Wood Anatomy and Growth-ring Boundaries of Selected Miombo Woodland Tree Species in Eastern Tanzania

Tulloh Zahabu
tulloh.zahabu@sua.ac.tz

Sokoine University of Agriculture
Sami Madundo
Sokoine University of Agriculture
Fortunatus Makonda
Sokoine University of Agriculture

Research Article

Keywords: Dendrochronology, Growth-rings, Increment core, Miombo woodlands, Wood anatomy

Posted Date: April 10th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9062947/v1

Additional Declarations: No competing interests reported.

Abstract

Dendrochronological studies in tropical regions remain limited due to uncertainties surrounding the formation and distinctiveness of annual growth rings. This study assessed the growth-ring distinctiveness and wood anatomical characteristics of selected dominant Miombo woodland tree species in eastern Tanzania, to evaluate their dendrochronological potential. The study was conducted in Kitulanghalo Forest Reserve, which is located in Morogoro Rural District, in Morogoro Region. Non-destructive increment core sampling was used to extract samples from adult individuals of *Brachystegia boehmii*, *Julbernardia globiflora*, *Senegalia nigrescens*, *Combretum molle*, and *Combretum zeyheri*. Macroscopic examination of polished transverse surfaces and microscopic analysis of histological sections were employed to describe growth-ring boundaries and associated anatomical features. The results revealed that *Brachystegia boehmii*, *Julbernardia globiflora*, and *Senegalia nigrescens* form distinct and continuous growth-rings, marked by changes in vessel size, vessel frequency, fibre characteristics, and terminal parenchyma, indicating strong dendrochronological potential. In contrast, *C. molle* and *C. zeyheri* displayed indistinct or discontinuous growth rings, limiting their suitability for reliable age determination. The study concludes that several Miombo species in eastern Tanzania are suitable for dendrochronological studies, while others require cautious interpretation. These findings provide a foundation for future cross-dating, climate growth analyses, and the development of sustainable forest management and harvesting strategies in Miombo woodlands.

1. Introduction

Dendrochronology, the science of dating and studying annual growth rings in trees, has become a powerful tool to study climate change [1], [2], [3], [4]. It provides important information for reconstructing past climate and assessing the impacts of climate change as well as disturbance events on tree growth [5]. In order to understand the historical behaviour of individual tree species and have insight on the potential effects of climate change, trees must show distinct annual growth-rings [6], [7]. This science is extensively developed and used in temperate regions where native tree species exhibit clear annual growth-rings [8]. Tropical dendrochronology, on the other hand, has had limited progress due to a lack of known tree species that form clear growth-rings [9].

The distinctiveness of growth-ring boundaries in the tropics varies widely in terms of wood anatomy and visibility [10]. This distinctiveness often depends on a number of environmental factors including water availability, temperature, and light intensity [1]. While some tree species show distinct, indistinct, or even absent growth-rings, others in regions with pronounced seasonality, such as the Miombo woodlands in southern Africa, show greater potential for ring formation. This potential is necessary for sustainable forest management, as the absence of reliable age determination methods prevents the ability to determine sustainable cutting rotations and implement long-term management plans. This challenge is particularly for Miombo woodland tree species [3], yet in Tanzania, limited studies have systematically assessed the growth-ring distinctiveness of these ecologically and economically important trees [11].

Despite the limited research in Tanzania, studies from other parts of Africa have shown that Miombo tree do form growth rings. In Zambia, were using oldest and dominant Miombo tree species which were *Julbernardia* (*Julbernardia paniculata*) and *Brachystegia* species (*Brachystegia longifolia* and *Brachystegia boehmii*) [12], while research in Namibia focused on *Dichrostachys cinerea* and *Senegalia mellifera* [13], [14]. In South Central Africa and Angola, *Brachystegia spiciformis* has been successfully dated [15]. These findings suggest that the dendrochronological potential of Tanzanian Miombo tree species is high but remains unexplored.

This study therefore aimed at determining whether dominant Miombo tree species form distinct and clearly visible growth rings. The specific objectives of this study were to; (i) examine the growth ring distinctiveness of selected dominant Miombo tree species (*Brachystegia boehmii*, *Julbernardia globiflora*, *Senegalia nigrescens*, *Combretum molle*, and *Combretum zeyheri*) (ii) to describe the macro and microscopic anatomical characteristics of growth rings in selected Miombo woodland tree species. The results of this study contribute to the list of tree species with dendrochronological potential in tropical Africa.

