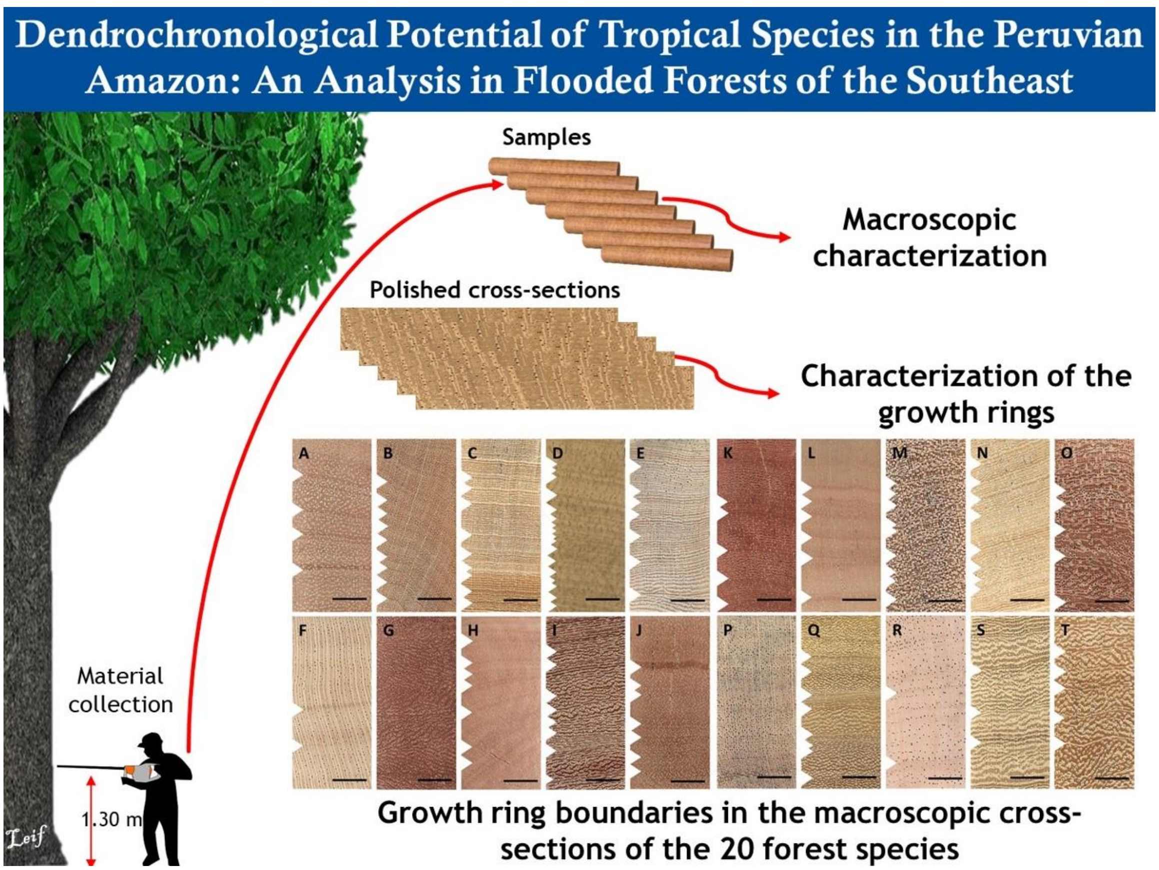
Dendrochronological Potential of Tropical Species in the Peruvian Amazon: An Analysis in Flooded Forests of the Southeast

Miguel A. Ranilla-Huamantuco,[a,f] Ingrid A. Cassana-Huáman,[b,e] John Canales-Ramirez,[c] Javier Navio-Chipa,[d] Kerly J. Macedo-Enriquez,[d] Robert F. Farfan-Huanca,[d] and Leif A. Portal-Cahuana[b,e,*]

*Corresponding author: leif.portal@untrm.edu.pe

DOI: 10.15376/biores.20.1.1482-1503

GRAPHICAL ABSTRACT



Dendrochronological Potential of Tropical Species in the Peruvian Amazon: An Analysis in Flooded Forests of the Southeast

Miguel A. Ranilla-Huamantuco,[a,f] Ingrid A. Cassana-Huáman,[b,e] John Canales-Ramirez,[c] Javier Navio-Chipa,[d] Kerly J. Macedo-Enriquez,[d] Robert F. Farfan-Huanca,[d] and Leif A. Portal-Cahuana [b,e,*]

Research on growth rings in tropical trees within flooded forests has unveiled the complexity of climate change in these ecosystems. However, there has been limited understanding regarding species and their potential for dendrochronology. This study assessed 20 species from 13 botanical families in a flooded forest in southeastern Peru. Wood samples were collected during the dry season using a non-destructive sampling with motorized drill, alongside botanical samples for identification. Growth ring features were described following the IAWA, at a macroscopic level. Thirteen species showed promise for dendrochronological studies, eight of which were previously undocumented. These findings are pivotal for prioritizing species in future dendrochronological investigations in the Peruvian Amazon.

DOI: 10.15376/biores.20.1.1482-1503

Keywords: Growth rings; Madre de Dios; Peruvian woods; Tropical dendrochronology; Tropical forest; Wood anatomy

*Contact information: a: Laboratorio Desconcentrado de Peritaje sede Madre de Dios, Ministerio Público, Puerto Maldonado, Perú; b: Instituto de Investigación, Innovación y Desarrollo para el Sector Agrario y Agroindustrial (IIDAA), Facultad de Ingeniería y Ciencias Agrarias (FICA), Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas (UNTRM), Calle Higos Urco 342 – Ciudad Universitaria, Chachapoyas, 01000, Perú; c: Empresa Agroforestal Orgánica R&H, Puerto Maldonado, Perú; d: Consultor independiente, Puerto Maldonado, Perú; e: Xiloteca Gocta, Escuela Profesional de Ingeniería Forestal, Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas, Perú; f: Universidad Nacional San Antonio Abad del Cusco, Cusco, Perú;*Corresponding author: leif.portal@untrm.edu.pe*

INTRODUCTION

Dendrochronology, an expanding field, has ventured into tropical forests, unveiling intriguing secrets and facing unique challenges. The presence of annual rings in over 20 tropical countries, as evidenced by Worbes (2002), highlights synchronized growth linked to extreme climatic events, such as brief droughts and prolonged floods. This technique has enabled an understanding of the influence of phenomena like El Niño on tree growth and the longevity of broadleaf trees in tropical lowlands. Rozendaal and Zuidema (2011) emphasize the relevance of understanding the growth and ecology of tropical trees to conserve and manage these ecosystems.

Despite the challenges posed by less pronounced changes in seasons, techniques, such as dendrometric measurement, cambial injuries, or carbon dating, have allowed us to comprehend the relationship between climate and tree growth in these regions. Meanwhile, Brienen *et al*. (2016) reveals that ring formation in the tropics is primarily linked to seasonal variations in rainfall or flooding rather than temperature. Despite the moderate sensitivity of tropical trees to climate, the ring studies offer valuable insights into the effects of climate change on these ecosystems.

Many studies have reinforced the importance of annual growth rings in understanding forest ecology and dynamics, as well as their application in projecting timber extraction and sustainable resource management (Schöngart *et al.* 2017; Marcelo-Peña *et al*. 2020). In the specific context of Peru, Portal-Cahuana *et al*. (2023a) highlight how the development of ring chronologies in tropical trees allows for the reconstruction of the neotropical environmental history. They identify sampling gaps and underscore Peru's high tree diversity as a natural laboratory to better comprehend the growth and functioning of tropical species in interaction with the climate. This specific research provides a detailed insight into dendrochronology in the Peruvian context, contributing to guiding future dendrochronological studies in this region.

The study of potential species for tropical dendrochronology is crucial for understanding tree growth under diverse climatic conditions. Several researchers have addressed this pertinent area (Brienen *et al*. 2006; Beltrán and Valencia 2013; Groenendijk *et al*. 2014; Schöngart *et al*. 2017; Bauer *et al*. 2020; Marcelo-Peña *et al*. 2020). Traditionally, the analysis of growth rings was believed to be feasible only in biomes with marked seasonality, such as temperate forests. However, studies in Peru have revealed the presence of annual rings in various species across altitudinal gradients. These findings debunk the seasonal limitation in the tropics for dendrochronological studies (Marcelo-Peña *et al*. 2020).

The association between the phylogenetic relationship and the distinctiveness of growth rings, as discussed by Marcelo-Peña *et al*. (2019), suggests a diversity of responses among deciduous and evergreen species to environmental conditions. Bauer *et al*. (2020) complement this picture by observing the relationship between leaf phenological patterns and growth rings in subtropical forests, through identifying species with clear anatomical boundaries in their rings. Beltrán and Valencia (2013) delve into the challenges and findings of the anatomical characterization of growth rings in potential species for dendrochronological studies in the Central Selva of Peru. These studies highlight issues, such as difficulty in ring visualization, irregularities, and the presence of parenchyma in bands, emphasizing the importance of understanding variability in cell dimensions to infer the annual formation of rings.

