937
		An3	1972	0.9649	2.7	1949
Juglandaceae	*Alfaroa williamsii*	Aw1	2001	1.0051	4.2	1954
		Aw2	2005	0.9800	2.6	1946
		Aw3	2007	0.9942	3.5	1954
Anacardiaceae	*Astronium graveolens*	Ag1	1956	1.0020	2.7	1955
		Ag2	1970	1.6013	3.7	1967
		Ag3	1981	1.2692	3.3	1981
Meliaceae	*Cedrela odorata*	Co1	2011	1.0497	2.7	2011
		Co2	2008	1.0493	3	2008
Malvaceae	*Ceiba pentandra*	Cp1	2008	1.0508	2.8	2008
		Cp2	2006	1.0642	2.7	2006

Sapindaceae	*Cupania americana*	Ca1	1979	1.2985	3.1	1979
		Ca2	1977	1.3136	3.1	1978
Fabaceae	*Inga edulis*	Ie1	2001	1.0793	3.5	2002
		Ie2	1997	1.0842	3.4	2000
		Ie3	2004	1.0775	4.2	2004
Moraceae	*Maclura tinctoria*	Mt1	1972	1.4945	3.5	1972
		Mt2	1963	1.6560	3.9	1963
		Mt3	1975	1.4064	3.7	1975
Lauraceae	*Nectandra cf laurel*	Nl1	1957	0.9792	3	1954
		Nl2	1966	1.6504	4.3	1966
		Nl3	1989	1.1808	3.3	1988
Fabaceae	*Neltuma juliflora*	Nj1	1987	1.5240	3.8	1970
		Nj2	1977	1.6539	4.1	1966
		Nj3	1957	1.0310	2.9	1956
Juglandaceae	*Oreomunnea munchiquensis*	Om1	1954	1.0023	2.1	1955
		Om2	1965	1.4321	2.6	1962
Fagaceae	*Quercus humboldtii*	Qh1	1994	1.5571	4.1	1968
		Qh2	2000	1.2840	4.2	1979
		Qh3	1979	0.9777	2.9	1954