2. Materials and methods

2.1 Study Site

The study was carried out in the Sokoine University of Agriculture - Kitulanghalo Forest Reserve (SUA-KFR), located in the Morogoro Region of Tanzania (Fig. 1). The reserve is situated at approximately 6°52'S and 37°38'E, at an elevation of about 300 m above sea level. KFR covers an area of roughly 1,700 ha and lies around 50 km northeast of Morogoro City and about 150 km west of Dar es Salaam. Of the total reserve area, 1,200 ha are managed by the Tanzania Forestry Services Agency (TFS), while the remaining 500 ha are under the administration of Sokoine University of Agriculture (SUA) and are primarily used for research and training activities.

Vegetation at KFR is classified as dry miombo woodland, receiving an average annual rainfall of 500–750 mm. The area experiences a semi-arid climate, with transitional characteristics toward coastal mosaic woodlands. The vegetation structure comprises three main canopy layers. The upper canopy is dominated by *Julbernardia globiflora* and *Brachystegia boehmii*, while the middle and lower strata consist mainly of short to medium-sized, often multi-stemmed species such as *Combretum*, *Dalbergia*, and *Commiphora*. Along the northern boundary of the reserve, riverine zones support evergreen species including *Manilkara* (*M. mochisia*, *M. discolor*) and *Maytenus* species [16], [17].The dry season lasts between four and seven months, and mean monthly temperatures range from 21°C to 25°C [17].

2.2 Field Sampling and Wood Collection

A purposive sampling design was utilized in this study, in which dominant tree species (Table 1) were selected for non-destructive sampling [18]. Wood cores of 5 mm [19] diameter were collected at breast height with an increment borer (Haglöf, Långsele, Sweden) from 62 trees, where by for dendrochronology core sampled trees should range at least from 10 trees [20]. For each tree sampled, two cores were obtained in opposite directions from the stem [21]. All core samples were immediately placed into labelled plastic straw tubes for transport to the wood science laboratory [22].

Table 1
Selected dominant Miombo tree species at KFR for dendrochronological assessment.

Species	Local name	n	Cores
Brachystegia boehmii Taub.	*Myombo*	15	30
Julbernardia globiflora (Benth.) Troupin	*Mhondolo*	15	30
Senegalia nigrescens (Oliv.) P.J.H.Hurter	*Mkambala*	12	24
Combretum zeyheri Sond.	*Mlama mweupe*	10	20
Combretum molle R.Br. ex G.Don	*Mlama mweusi*	10	20

Source for local names: Msanya, Kimaro & Shayo-Ngowi (1995); Obiri, Hall & Healey (2010) and Njoghomi (2021).

2.3 Sample Preparation and Anatomical Analysis

2.3.1 Macroscopic Analysis

For macroscopic description, all core samples were air dried, mounted and sanded progressively with micro abrasive paper (up to 1200 grit) and polished until individual fibres within annual rings will be visible to the naked eye following standard dendrochronological procedures [22], [23], [24]. The transverse surfaces of the wood cores, were photographed using a camera attached to a stereomicroscope. We looked for general characteristics of well-marked and more complex rings.

2.3.2 Microscopic Analysis

For the microscopic analysis, wood blocks (approximately $1cm^3$) were taken from five representative trees per species (n = 25 blocks). We produced histological slides, 10–30 µm thick, using a sliding microtome for each tree species in the three anatomical planes (transverse (TS), radial longitudinal (RLS) and tangential longitudinal (TLS) sections) (Johansen 1940; Sass 1958). Sections were stained with safranin and Astra blue, dehydrated through an ethanol series (50% and 100%), and permanently mounted using a UV-based mounting medium [25], [26]. In addition, wood specimens were macerated in diluted Nitric acid to isolate individual cells for measurement [27]. Digital images were captured by a camera (AmScope MU Series 10.0MP USB 3.0 Color CMOS C) attached to a light microscope.

2.4 Statistical Analyses

Cell dimensions were measured from the digital images using the open-source digital imaging software, ImageJ (version 1.52a for Windows). For each species, 10 measurements per anatomical feature were taken across rings per section. Quantitative wood anatomical descriptors follow the IAWA Committee 1989 [28].

3. Results

3.1 Macroscopic Wood Description and Growth-Ring Distinctiveness

Macroscopic examination of polished transverse surfaces revealed clear differences in growth ring distinctiveness among the studied Miombo woodland species. All tree species were found to have diffuse porous wood. Based on the visibility, continuity, and sharpness of ring boundaries, species could be grouped into two groups: those with distinct growth rings and those with indistinct or weakly defined growth rings.

Three species *Brachystegia boehmii*, *Julbernardia globiflora*, and *Senegalia nigrescens* exhibited distinct growth rings (Fig. 2). In these species, ring boundaries and rays were visible to the naked eye or under low magnification and could be traced continuously along the transverse surface of the increment cores. Growth ring boundaries were primarily marked, these anatomical transitions resulted in sharp and consistent ring delimitation from bark to pith.