Groenendijk *et al*. (2014) and other researchers have assessed the potential for applying growth ring analysis in tropical tree species under moist conditions. Despite the lack of seasonal variation in certain tropical forests, distinct boundaries in tree rings were identified, demonstrating the potential for obtaining precise growth data. Collectively, these studies underscore the significance of investigating and understanding potential species for tropical dendrochronology, particularly in the flooded forests of southeastern Peru. The complexity and unique conditions of these ecosystems, characterized by seasonal flooding, highlight the necessity of dendrochronological research in this region. This not only expands knowledge about growth ring formation in diverse tropical conditions but also provides valuable insights for sustainable forest management and understanding tree responses to climate change in these ecosystems. The upland forests exhibit greater species diversity compared to flooded forests (Myster 2015). These forests face annual flooding, raising water levels by over 10 m and submerging seedlings, and trees for up to seven months. This disrupts nutrients, oxygen, and toxins, creating optimal conditions for plant growth, and demanding adaptations (Parolin *et al*. 2004). Amid current climate changes, understanding the mechanisms of floods and water flows and their impact on the development and alterations of riparian forests becomes essential (Berthelot *et al*. 2015).

This is one of the first studies assessing the potential of tree species growing in a flooded forest in southeastern Peru. To achieve this, the authors distinguished and characterized the growth rings of 20 tree species. Specifically, the following questions were addressed: (i) How do the growth ring boundaries of 20 tree species growing in a flooded forest differ?; (ii) What are the anatomical characteristics of the growth ring boundaries of 20 tree species in a flooded forest?; (iii) Which tree species show greater potential for dendrochronological studies in this flooded forest? The authors approached these inquiries using 20 tree species from 13 different botanical families.

EXPERIMENTAL

Study Area

The study area focuses on the Low Terrace Forests (LTF) situated along the right bank of the Madre de Dios River in the Madre de Dios Department, Peru. These forests fall under the jurisdiction of the Amazon Producers Association of Camu Camu, known as APAYCNA-MDD, positioned at an altitude of approximately 120 m around coordinates 12°35'26.69"S - 69°18'25.52"W. The sampling sites are located 600 m away from the Madre de Dios River (Fig. 1).

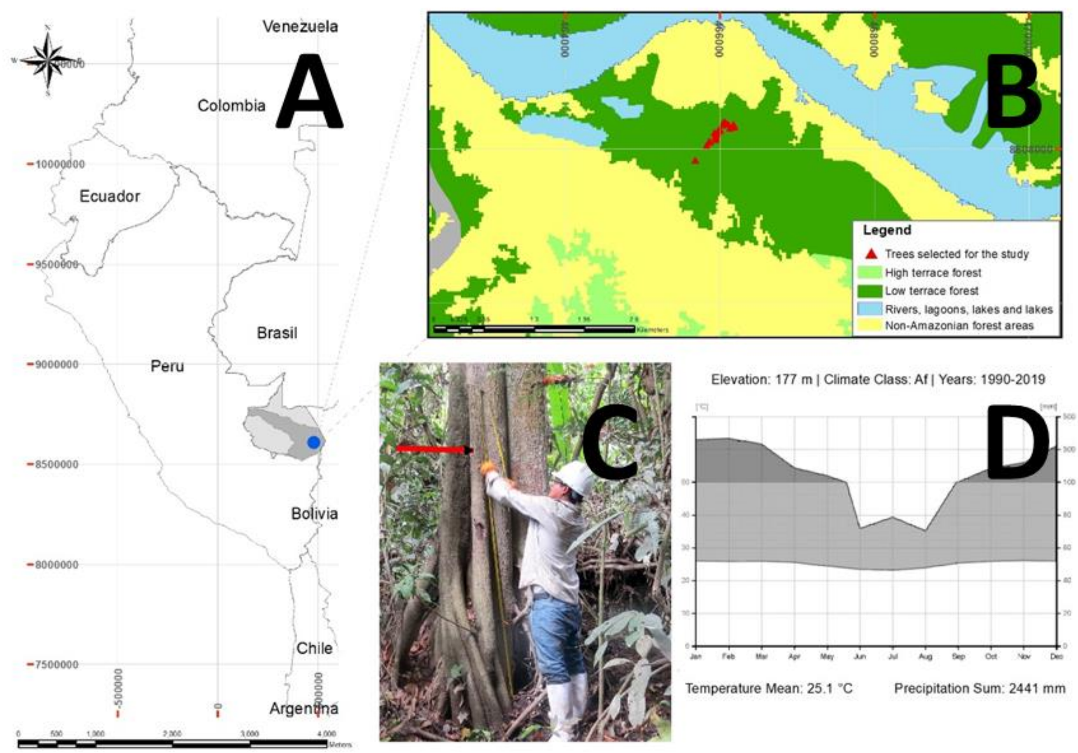


Fig. 1. Location of the study site in the Madre de Dios region, southeastern Peru: A) Terrace Forest (blue circle). The color map illustrates the forest types. B) Red triangles indicate the position of sampled trees. C) The red arrow marked on the tree image indicates the maximum flood level in the area. D) Climate diagram for the period 1990 to 2019 is shown (Walter and Lieth 1960), where darker gray areas represent periods with over 100 mm of precipitation.

The Low Terrace Forests (Btb), also known as floodable forests, undergo annual flooding lasting between 3 to 8 months (Poma 2007). The diversity and floristic composition of tree species in these forests differ and are lower compared to upland forests (Normand *et al*. 2006; Féret and Asner 2014).

In climatic terms, this region is characterized by a warm, humid, and seasonal climate, with an average annual precipitation ranging between 2200 and 2400 mm, and an average annual temperature of 24.2 °C. Maximum temperatures reach 37.9 °C, while minimum temperatures drop to 11.3 °C (Terborgh and Andresen 1998; Román-Dañobeytia *et al*. 2015; Best *et al*. 2021).

Species, Processing, and Analysis of Growth Rings

Twenty tree species from a low terrace forest, belonging to 18 genera and 13 different botanical families, representative of the study area, were selected; detailed information regarding the wood samples is provided in Table 1. Botanical samples were collected, and photographs of leaves, flowers, fruits, trunk, roots, and outer and inner bark were recorded. Subsequently, the samples were preserved and sent to the Forest Herbarium (MOL) at the National Agrarian University La Molina (UNALM) in Lima, Peru, for proper classification and deposition.

Wood samples were collected during the dry season (May to August) using a non-destructive method employing the Stihil BT45 gasoline-powered motorized drill with hollow bits (Fig. 3), measuring 2.5 cm in diameter and adjustable in length to fit the tree diameter, ranging from 60 to 110 cm, collected at 1.30 m in a 90° angle from the tree axis (Marcelo-Peña *et al*. 2019; Aragão *et al*. 2022). The wound created on the tree trunk was covered with a protective and wound-healing paste and subsequently sealed with a liquid silicone gun to prevent the entry of insects and pathogens (Portal-Cahuana *et al*. 2023c).

Fig. 2. In the field: A) Non-destructive collection; B) Sample extraction; C) Fungicide paste; and D) Sealed with silicone

The samples were placed on coded wooden mounts and secured with twine. They were then left at room temperature to air dry at the Xiloteca Gocta (specialized environment) of the National University Toribio Rodríguez de Mendoza de Amazonas. Subsequently, they were affixed to the wooden mounts with the cross-section facing upward and sanded and polished using an 80 to 600 grain/cm^2 sandpaper sequence (Portal *et al*. 2021; Roquette *et al*. 2023b) to aid in the precise visualization of ring growth boundaries (Roquette *et al*. 2023a). The samples were digitized at 1200 dpi using a scanner with a scale and examined under a stereoscopic microscope at various magnifications (Aragão *et al*. 2019; Menezes *et al*. 2022).

Finally, the growth rings of the twenty wood samples (Fig. 3) were described following the IAWA guidelines of (IAWA 1989); including their general and macroscopic descriptions. Additionally, the qualitative information was systematized, and a Principal Component Analysis (PCA) was conducted to distinguish and describe the growth ring boundaries using the PAST software (Hammer, Øyvind, version 1.0, Tromsø, Norway) (Hammer 2001).

RESULTS AND DISCUSSION

General and Macroscopic Description of Woods

A comprehensive study was conducted to provide a general and macroscopic description of 20 types of wood from a flooded Forest of Southeast Peru, as detailed in the accompanying Table 1.

Through meticulous observation and analysis, the distinctive and anatomical features of each wood species have been recorded. Additionally, macrophotographs of the transverse cuts of each species are presented for better visual understanding. Furthermore, a PCA analysis was performed, which provides a visual representation of the similarity between forest species, along with clustering to facilitate the identification and characterization of groups of species with similar anatomical characteristics (Appendix, Supplementary Material).

The findings of the study support the importance of investigating wood anatomy as a crucial tool to address the issue of illegal logging in the Peruvian Amazon, by providing a means to accurately identify tree species and their origins, which can help trace and prevent illegal harvesting practices (Portal-Cahuana *et al*. 2023c). A detailed understanding of the anatomical characteristics of different wood species allows for better identification and classification of wood, playing a fundamental role in combating the trade of illegally extracted timber.

Furthermore, the implementation of precise and reliable wood identification systems, such as the convolutional neural networks mentioned in the article (Ferreira *et al*. 2020), facilitates the distinction between legal and illegal timber, thereby strengthening efforts to promote sustainable logging practices and protect valuable forest resources. It is necessary to emphasize the importance of monitoring, incentivizing, and monetizing legal and sustainable wood value chains in the Peruvian Amazon, thus highlighting the ongoing need for studies on wood anatomy to address environmental and socio-economic challenges in the region (Da Cunha Soares 2017).

Table 1. General and Macroscopic Description of 20 Wood Species from Flooded Forests in Southeast Peru

Species			*Brosimum lactescens*	*Calycophyllum*	*Clarisia racemosa*	*Diospyros* sp.	*Ficus insipida*	*Guatteria* sp.	*Inga* sp.	*Luehea grandiflora*	NN	*Pouteria baehniana*	*Pouteria* sp. (1)	*Pouteria* sp. (2)	*Pseudolmedia laevis*	*Pterocarpus rohrii*	*Senegalia* sp.	*Spondias mombin*	*Terminalia oblonga*	*Virola elongata*	*Zanthoxylum acuminatum*	*Zygia* sp.
General Characteristics	Color	White					■											■				
		Yellow	■	■	■	■		■							■	■			■		■	■
		Red							■	■	■	■	■	■			■			■		
		Brown																				
	Texture	Fine		■								■	■									
		Medium	■		■	■	■	■	■	■	■			■	■	■		■	■	■	■	■
		Coarse															■					
	MCR	Soft				■	■	■										■		■	■	
		Hard	■	■	■				■	■	■	■	■	■	■	■	■		■			■
Macroscopic Characteristics	Parenchyma VIS	NV10X		■																		
		V10X	■		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Parenchyma APO	Diffuse				■																
		DI.A				■																
	Parenchyma PAR	VAS				■				■								■		■		
		Aliform	■						■		■				■	■	■		■		■	■
		Confluent	■		■				■		■				■	■	■		■		■	■
	Parenchyma Bands	Marginal													■					■	■	
		Fine										■	■	■								
		Wide					■															
		Reticulate																				
		SCA						■														
	Rays VIS	Fine		■					■	■		■	■	■			■		■	■		
		Medium	■		■	■	■				■				■	■		■			■	■
		Widths						■														
	Rays	Stratified								■						■						■
		Not stratified	■	■	■	■	■	■	■		■	■	■	■	■		■	■	■	■	■	
	Inclusions	Gums							■		■											
		Silica			■																	
		Tyloses	■									■	■	■								

Note: MCR: Manual cutting resistance; VIS: Visibility; APO: Apotracheal; DIA: Diffuse in aggregate; PAR: Paratracheal; VAS: Vasicentric; SCA: Scalariform

Distinguishing the Boundaries of the Growth Ring

The distinction of growth ring boundaries is a relevant aspect of wood anatomy, which aids in the identification of tree species. Among the 20 studied species, varied growth ring patterns were observed: three species (15%) displayed highly distinct growth rings, ten species (50%) showed moderately distinct growth rings, seven species (30%) presented growth rings with low distinctiveness, and in one species (5%), the growth rings were indistinct or absent (Table 2).

Table 2. Characterization of Growth Rings of Twenty Trees from the Madre de Dios Region

No.	Scientific Name	Family	DLAC	DLA
1	*Brosimun lactescens* (Moore) C. C. Berg. *	Moraceae	MD	CEPFyPM
	Calycophyllum spruceanum Benth. *	Rubiaceae	MD	CEPF
3	*Clarisia racemosa* R.et P *	Moraceae	PD	CEPF
4	*Diospyros* sp. *	Ebenaceae	MD	CEPF
5	*Ficus insipida* Willd. *	Moraceae	MD	CEPF
6	*Guatteria* sp.	Annonaceae	PD	CEPF
7	*Inga* sp. *	Fabaceae	PD	CEPF
8	*Luehea grandiflora* C. Martius cf.	Malvaceae	MD	CEPF
9	NN	Fabaceae	MD	CEPF
10	*Pouteria baenhiana* Monachino. *	Sapotaceae	PD	CEPF
11	*Pouteria* sp. (1)	Sapotaceae	MD	CEPF
12	*Pouteria* sp. (2)	Sapotaceae	MD	CEPF
13	*Pseudolmedia laevis* (R. et P.) J.F.	Moracea	PD	CEPF
14	*Pterocarpus rorhii* Vahl. *	Fabaceae	MD	CEPF
15	*Senegalia* sp.	Fabaceae	PD	CEPF
16	*Spondias mombin* L. *	Anacardiaceae	IoA	CEPF
17	*Terminalia oblonga* (R.et P) Steud. *	Combretaceae	MuyD	CEPFyPM
18	*Virola elongata* (Benth.) Warb.	Myristicaceae	MD	CEPFyPM
19	*Zanthoxylum acuminatum* (Sw.) Sw. *	Rutaceae	MuyD	CEPFyPM
20	*Zygia* sp. *	Fabaceae	MuyD	PM

DLAC = Distinction of growth ring boundaries; MuyD = Very distinct; MD = Moderately distinct; PD = Less distinct; IoA = Indistinct or Absent; DLA = Anatomical limits descriptor; CEPF = Change in fiber wall thickness; PM = Marginal parenchyma; CEPFyPM= Change in fiber wall thickness and Marginal parenchyma

The research on the distinction of growth ring boundaries in Peru has been limited. A previous study conducted in the Central Selva pointed out notable issues in this distinction, highlighting difficulties in visualizing some rings, irregular growth patterns, and the presence of parenchyma in bands (Beltrán and Valencia 2013). These same characteristics identified in the prior research have been reaffirmed in the current study on the distinction of growth ring boundaries, emphasizing the persistence and relevance of these particularities in the tree rings of the region. Additionally, more recent investigations have shown that deciduous species in seasonally dry tropical forests exhibit distinct growth rings, mainly marked by the presence of marginal parenchyma, while evergreen trees in lowland Amazonian and premontane forests show indistinguishable growth rings (Marcelo-Peña *et al*. 2020). The coherence between the current findings and previous studies underscores the consistency of patterns found in diverse types of tropical forests regarding the formation of growth rings and the relevance of environmental factors in this process.

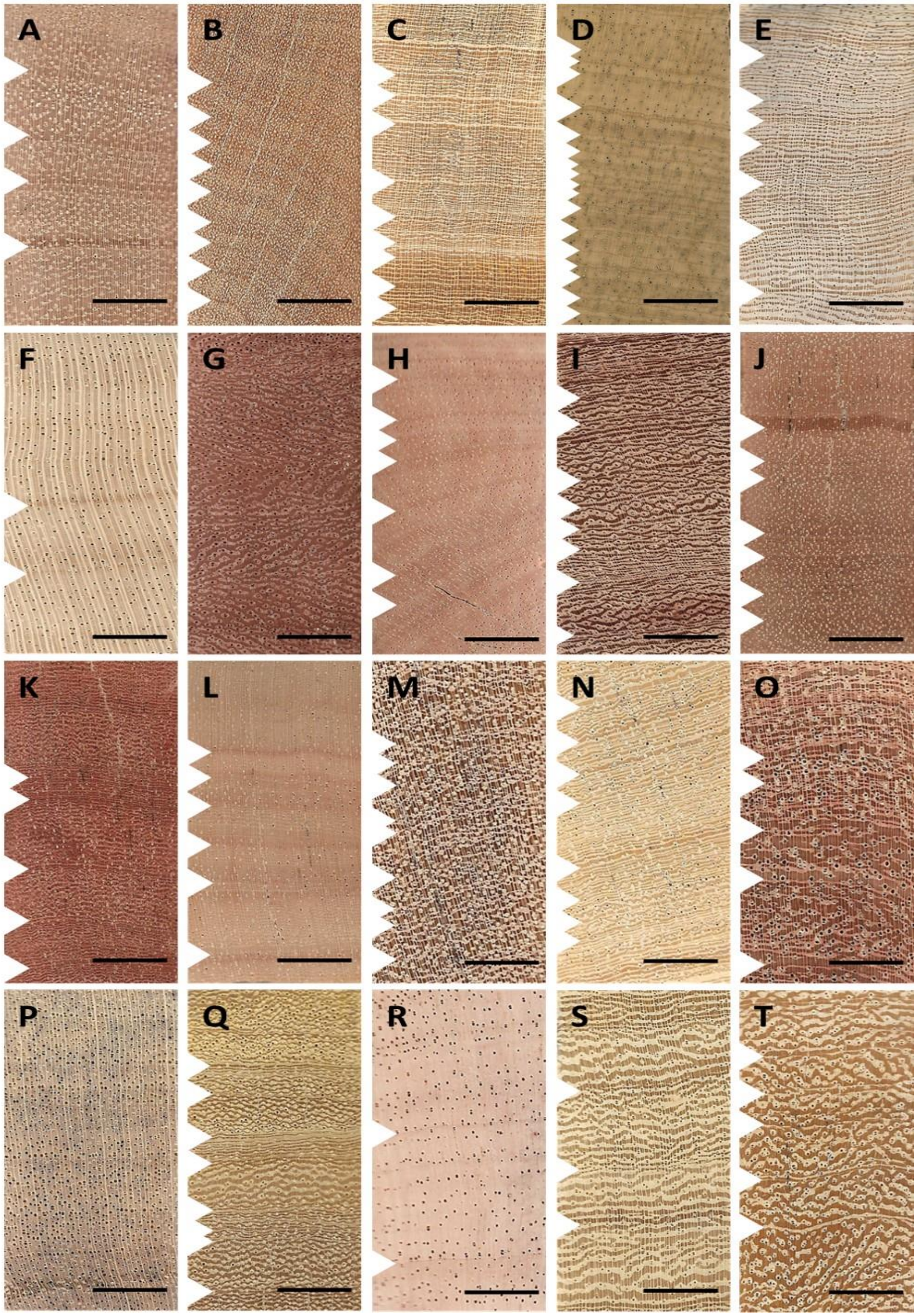


Fig. 3. Growth ring boundaries in the macroscopic cross-section: A) *Brosimun lactescens;* B) *Calycophyllum spruceanum*; C) *Clarisia racemosa*; D) *Diospyros* sp.; E) *Ficus insipida*; F) *Guatteria* sp; G) *Inga* sp.; H) *Luehea grandiflora*; I) NN; J) *Pouteria baenhiana*; K) *Pouteria* sp; (1). L) *Pouteria* sp; (2). M) *Pseudolmedia laevis*; N) *Pterocarpus rorhii*; O) *Senegalia* sp.; P) *Spondias mombin*; Q) *Terminalia oblonga*; R) *Virola elongata*; S) *Zanthoxylum acuminatum*; T) *Zygia* sp.; The scale bar is 5 mm. White triangle marks the limit of the growth ring.