In contrast, *Combretum molle* and *Combretum zeyheri* displayed indistinct or weakly defined growth rings (Fig. 2). Ring boundaries in these species were difficult to identify consistently and were often discontinuous or locally absent. Growth increments were mainly distinguished by subtle differences in vessel distribution rather than by pronounced terminal parenchyma marking. In several samples, growth rings appeared irregular or wedging, complicating macroscopic ring identification. The darker heartwood contrasted with the lighter sapwood, but this did not aid in identifying individual growth increments.

3.2 Microscopic Anatomical Characteristics

Microscopic analysis provided detailed understanding into the anatomical features underlying the observed macroscopic differences. Quantitative measurements are summarized in Table 2, and representative images are shown in Fig. 3.

3.2.1 Vessel and Ray Characteristics

Vessel and ray features varied considerably among the species (Table 2). *Senegalia nigrescens* and *Combretum zeyheri* had the largest mean vessel diameters (136 µm), while *Combretum molle* had the smallest (91.1 µm). Vessel frequency was highest in *C. molle* (12 vessels/mm²) meaning many vessels per unit area, which makes the wood appear uniform and reduces ring contrast and lowest in *Brachystegia boehmii* (4.8 vessels/mm²) this supports distinct ring visibility. Ray structure also differed significantly; *S. nigrescens* had the tallest rays (mean 398.4 µm) which may increase visibility of anatomical patterns, but the lowest frequency (8.8 rays/mm), whereas *C. zeyheri* had the most frequent rays (16.2 rays/mm), but also *J. globiflora* had wider rays (32.9 µm) which may improve the contrast and structural organization in wood, which can assist in recognizing ring boundaries.

3.2.2 Microscopic Markers of Growth-Ring Boundaries

The anatomical features marking growth-ring boundaries explained the macroscopic observations. In the species with distinct rings, the boundaries were clearly defined by a combination of features. In *B. boehmii*, the boundary was marked by a decrease in vessel diameter and frequency, accompanied by terminal parenchyma. In *S. nigrescens*, rings were demarcated by terminal parenchyma and a clear variation in vessel size. For *J. globiflora*, the microscopic markers were more visible, with only slight changes in vessel distribution but also marked with terminal parenchyma, which corresponded to its rings being visible even under the microscope.

For the Combretum species, microscopic examination revealed features that were not always macroscopically apparent. In *C. molle* and *C. zeyheri*, boundaries were marked by terminal parenchyma bands and changes in vessel arrangement. However, these features were weak and did not create a strong visual contrast, explaining why the rings appeared indistinct or discontinuous during macroscopic examination.

Table 2
Quantitative microscopic wood anatomical characteristics of selected Miombo woodland tree species from KFR, including vessel dimensions and ray characteristics.

Vessel Diameter	***Brachystegia boehmii***	***Julbernardia globiflora***	***Senegalia nigrescens***	***Combretum molle***	***Combretum zeyheri***
	120.2(100.5–143, ± 15.6)	**123.2(51.8-200.1, ± 37)**	**136(84.7-205.5, ± 38.8)**	**91.1(56.9–128, ± 45.1)**	**136(75-242.7, ± 70.3)**
Vessel Frequency	4.8(4–6, ± 0.8)	5.9(4–8, ± 1.6)	6.2(4–8, ± 1.6)	12(9–14, ± 2.3)	10.8(4–12, ± 2.7)
Ray Number	10.4(5–15, ± 1.4)	9.4(7–19, ± 2.2)	8.8(5–11, ± 1.9)	14.8(12–19, ± 2.8)	16.2(13–18, ± 1.9)
Ray Height	263.9(198.6-310.1, ± 145.3)	361.7(114–404, ± 132.5)	398.4(199.9-791.2, ± 183.8)	226.1(94.4–265, ± 117.3)	206(187.3-267.8, ± 115.9)
Ray Width	25.3(12.9–33.6, ± 7.9)	32.9(22.2–50, ± 7.6)	29.5(13.9–47.2, ± 11.6)	17.5(9.2–21.9, ± 2.8)	16.1(9.7–18.6, ± 4.3)

Mean (range ± SD) values of quantitative microscopic wood anatomical features

4. Discussion

4.1 Growth-Ring Distinctiveness and Dendrochronological Potential

A certain degree of difficulty was present in detecting the growth-ring boundaries in tropical species of several of the study species due to irregular rainfall patterns and anatomical variability [29]. The most frequent problems related to ring boundary identification were ring wedging, indistinct boundaries, and/or occasionally fire scars [30]. It has been noted that tropical ring boundaries tend to be clearer and more distinct in regions that exhibit a unimodal rainfall distribution [20]. The single annual rainy season allows for a more pronounced dry period in which the ring boundary can be formed.