The clear identification of growth ring boundaries is essential for dendrochronological studies, as it directly impacts the ability to accurately determine tree age, assess growth rates, and understand how trees respond to environmental variables such as climate fluctuations, flooding, and droughts. This makes the distinction of growth rings a critical tool for exploring past climate conditions and for monitoring long-term environmental changes in tropical forests (Brienen *et al*. 2009; Marcelo-Peña *et al*. 2020; Roquette *et al*. 2023).

Anatomical Boundary Description

In the trees analyzed in this study, the authors identified different criteria to define the growth ring boundaries. In a total of 15 species (75%), this boundary is characterized by changes in fiber wall thickness in latewood. In four species (20%), the boundary is defined by a combination of changes in fiber wall thickness in latewood and the presence of marginal parenchyma. Finally, in one species (5%), the growth ring boundary is exclusively based on the observation of marginal parenchyma (Table 2).

Beltrán and Valencia (2013) and Marcelo-Peña *et al*. (2020), in their studies on anatomical boundary descriptors of growth rings in Peru, align with these findings by observing that the majority of the studied species were characterized by changes in fiber wall thickness as a boundary. This suggests that tropical trees in Peru commonly exhibit this delineation in their growth rings. However, although changes in the fiber wall thickness can mark the growth ring boundary in some species, this criterion is not always sufficient, as in the case of *Spondias mombin*.

These investigations into the delineation and descriptors of growth rings in tropical forests can be linked to phenology (Bauer *et al*. 2020) and cambial activity (Marcati *et al*. 2006, 2008; Lisi *et al.* 2008). Phenological events, such as seasonal variations in temperature and rainfall, influence the timing of cambial activity, which in turn affects the formation of distinct anatomical boundaries in the wood (Marcati *et al*. 2006). Cambial activity, driven by these environmental cues, leads to the differentiation between earlywood and latewood, creating clear boundaries in species with pronounced growth rings (Lisi *et al.* 2008). Understanding these processes is essential for interpreting the relationship between tree growth and climatic conditions, especially in tropical forests where such patterns may vary.

The principal component analysis yielded notable outcomes in distinguishing the growth ring boundaries (Fig. 4) and describing the anatomical limits (Fig. 5). These findings prove highly valuable for species identification and understanding the potential of growth rings in future dendrochronological studies in a low terrace forest located in the Madre de Dios region, Peru.

In particular, certain species with high potential for dendrochronological studies were identified, such as *Terminalia oblonga*, *Zygia* sp., and *Zanthoxylum acuminatum*, due to the pronounced distinction in their growth rings, as well as variations in fiber wall thickness and marginal parenchyma. These two descriptors play a crucial role in the accurate delimitation of growth rings.

In contrast, it was observed that certain species have potential for dendrochronological studies: *Pouteria* sp. (1), NN, *Calycophyllum spruceanum*, *Brosimum lactescens*, *Luehea grandiflora*, *Pterocarpus rohrii*, *Virola elongata*, *Pouteria* sp., *Diospyros* sp., and *Ficus insipida* exhibited moderately distinct rings with changes in fiber wall thickness in latewood, while only *Virola elongata* showed marginal parenchyma.

In contrast, a group of species displayed rings that were slightly distinct, indistinct, or even absent, suggesting a limited potential for dendrochronological studies. This group includes *Clarisia racemosa*, *Pouteria baehniana*, *Pseudolmedia laevis*, *Inga* sp., *Senegalia* sp., *Guatteria* sp., and *Spondias mombin*.

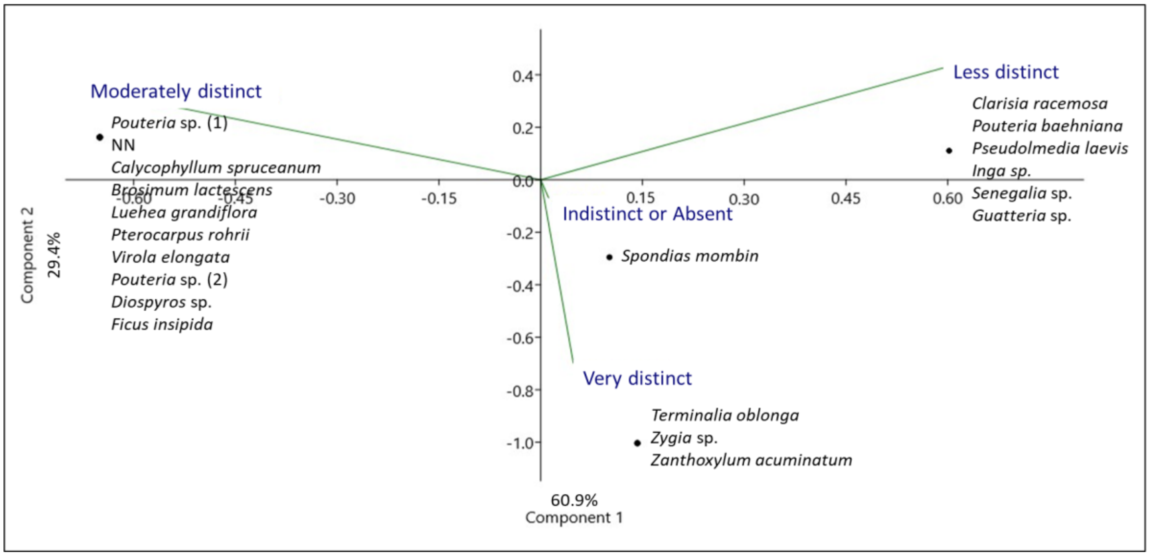


Fig. 4. Principal component analysis on the distinction of growth ring boundaries among the twenty studied tree species

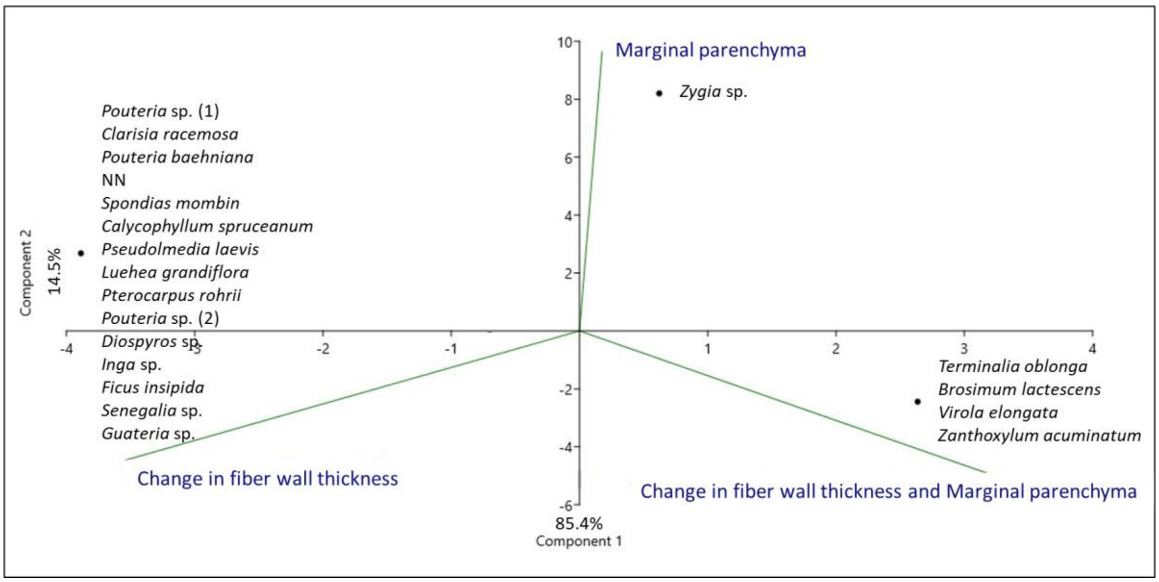


Fig. 5. Principal component analysis on the anatomical boundary descriptor of growth ring limits among the twenty studied tree species

The authors report that 65%, equivalent to 13 species found in a low terrace forest located in the Madre de Dios region, Peru, show potential for dendrochronological studies. Among these, 12 species have had their growth ring potential analyzed in other types of tropical forests (Worbes 2002; Schöngart *et al*. 2007, 2017; Beltrán and Valencia 2013; Marcelo-Peña *et al*. 2020).

Regarding the potential of forest species for dendrochronological studies, growth rings have been studied in the states of Cajamarca, La Libertad, Pasco, Ucayali, and Junín (Beltrán and Valencia 2013; Marcelo-Peña *et al*. 2020). However, there has been limited exploration in the Southeastern region of Peru, especially in forests partially submerged in water for parts of the year. It is valuable to collect wood samples in tropical areas experiencing seasonal changes to obtain precise data on tree rings. For instance, in areas affected by seasonal flooding, where cambial activity diminishes, these changes might be evident in wood cells, revealing variations in tree growth rings and highlighting their patterns.

In terms of using forest species in dendrochronological studies, growth rings have been examined across various regions in Peru such as Cajamarca, La Libertad, Pasco, Ucayali, and Junín (Beltrán and Valencia 2013; Marcelo-Peña *et al*. 2020). However, exploration in the southeastern part of the country and in forests partially submerged seasonally remains limited. It is crucial to collect wood samples in tropical areas with seasonal changes to obtain precise information about tree rings (Rozendaal and Zuidema 2011; Blagitz *et al*. 2019) For instance, in temporarily flooded forests where cambial activity reduces growth, this is reflected in wood cells, showcasing variations in growth rings and highlighting them as relevant indicators (Wimmer 2002; Schöngart *et al*. 2005).

Finally, regarding species with high potential for dendrochronological studies, there have been investigations on growth rings within the genera *Terminalia* and *Zanthoxylum*. Studies have been conducted on species like *Terminalia amazonica*, *T. catappa*, *T. guyanensis*, *T. quintalata*, *Zanthoxylum caribaeum*, *Z. kellermanii*, and Z. *rhoifolium* (Schöngart *et al*. 2017; Portal-Cahuana *et al*. 2023b). However, for *Zygia* sp., no research with species from this genus has been found.

CONCLUSIONS

1. The authors delineated the growth ring patterns in 20 tree species from a lowland terrace forest in Madre de Dios, Peru. Notably, eight previously undocumented species were discovered. These species exhibited a range of growth ring patterns, with 15% showing highly distinct rings, 50% displaying moderately distinct rings, 30% having rings with low differentiation, and 5% presenting indistinct or absent rings.
2. Criteria for defining growth ring boundaries varied: in 75% of the species, changes in the fiber wall thickness in latewood defined the boundary, while in 20%, it was a combination of these changes and the presence of marginal parenchyma. In the remaining 5%, the boundary was exclusively defined by observing marginal parenchyma.
3. Principal component analysis showcased noticeable differentiation in growth ring boundaries, as well as in anatomical descriptions of these limits. These outcomes are crucial for identifying species with high potential for dendrochronological studies, such as *Terminalia oblonga*, *Zygia* sp., and *Zanthoxylum acuminatum*, which exhibited distinct rings.
4. Conversely, some species showed rings with low differentiation or were absent, limiting their suitability for dendrochronological studies. These findings are essential for future dendrochronological investigations in the region and a better understanding of the ecological history of these forests.

5. This study contributes to a broader understanding of growth ring diversity in tropical forests in the Madre de Dios region, Peru. The findings offer valuable insights for future dendrochronological research and underscore the importance of environmental factors in influencing growth ring formation in these ecosystems.

ACKNOWLEDGMENTS

The author acknowledges the Universidad Nacional San Antonio Abad del Cusco - UNSAAC, for the funding provided for the research work of the Master's thesis in Ecology and Environmental Management.

REFERENCES CITED

Aragão, J. R. V., Zuidema, P. A., and Groenendijk, P. (2022). "Climate-growth relations of congeneric tree species vary across a tropical vegetation gradient in Brazil," *Dendrochronologia* 71, article ID 125913. DOI: 10.1016/j.dendro.2021.125913

Aragão, J., Groenendijk, P., and Lisi, C. S. (2019). "Dendrochronological potential of four neotropical dry-forest tree species: Climate-growth correlations in northeast Brazil," *Dendrochronologia* 53, 5-16. DOI: 10.1016/j.dendro.2018.10.011

Bauer, D., Schmitt, J. L., and 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. DOI: 10.1590/0102-33062019abb0395

Beltrán, L. A., and Valencia, G. M. (2013). "Anatomía de anillos de crecimiento de 80 especies arbóreas potenciales para estudios dendrocronológicos en la Selva Central, Perú [Anatomy of growth rings of 80 tree species potential for dendrochronological studies in the Central Amazon, Peru]," *Revista de Biología Tropical* 61(3), article 11778. DOI: 10.15517/rbt.v61i3.11778

Berthelot, J.-S., Saint-Laurent, D., Gervais-Beaulac, V., and Présent, A. (2015). "A comparison of the composition and diversity of tree populations along a hydrological gradient in floodplains (Southern Québec, Canada)," *Forests* 6(4), 929-956. DOI: 10.3390/f6040929

Best, I., Rengifo, H., Velarde, E., Loja, J. F., Portugal, A., Rengifo, P., Aguilar, L., Ramos-Escudero, F., and Muñoz, A. M. (2021). "Phenology of *Oenocarpus mapora* H. Karst in low-terrace and high-terrace forests of the Madre de Dios Region, Peru," *Forests* 12(10), article 1424. DOI: 10.3390/f12101424

Blagitz, M., Botosso, P. C., Longhi-Santos, T., and Bianchini, E. (2019). "Tree rings in tree species of a seasonal semi-deciduous forest in southern Brazil: Wood anatomical markers, annual formation and radial growth dynamic," *Dendrochronologia* 55, 93-104. DOI: 10.1016/j.dendro.2019.04.006

Brienen, R. J. W., Zuidema, P. A., and During, H. J. (2006). "Autocorrelated growth of tropical forest trees: Unraveling patterns and quantifying consequences," *Forest Ecology and Management* 237(1-3), 179-190. DOI: 10.1016/j.foreco.2006.09.042

Brienen, R. W., Lebrija, E., Acevedo, M., Pérez, E. A., Bongers, F., Meave, J. A., and Martínez, M. (2009). "The potential of tree rings for the study of forest succession in southern Mexico," *Biotropica*, 41(2), 186-195. DOI: 10.1111/j.1744-7429.2008.00462.x

Brienen, R., Schöngart, J., and Zuidema, P. A. (2016). "Tree rings in the tropics: Insights into the ecology and climate sensitivity of tropical trees," in: *Tropical Tree Physiology*, Vol. 6, G. Goldstein, and L. S. Santiago (eds.), Springer International Publishing, Cham, Switzerland, pp. 439-461. DOI: 10.1007/978-3-319-27422-5_20

Da Cunha Soares, C. (2017, November 25). "A importância da identificação de madeiras para a sustentabilidade da floresta Amazônica [The importance of wood identification for the sustainability of the Amazon Forest,]," in: *Anais do Fórum de Anatomistas de Madeira da Amazônia [Proceedings of the Forum of Wood Anatomists of the Amazon], I Fórum de Anatomistas de Madeira da Amazônia [1st Forum of Wood Anatomists of the Amazon]*, .

Féret, J.-B., and Asner, G. P. (2014). "Microtopographic controls on lowland Amazonian canopy diversity from imaging spectroscopy," *Ecological Applications* 24(6), 1297-1310. DOI: 10.1890/13-1896.1

Ferreira, C. A., Ribeiro, A. D. O., Urbinati, C. V., Duarte, P. J., Mori, F. A., and Moglio, B. V. (2020). "Comparative wood anatomy of two tropical species," *Scientia Agraria Paranaensis* 19(1), 43-51. DOI: 10.18188/sap.v19i1.22640

Groenendijk, P., Sass-Klaassen, U., Bongers, F., and 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. DOI: 10.1016/j.foreco.2014.03.037

Hammer (2001). "PAST: Paleontological Statistics software package for education and data analysis," *Palaeontologia Electronica* 4(1), article 9.

IAWA (1989). "IAWA list of microscopic features of hardwood identification," *IAWA Bull.* 10, 219-332.

Lisi, C. S., Fo, M. T., Botosso, P. C., Roig, F. A., Maria, V. R., Ferreira-Fedele, L., and 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.

Marcati, C. R., Angyalossy, V., and Evert, R. F. (2006). "Seasonal variation in wood formation of *Cedrela fissilis* (Meliaceae)," *IAWA Journal* 27(2), article 2. DOI: 10.1163/22941932-90000149

Marcati, C. R., Milanez, C. R., and Machado, S. R. (2008). "Seasonal development of secondary xylem and phloem in *Schizolobium parahyba* (Vell.) Blake (Leguminosae: Caesalpinioideae)," *Trees* 22(1), 3-12. DOI: 10.1007/s00468-007-0173-8

Marcelo-Peña, J., Roig, F., Goodwin, Z., and Tomazello, M. (2020). "Characterizing growth rings in the trees of Perú: A wood anatomical overview for potential applications in dendroecological-related fields," *Dendrochronologia* 2020, article ID 125728. DOI: 10.1016/j.dendro.2020.125728

Marcelo-Peña, J., Santini, L., and Tomazello, M. (2019). "Wood anatomy and growth rate of seasonally dry tropical forest trees in the Marañón River Valley, northern Peru," *Dendrochronologia* 55, 135-145. DOI: 10.1016/j.dendro.2019.04.008

Menezes, I. R. N., Aragão, J. R. V., Pagotto, M. A., and Lisi, C. S. (2022). "Teleconnections and edaphoclimatic effects on tree growth of *Cedrela odorata* L. in a seasonally dry tropical forest in Brazil," *Dendrochronologia* 72, article ID 125923. DOI: 10.1016/j.dendro.2022.125923

Myster, R. W. (2015). "Comparing and contrasting flooded and unflooded forests in the Peruvian Amazon: Seed rain," *New Zealand Journal of Forestry Science* 45(1), article 5. DOI: 10.1186/s40490-015-0033-z

Normand, S., Vormisto, J., Svenning, J.-C., Grández, C., and Balslev, H. (2006). "Geographical and environmental controls of palm beta diversity in paleo-riverine terrace forests in Amazonian Peru," *Plant Ecology* 186(2), 161-176. DOI: 10.1007/s11258-006-9120-9