Despite difficulties, several of the species showed a useful potential for dendrochronology. These species include *Brachystegia boehmii, Julbernardia globiflora*, and *Senegalia nigrescens* exhibited distinct and continuous growth rings, while *Combretum molle* and *Combretum zeyheri* showed indistinct or irregular boundaries. This variation aligns with the general agreement that, not all tropical species form anatomically distinct annual rings, even under similar climatic regimes [1].

These findings are consistent with earlier work in Zambia, where *Julbernardia paniculata* and *Brachystegia longifolia* were identified as reliable species for dendrochronological analysis [3], [12]. The anatomical transitions observed in this study particularly the reduction in vessel diameter mirror diagnostic traits reported in tropical dendrochronology research [1], [31].

The presence of distinct growth rings in *B. boehmii* and *J. globiflora* is consistent with dendrochronological studies conducted in Miombo woodlands of Zambia, Angola, and south-central Africa, where species of *Brachystegia* and *Julbernardia* have been shown to form recognizable annual increments linked to seasonal climate variability [3], [6], [15], [32]. Trouet *et al.*, (2010) [15] demonstrated that *Brachystegia spiciformis* in South Central Africa forms annual rings that correlate with rainfall variability, while Chiteculo & Surovy (2018) [33] confirmed similar patterns in Angola. In Namibia, Shikangalah *et al.*, (2020) [13] found that species such as *Dichrostachys cinerea* and *Senegalia mellifera* also produce distinct rings under semi-arid conditions. These findings reinforce the growing body of evidence that Miombo woodlands, despite being tropical systems, offer favorable conditions for growth ring formation due to their prolonged dry season.

In contrast, the indistinct rings observed in *Combretum* species echo earlier reports from southern Africa, where *Combretum imberbe* displayed irregular growth increments, complicating age determination [34]. This suggests that while *Combretum* species may exhibit anatomical markers such as terminal parenchyma, their discontinuous boundaries limit their dendrochronological utility.

4.2 Anatomical Basis for Growth-Ring Formation

Microscopic analysis showed that vessel size, frequency, and ray structure are critical markers of growth ring boundaries. In this study, most of the species showed diffuse porosity, a feature typical of tropical forest species with or without visible growth-ring boundaries [10], [35], [36], [37]. The study of Santos-

Malengue *et al.*, (2023) [39] in Angolan miombo woodlands on *B. boehmii and J. globiflora*, both species formed diffuse-porous wood with distinct ring boundaries delimited by terminal parenchyma, where diffuse-porous vessel distribution was consistently associated with distinct ring boundaries. In addition to diffuse porosity, several species in this study showed an alignment of the vessels in diagonal or radial rows, which is also characteristic of tropical species [37]. Also, dendritic patterns and tangential bands of vessels occurred that do not necessarily involve contact between vessels [40], [41], [42].

Terminal parenchyma was particularly important in determining ring boundaries in *S. nigrescens* and both *Combretum* species. Similar observations have been reported for Miombo species in Angola and Zambia, where terminal parenchyma bands reflect cambial dormancy at the end of the growing season [6], [39]. However, the presence of microscopic markers alone does not guarantee dendrochronological usefulness, as laterally discontinuous or irregular boundaries may prevent reliable cross-dating [43].

5. Conclusion

This study provides the first systematic assessment of growth-ring distinctiveness in dominant Miombo tree species of eastern Tanzania. Our results confirm that *B. boehmii*, *J. globiflora*, and *S. nigrescens* possess anatomical markers that result in distinct growth rings, marking them as high-potential candidates for developing dendrochronological chronologies in the region. These chronologies are essential for reconstructing past climate variability and for establishing sustainable forest management plans, including determining optimal cutting rotations.

Conversely, the challenges identified with *C. molle* and *C. zeyheri* present the need for careful species selection in tropical dendrochronology. By adding these Tanzanian species to the list of evaluated trees, this research contributes valuable knowledge to the broader effort to expand dendrochronology in tropical Africa. Future work should focus on cross-dating these species to confirm their annual nature and to begin building the long-term climate records needed for effective conservation and management of the Miombo woodlands.

Declarations

Acknowledgements

The authors thank the College of Forestry, Wildlife and Tourism at Sokoine University of Agriculture, for access to the Wood Science Laboratory, and the management of Kitulanghalo Forest Reserve for support during data collection.

Author Contributions

Conceptualization: TYZ; Methodology: TYZ, SDM, and FBM; Data collection: TYZ, and SDM; Investigation: TYZ; Formal Analysis: TYZ; Writing – Original draft: TYZ; Writing – Review and Editing: TYZ, SDM, and FBM. All authors read and approved the final version of the manuscript.