Parolin, P., De Simone, O., Haase, K., Waldhoff, D., Rottenberger, S., Kuhn, U., Kesselmeier, J., Kleiss, B., Schmidt, W., Piedade, M. T. F., *et al*. (2004). "Central Amazonian floodplain forests: Tree adaptations in a pulsing system," *The Botanical Review* 70(3), 357-380. DOI: 10.1663/0006-8101(2004)070[0357:CAFFTA]2.0.CO;2

Portal, L. A., Huamán, B. A., Mamani, E. M., Palermo, P. de M., and Latorraca, J. V. (2021). "Dendrochronology of two forest species in the urban area of the city of Puerto Maldonado, Peru," *Floresta* 51(3), article 72410. DOI: 10.5380/rf.v51i3.72410

Portal-Cahuana, L. A., Fontana, C., Assis-Pereira, G., Groenendijk, P., Roig, F. A., and Tomazello-Filho, M. (2023a). "Thirty-four years of dendrochronological studies in Perú: A review of advances and challenges," *Dendrochronologia* 78, article ID 126058. DOI: 10.1016/j.dendro.2023.126058

Portal-Cahuana, L. A., Huamán-Guevara, R. M., and Colina-Nano, H. C. (2023b). "*Zanthoxylum rhoifolium* y su potencial para estudios dendrocronológicos en la Amazonía peruana [English translation]," *Ciência Florestal* 33(1), article e67592. DOI: 10.5902/1980509867592

Portal-Cahuana, L. A., Kohagura-Arrunátgui, J. A. H., Flores, C. E. M., Frías-Quiñones, T. de M., and Tomazello-Filho, M. (2023c). "Wood anatomical structure and density of *Tachigali aubl* species occurring in the southeastern Peruvian Amazon forest," *Revista Floresta* 53(2), 174-183. DOI: 10.5380/rf.v53i2.83247

Román-Dañobeytia, F., Huayllani, M., Michi, A., Ibarra, F., Loayza-Muro, R., Vázquez, T., Rodríguez, L., and García, M. (2015). "Reforestation with four native tree species after abandoned gold mining in the Peruvian Amazon," *Ecological Engineering* 85, 39-46. DOI: 10.1016/j.ecoleng.2015.09.075

Roquette, J. G., de Almeida Lobo, F., Vourlitis, G. L., Roig, F. A., Ortíz, C. E. R., Banga, N. M., Portal-Cahuana, L. A., and Tomazello-Filho, M. (2023a). "*Hymenaea stignocarpa* Mart. Ex Hayne growth–climate relationships are regulated by soil water saturation in Cerrado-Pantanal ecotone," *Dendrochronologia* 81, article ID 126130. DOI: 10.1016/j.dendro.2023.126130

Roquette, J. G., Ortega-Rodriguez, D. R., Portal-Cahuana, L. A., de Almeida Lobo, F., Hevia, A., Sánchez-Salguero, R., Pereira de Carvalho, H. W., and Tomazello-Filho, M. (2023b). "Environmental forensics evaluation of residual soybean sludge using trees of Brazilian savannah," *Environmental Nanotechnology, Monitoring and Management* 20, article ID 100814. DOI: 10.1016/j.enmm.2023.100814

Rozendaal, D. M., and Zuidema, P. A. (2011). "Dendroecology in the tropics: A review," *Trees* 25(1), 3-16. DOI: 10.1007/s00468-010-0480-3

Schöngart, J., Bräuning, A., Barbosa, A., Lisi, C., and de Oliveira, J. (2017). "Dendroecological studies in the neotropics: history, status and future challenges," in: *Dendroecology*, Vol. 231, M. Amoroso, L. Daniels, P. Baker, and J. Camarero (eds.), Springer International Publishing, Cham, Switzerland, pp. 35-73. DOI: 10.1007/978-3-319-61669-8_3

Schöngart, J., Piedade, M. T. F., Wittmann, F., Junk, W. J., and Worbes, M. (2005). "Wood growth patterns of *Macrolobium acaciifolium* (Benth.) Benth. (Fabaceae) in

Amazonian black-water and white-water floodplain forests," *Oecologia* 145(3), 454-461. DOI: 10.1007/s00442-005-0147-8

Schöngart, J., Wittmann, F., Worbes, M., Piedade, M. T. F., Krambeck, H.-J., and Junk, W. J. (2007). "Management criteria for *Ficus insipida* Willd. (Moraceae) in Amazonian white-water floodplain forests defined by tree-ring analysis," *Annals of Forest Science* 64(6), 657-664. DOI: 10.1051/forest:2007044

Terborgh, J., and Andresen, E. (1998). "The composition of Amazonian forests: Patterns at local and regional scales," *Journal of Tropical Ecology* 14(5), 645-664. DOI: 10.1017/S0266467498000455

Walter, H., and Lieth, H. (1960). "DoNum, Klimadiagram-Weltatlas [Climate Diagram World Atlas]," Gustav Fisch, (https://donum.uliege.be/handle/2268.1/7079), Accessed 05 June 2024.

Wimmer, R. (2002). "Wood anatomical features in tree-rings as indicators of environmental change," *Dendrochronologia* 20(1-2), 21-36. DOI: 10.1078/1125-7865-00005

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. DOI: 10.1078/1125-7865-00018

Article submitted: October 28, 2024; Peer review completed: December 9, 2024; Revised version received and accepted: December 10, 2024; Published: December 17, 2024.
DOI: 10.15376/biores.20.1.1482-1503

APPENDIX
Supplementary Information

Dendrochronological Potential of Tropical Species in the Peruvian Amazon: An Analysis in Flooded Forests of the Southeast

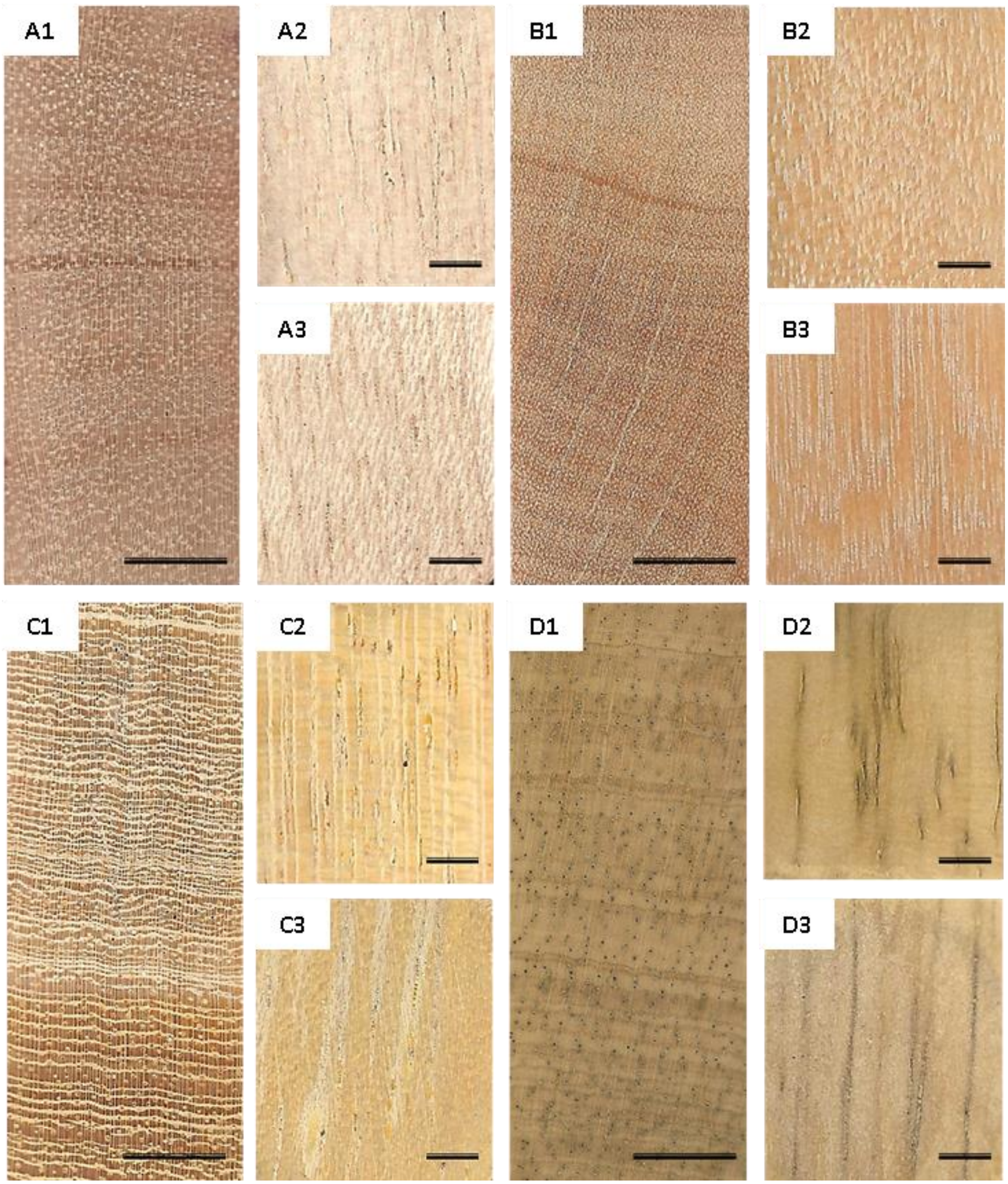


Fig. S1. Macroscopic sections of the species. A) *Brosimun lactescens* (Moore) C.C.Berg. B) *Calycophyllum spruceanum* Benth. C) *Clarisia racemosa* R.et P. D) *Diospyros* sp. Image 1: Cross-section, 2: Radial section, and 3: Tangential section. Note: The bar measures 20 mm in the cross-section, and 10 mm in the radial and tangential sections.

Fig. S2. Macroscopic sections of the species. E) *Ficus insipida* Willd. F) *Guatteria* sp. G) *Inga* sp. H) *Luehea grandiflora* C. Martius cf. Image 1: Cross-section, 2: Radial section, and 3: Tangential section. Note: The bar measures 20 mm in the cross-section, and 10 mm in the radial and tangential sections.

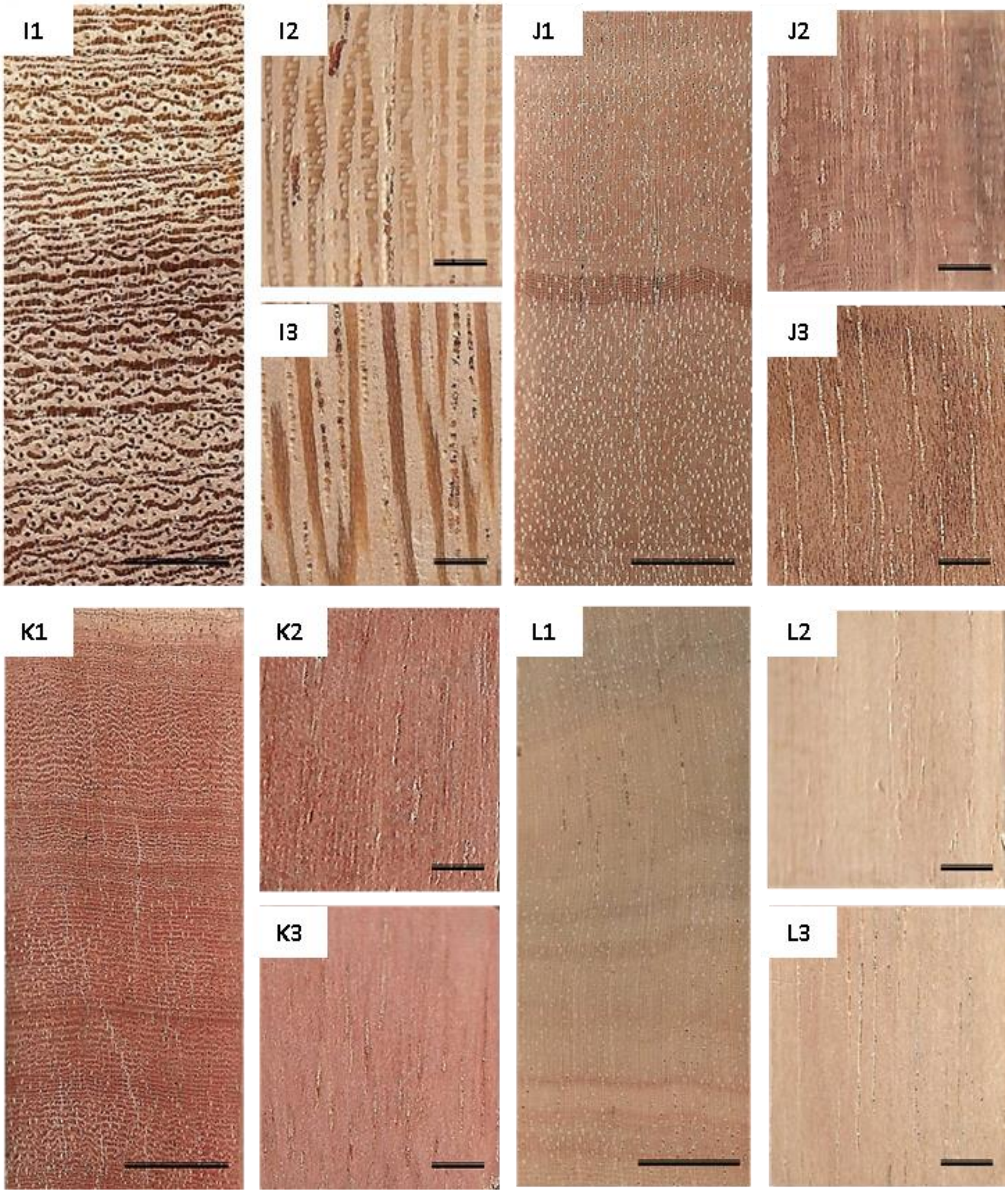


Fig. S3. Macroscopic sections of the species. I) NN J) *Pouteria baenhiana* Monachino. K) *Pouteria* sp. (1). L) *Pouteria* sp. (2). Image 1: Cross-section, 2: Radial section, and 3: Tangential section. Note: The bar measures 20 mm in the cross-section, and 10 mm in the radial and tangential sections.

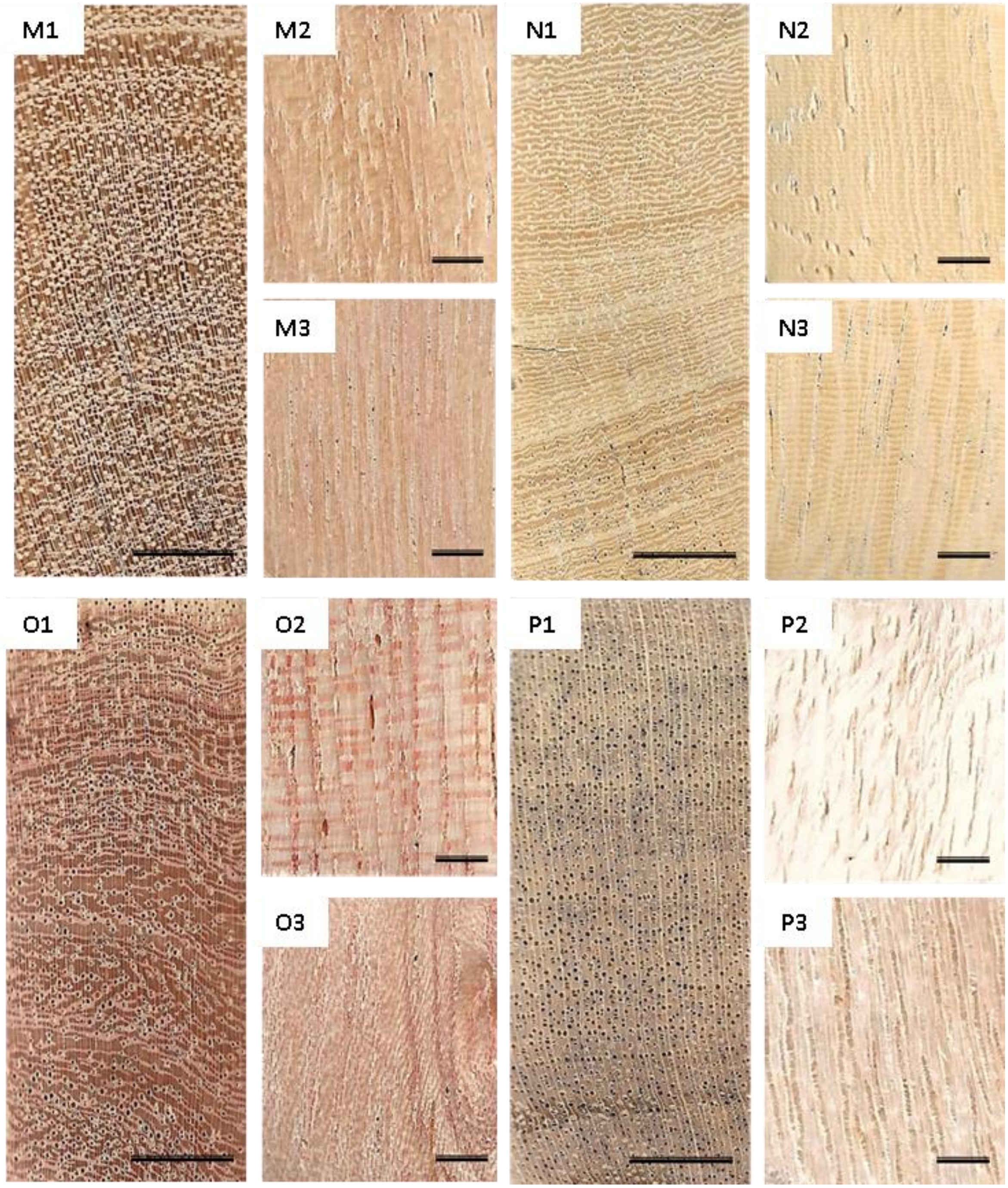


Fig. S4. Macroscopic sections of the species. M) *Pseudolmedia laevis* (R. et P.) J.F. N) *Pterocarpus rorhii* Vahl. O) *Senegalia* sp. P) *Spondias mombin* L. Image 1: Cross-section, 2: Radial section, and 3: Tangential section. Note: The bar measures 20 mm in the cross-section, and 10 mm in the radial and tangential sections.