ORCID

Tulloh Y. Zahabu https://orcid.org/0009-0001-8287-9156

Sami D. Madundo https://orcid.org/0000-0002-4661-8629

Fortunatus B. Makonda https://orcid.org/0009-0007-3077-9472

Declaration of conflicting Interest

The authors have no conflict of interest to declare.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not for profit sectors.

Ethics and consent to participate

Tree sampling was conducted using increment borers to collect wood cores from living trees, which is a non-destructive sampling technique commonly used in dendrochronological studies. The collection was carried out in compliance with all relevant local and national guidelines for the research use of plant material. Permission to conduct sampling within the forest reserve was issued by the Tanzania Forestry Services Agency (TFS) under permit Ref. No. DA.111/239/01/84. All wood core samples are stored in the Wood Science Laboratory at Sokoine University of Agriculture, Tanzania, under the reference ID: KFR/WC/001/2025. Also, voucher specimens of the studied species were deposited at the Herbarium of Sokoine University of Agriculture, Tanzania, under voucher numbers KFR/BRA/037 (*Brachystegia boehmii*), KFR/JUL/039 (*Julbernardia globiflora*), KFR/SN/038 (*Senegalia nigrescens*), KFR/CM/041 (*Combretum molle*), and KFR/CZ/040 (*Combretum zeyheri*). Species identification was performed by Mr. Amani Mpwai a botanist from Kitulanghalo Forest Reserve.