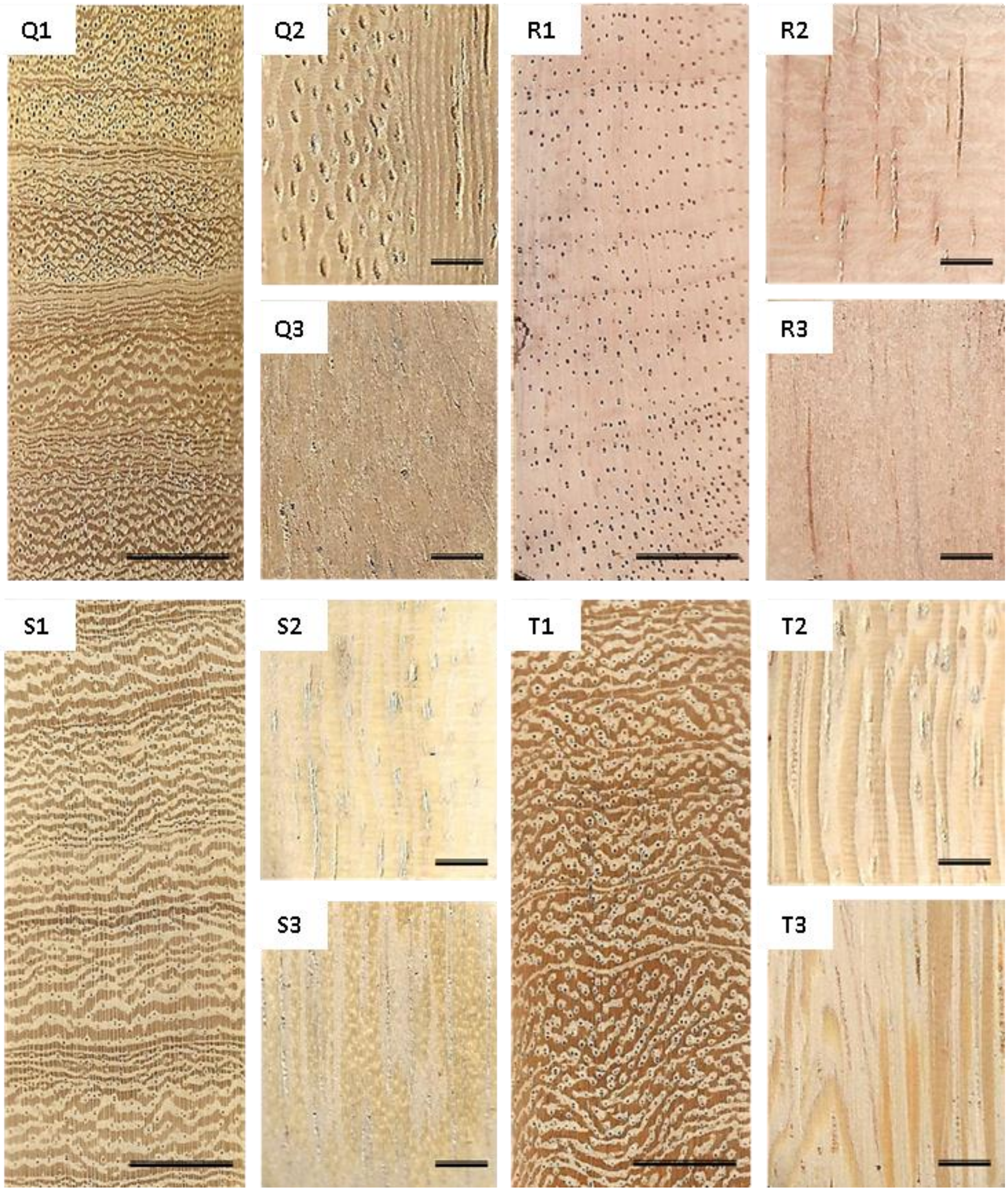


Fig. S5. Macroscopic sections of the species. Q) *Terminalia oblonga* (R.et P) Steud. R) *Virola elongata* (Benth.) Warb. S) *Zanthoxylum acuminatum* (Sw.) Sw. T) *Zygia* sp. Image 1: Cross-section, 2: Radial section, and 3: Tangential section. Note: The bar measures 20 mm in the cross-section, and 10 mm in the radial and tangential sections.

Table S1. Popular Name and Main Uses of the Wood of the 20 Forest Species in the Flooded Forest of Southeastern Peru

Species	Botanical family	Popular name	Main uses wood
Brosimum lactescens	Moraceae	Manchinga	Construction, Formwork, Drawers. [b]
Calycophyllum spruceanum	Rubiaceae	Capirona	Floors, sleepers, carriages, and heavy structures.[a]
Clarisia racemosa	Moraceae	Mashonaste	Buildings, beams, columns, floors, furniture, cladding, and parquet.[b]
Diospyros sp.	Ebenaceae	Moena Negra	Sawing, turning.[c]
Ficus insipida	Moraceae	Ojé	Doors, wood veneers, and boxes.[d]
Guatteria sp.	Annonaceae	Carahuasca	Housing general, fittings, packing.[c]
Inga sp.	Fabaceae	Shimbillo	Plywood and veneer, turning, packing.[c]
Luehea grandiflora	Malvaceae	Payaso	Furniture, veneer, packaging, handicrafts, pencil, matches.[c]
NN	Fabaceae	Huayruro negro	
Pouteria baenhiana	Sapotaceae	Caimito	Postes, vigas, chapas.[c]
Pouteria sp. *(1)*	Sapotaceae	Quinilla	Postes, vigas, chapas.[c]
Pouteria sp. *(2)*	Sapotaceae	Caimito	Postes, vigas, chapas.[c]
Pseudolmedia laevis	Moracea	Chimicua	Bridges, poles, stakes posts, crossarms, piers.[c]
Pterocarpus rorhii	Fabaceae	Palisangre	Beams, panelling, fittings.[c]
Senegalia sp.	Fabaceae	Pashaco	…
Spondias mombin	Anacardiaceae	Ubos	Plywood, aeromodelling, models. [e]
Terminalia oblonga	Combretaceae	Yacushapana	Carpentry, parquet, decorative veneers.[e]
Virola elongata	Myristicaceae	Cumala	Cladding, Packaging, Furniture.[c]
Zanthoxylum acuminatum	Rutaceae	Limoncillo	Tablas, Carcassing.[b]
Zygia sp.	Fabaceae	Tigre caspi	…

[a] [1]; [b] [2]; [c] http://www.tropicaltimber.info/es/; [d] [3]; e [4].

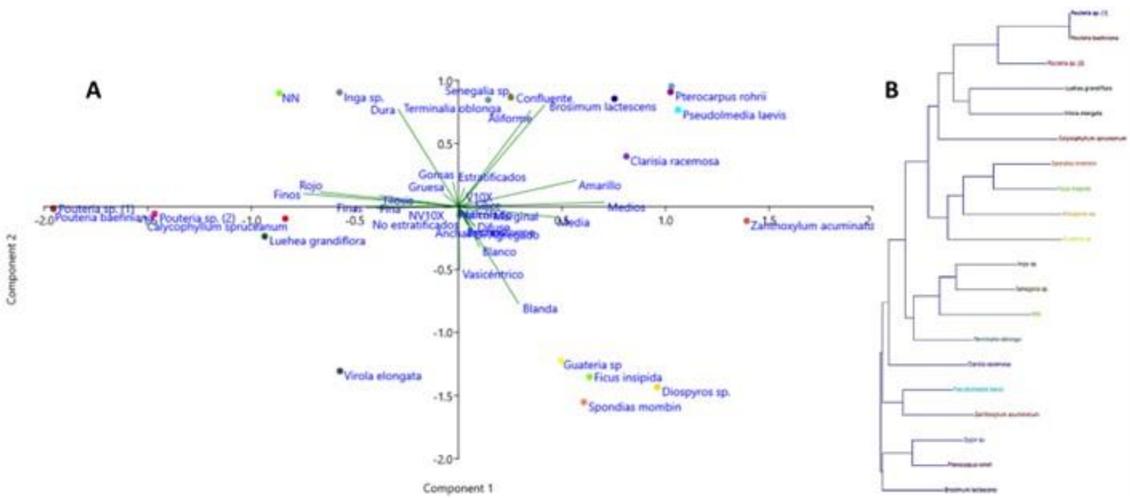


Fig. S6. A) Principal Component Analysis. **B)** Clustering of the twenty tree species in the flooded forest of southeastern Peru.

In Fig. S6, it is evident that PCA analysis provides a visual representation of the similarity among tree species in a reduced coordinate space, while clustering allows the identification and characterization of groups of species with similar anatomical features. Combining these approaches offers a more comprehensive understanding of the diversity and variability of tree species based on their wood anatomy.

REFERENCES

1. Ugarte J., and Mori, I. (2017). "Guía para la identificación de la madera de 50 especies forestales del Perú," 1a. Lima, Perú: *Centro de Innovación Productiva y Transferencia Tecnológica de la Madera - CITEmadera*; 2017. 98 p.

2. MAE M del A del E, FAO O de las NU para la A y la A. "Propiedades Anatómicas, Físicas y Mecánicas de 93 Especies Forestales," Quito, Ecuador; 2014. 171 p.

3. Ferreira C., and Guía, I. G. (2022). "de anatomía e identificación de 50 especies maderables comerciales en Selva Central, Perú," Huancayo, Perú: Universidad Continental; 2022. 164 p.

4. Rodríguez, M., and Sibille, A. (1996). "Manual de identificación de especies forestales de la subregión andina: Proyecto PD 150/91 Rev. 1 (I) «Identificación y Nomenclatura de las Maderas Tropicales Comerciales en la Subregión Andina»," Lima, Perú: Ministerio de Agricultura, INIA, Instituto Nacional de Investigación Agraria, Organización Internacional de las Maderas Tropicales, OIMT; 1996.