Data availability statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. M. Worbes, “One hundred years of tree-ring research in the tropics - A brief history and an outlook to future challenges,” *Dendrochronologia*, vol. 20, no. 1–2, pp. 217–231, Jan. 2002, doi: 10.1078/1125-7865-00018.
2. J. C. Balouet, K. T. Smith, D. Vroblesky, and G. Oudijk, “Use of dendrochronology and dendrochemistry in environmental forensics: Does it meet the Daubert criteria?,” *Environ. Forensics*, vol. 10, no. 4, pp. 268–276, Dec. 2009, doi: 10.1080/15275920903347545.
3. S. Syampungani, C. Geledenhuys, and P. W. Chirwa, “Age and growth rate determination using growth rings of selected miombo woodland species in charcoal and, slash and burn regrowth stands in Zambia,” *Ecol. Nat. Environ.*, vol. 2, no. 8, pp. 167–174, 2010, [Online]. Available: http://repository.up.ac.za/bitstream/handle/2263/16307/Syampungani_Age(2010).pdf?sequence=1
4. L. Dinca, C. Constandache, G. Murariu, M. M. Antofie, T. Draghici, and I. Bratu, “Environmental Archaeology Through Tree Rings: Dendrochronology as a Tool for Reconstructing Ancient Human–Environment Interactions,” Nov. 01, 2025, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/heritage8110482.
5. S. Shah, “forest growth TREE RINGS FOR THE ASSESSMENT OF THE POTENTIAL,” no. January 2015, 2016, doi: 10.15666/aeer/1301.
6. J. Ngoma, J. H. Speer, R. Vinya, B. Kruijt, E. Moors, and R. Leemans, “The dendrochronological potential of Baikiaea plurijuga in Zambia,” *Dendrochronologia*, vol. 41, pp. 65–77, 2017, doi: 10.1016/j.dendro.2016.05.002.
7. A. Gauli, P. R. Neupane, P. Mundhenk, and M. Köhl, “Effect of Climate Change on the Growth of Tree Species: Dendroclimatological Analysis,” *Forests*, vol. 13, no. 4, Apr. 2022, doi: 10.3390/f13040496.
8. P. Groenendijk *et al.*, “The importance of tropical tree-ring chronologies for global change research,” *Quat. Sci. Rev.*, vol. 355, no. February, 2025, doi: 10.1016/j.quascirev.2025.109233.
9. A. Quesada-Román, J. A. Ballesteros-Cánovas, S. St. George, and M. Stoffel, “Tropical and subtropical dendrochronology: Approaches, applications, and prospects,” *Ecol. Indic.*, vol. 144, no. May, 2022, doi: 10.1016/j.ecolind.2022.109506.
10. Y. Tarelkin, C. Delvaux, M. De Ridder, T. El Berkani, C. De Cannière, and H. Beeckman, “GROWTH-RING DISTINCTNESS and BOUNDARY ANATOMY VARIABILITY in TROPICAL TREES,” *IAWA J.*, vol. 37, no. 2, pp. 275–294, 2016, doi: 10.1163/22941932-20160134.
11. V. Trouet, K. Haneca, P. Coppin, and H. Beeckman, “TREE RING ANALYSIS OF BRACHYSTEGIA SPICIFORMIS AND ISOBERLINIA TOMENTOSA: EVALUATION OF THE ENSO-SIGNAL IN THE MIOMBO WOODLAND OF EASTERN AFRICA,” *IAWA J.*, vol. 22, no. 4, pp. 385–399, Jan. 2001, doi: 10.1163/22941932-90000384.
12. J. Ngoma, “Tree-Ring Formation of Zambia ’ s Wet Tropical Miombo Woodlands- Exploratory Research Through African Dendrochronology Fieldschools,” *EGU Gen. Assem. 2023*, pp. 10–12, 2023, doi: 10.5194/egusphere-egu23-3917
13. R. Shikangalah, B. Mapani, I. Mapaure, U. Herzschuh, A. Musimba, and X. Tabares, “Growth ring formation of Dichrostachys cinerea and Senegalia mellifera in arid environments in Namibia,” *Dendrochronologia*, vol. 59, p. 125661, Feb. 2020, doi: 10.1016/j.dendro.2019.125661.
14. R. N. Shikangalah, “Dendrochronology in Namibia: A Review,” *Int. J. Environ. Sci. Nat. Resour.*, vol. 24, no. 3, 2020, doi: 10.19080/ijesnr.2020.24.556136.
15. V. Trouet, J. Esper, and H. Beeckman, “Climate/growth relationships of Brachystegia spiciformis from the miombo woodland in south central Africa,” *Dendrochronologia*, vol. 28, no. 3, pp. 161–171, Jan. 2010, doi: 10.1016/j.dendro.2009.10.002.
16. E. J. Luoga, E. T. F. Witkowski, and K. Balkwill, “Differential utilization and ethnobotany of trees in Kitulanghalo forest reserve and surrounding communal lands, Eastern Tanzania,” *Econ. Bot.*, vol. 54, no. 3, pp. 328–343, 2000, doi: 10.1007/BF02864785.
17. E. Njoghomi, “Tree growth dynamics and ecological recovery in Kitulangalo miombo woodlands Morogoro, Tanzania,” *Diss. For.*, vol. 2021, no. 313, 2021, doi: 10.14214/df.313.
18. V. L. Caetano Andrade *et al.*, “Insights into Growth, Ring Formation and Maximum Ages of Brazil Nut Trees (Bertholletia excelsa) Using 14C Dating and Tree-Ring Analysis,” *Radiocarbon*, vol. 66, no. 2, pp. 306–325, 2024, doi: 10.1017/RDC.2024.39.
19. J. R. V. Aragão, P. Groenendijk, and C. S. Lisi, “Dendrochronological potential of four neotropical dry-forest tree species: Climate-growth correlations in northeast Brazil,” *Dendrochronologia*, vol. 53, pp. 5–16, 2019, doi: 10.1016/j.dendro.2018.10.011.
20. M. Worbes, “How to Measure Growth Dynamics in Tropical Trees a Review,” *IAWA J.*, vol. 16, no. 4, pp. 337–351, 1995, doi: 10.1163/22941932-90001424.
21. B. R. Lockwood, J. T. Maxwell, S. M. Robeson, and T. F. Au, “Assessing bias in diameter at breast height estimated from tree rings and its effects on basal area increment and biomass,” *Dendrochronologia*, vol. 67, no. May, 2021, doi: 10.1016/j.dendro.2021.125844.
22. O. T. Nguyen, T. Van Vu, and N. C. Le, “Dendrochronology for Labeling Heritage Trees Toward Green Tourism and Sustainable Development—A Case Study in Tay Giang District (Quang Nam, Vietnam),” in *Contemporary Economic Issues in Asian Countries: Proceeding of CEIAC 2022, Volume 2*, Springer Nature Singapore, 2023, pp. 435–454. doi: 10.1007/978-981-99-0490-7_25.
23. L. A. (Eds.). Cook, E. R., & Kairiukstis, *Methods of dendrochronology: Applications in the environmental sciences.* Kluwer Academic Publishers, 1990. doi: 10.1007/978-94-015-7879-0.
24. M. A. Stokes and T. L. Smiley, “An introduction to tree-ring dating,” *An Introd. to tree-ring dating*, 1996, Accessed: Oct. 13, 2025. [Online]. Available: https://books.google.com/books/about/An_Introduction_to_Tree_ring_Dating.html?id=SvBF2Ora-eUC
25. A. Novikov and M. Sup-Novikova, “Modified staining protocol with Safranin O and Astra Blue for the plant histology,” *Plant Introd.*, vol. 89–90, pp. 110–113, Jun. 2021, doi: 10.46341/pi2021005.

26. R. Falcioni, T. Moriwaki, R. H. Furlanetto, M. R. Nanni, and W. C. Antunes, "Simple, Fast and Efficient Methods for Analysing the Structural, Ultrastructural and Cellular Components of the Cell Wall," *Plants*, vol. 11, no. 7, p. 995, Apr. 2022, doi: 10.3390/plants11070995.
27. S. Mahesh, P. Kumar, and S. A. Ansari, "A rapid and economical method for the maceration of wood fibers in Boswellia serrata Roxb," *Trop. Plant Res.*, vol. 2, no. 2, pp. 2349–9265, 2015, Accessed: Mar. 07, 2026. [Online]. Available: https://www.researchgate.net/publication/351307945_A_rapid_and_economical_method_for_the_maceration_of_wood_fibers_in_Boswellia_serrata_Roxl
28. E. Wheeler, P. Gasson, and P. Baas, "IAWA List of Microscopic Bark Features," *IAWA J.*, vol. 37, no. 4, pp. 517–615, 1989, doi: 10.1163/22941932-20160151.
29. R. Moya, C. Tenorio, and L. Acosta-Vargas, "Growth Rings in Nine Tree Species on a Neotropical Island with High Precipitation: Coco Island, Costa Rica," *Forests*, vol. 15, no. 5, 2024, doi: 10.3390/f15050885.
30. E. T. David, S. Chhin, and D. Skole, "Dendrochronological potential and productivity of tropical tree species in Western Kenya," *Tree-Ring Res.*, vol. 70, no. 2, pp. 119–135, 2014, doi: 10.3959/1536-1098-70.2.119.
31. R. Wimmer, "Wood anatomical features in tree-rings as indicators of environmental change," *Dendrochronologia*, vol. 20, no. 1–2, pp. 21–36, Jan. 2002, doi: 10.1078/1125-7865-00005.
32. N. J., K. O.L., and Hofiço N.D.S.A, "Dendrochronological potential of the tropical wet miombo trees unveiled through African Fieldschools | PAGES," *Past Global Changes Magazine*, Kitwe, Zambia, 2023. [Online]. Available: https://pastglobalchanges.org/publications/pages-magazines/pages-magazine/137619
33. V. Chiteculo and P. Surovy, "Dynamic patterns of trees species in miombo forest and management perspectives for sustainable production-case study in Huambo Province, Angola," *Forests*, vol. 9, no. 6, 2018, doi: 10.3390/f9060321.
34. E. Fichtler, "Dendroclimatology using tropical broad-leaved tree species – A review," *Erdkunde*, vol. 71, no. 1, 2017, doi: 10.3112/ERDKUNDE.2017.01.01.
35. C. Couralet, F. J. Sterck, U. Sass-Klaassen, J. Van Acker, and H. Beeckman, "Species-specific growth responses to climate variations in understory trees of a central african rain forest," *Biotropica*, vol. 42, no. 4, pp. 503–511, 2010, doi: 10.1111/j.1744-7429.2009.00613.x.
36. N. Pumijumnong, C. Muangsong, S. Buajan, P. Songtrirat, R. Chatwatthana, and U. Chareonwong, "Factors Affecting Cambial Growth Periodicity and Wood Formation in Tropical Forest Trees: A Review," May 15, 2023, *Multidisciplinary Digital Publishing Institute*. doi: 10.3390/f14051025.
37. J. A. A. Chamba, A. Bräuning, and D. A. Pucha-Cofrep, "Anatomical Types of Xylem Growth-Ring Boundaries in 16 Tree Species from a Rainforest in Southern Ecuador," *Tree-Ring Res.*, vol. 81, no. 2, pp. 54–71, 2025, doi: 10.3959/TRR2023-3.
38. A. Santos-Malengue, D. Ariza-Mateos, R. Navarro-Cerrillo, A. M. Cachinero-Vivar, and J. J. Camarero, "Ring data provide management clues and pinpoint climate drivers of growth in two species of miombo trees (Brachystegia spiciformis, Julbernardia paniculata)," *Dendrochronologia*, vol. 81, p. 126117, Oct. 2023, doi: 10.1016/j.dendro.2023.126117.
39. A. Santos-Malengue, D. Ariza-Mateos, R. Navarro-Cerrillo, A. M. Cachinero-Vivar, and J. J. Camarero, "Ring data provide management clues and pinpoint climate drivers of growth in two species of miombo trees (Brachystegia spiciformis, Julbernardia paniculata)," *Dendrochronologia*, vol. 81, p. 126117, Oct. 2023, doi: 10.1016/J.DENDRO.2023.126117.
40. E. A. Wheeler, P. Baas, and S. Rodgers, "Variations in dicot wood anatomy: A global analysis based on the insidewood database," *IAWA J.*, vol. 28, no. 3, pp. 229–258, 2007, doi: 10.1163/22941932-90001638.
41. D. W. Woodcock, "A TYPOLOGY OF VESSEL PATTERNING IN TREES WITH EXAMPLES FROM THE FOSSIL RECORD," *Int. J. Plant Sci.*, vol. 183, no. 3, pp. 235–250, Mar. 2022, doi: 10.1086/718086.
42. L. G. Esteban, P. de Palacios, P. Gasson, A. García-Iruela, F. García-Fernández, and L. García-Esteban, "Hardwoods: Anatomy and Functionality of Their Elements—A Short Review," *Forests*, vol. 15, no. 7, 2024, doi: 10.3390/f15071162.
43. V. Winchester, "Lichenometric Dating and Its Limitations and Problems: A Guide for Practitioners," Mar. 02, 2023, *Multidisciplinary Digital Publishing Institute*. doi: 10.3390/land12030611.

Figures

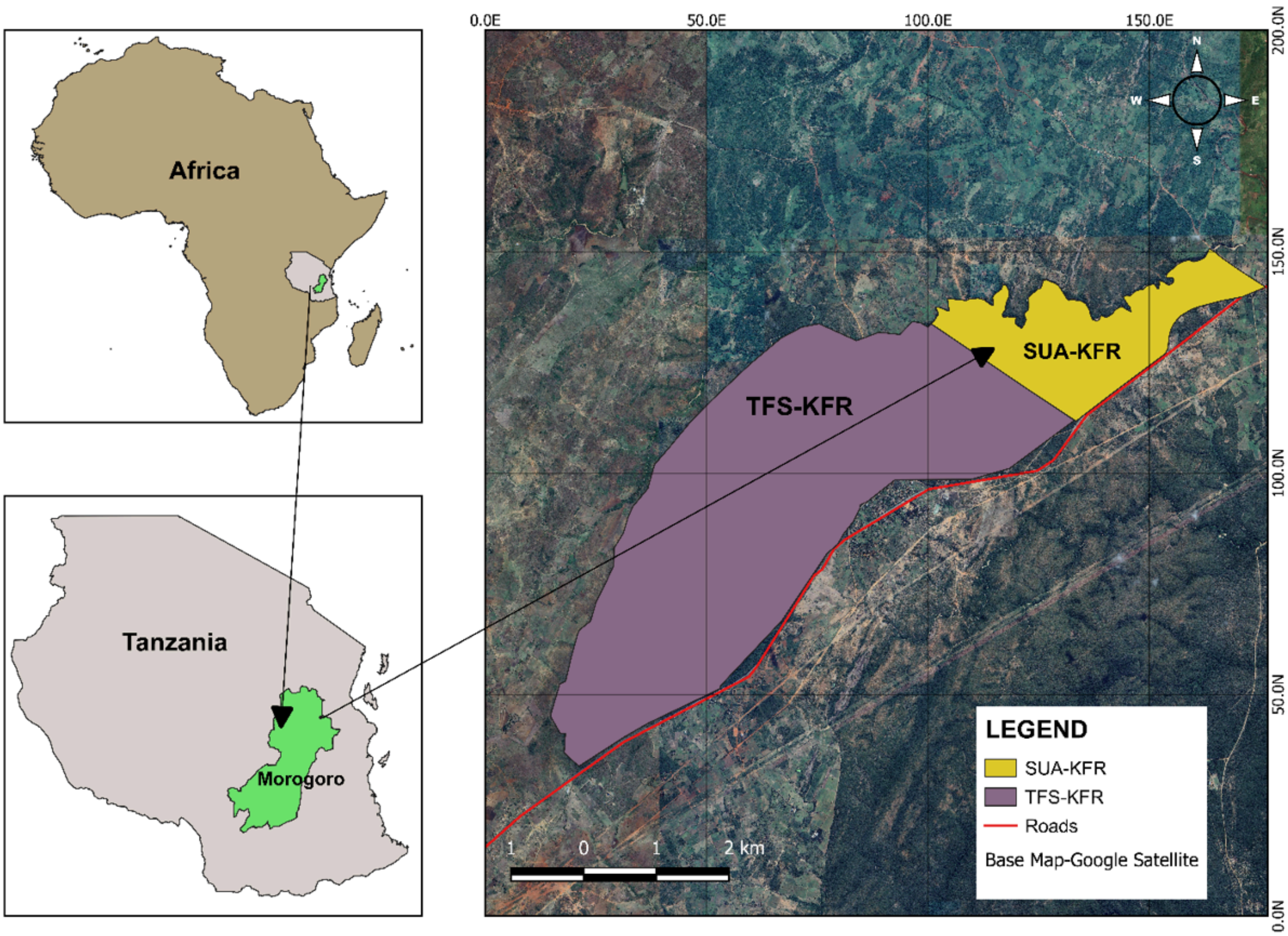

Figure 1

Sampling site location within SUA-Kitulanghalo forest reserve, in Morogoro, Tanzania.

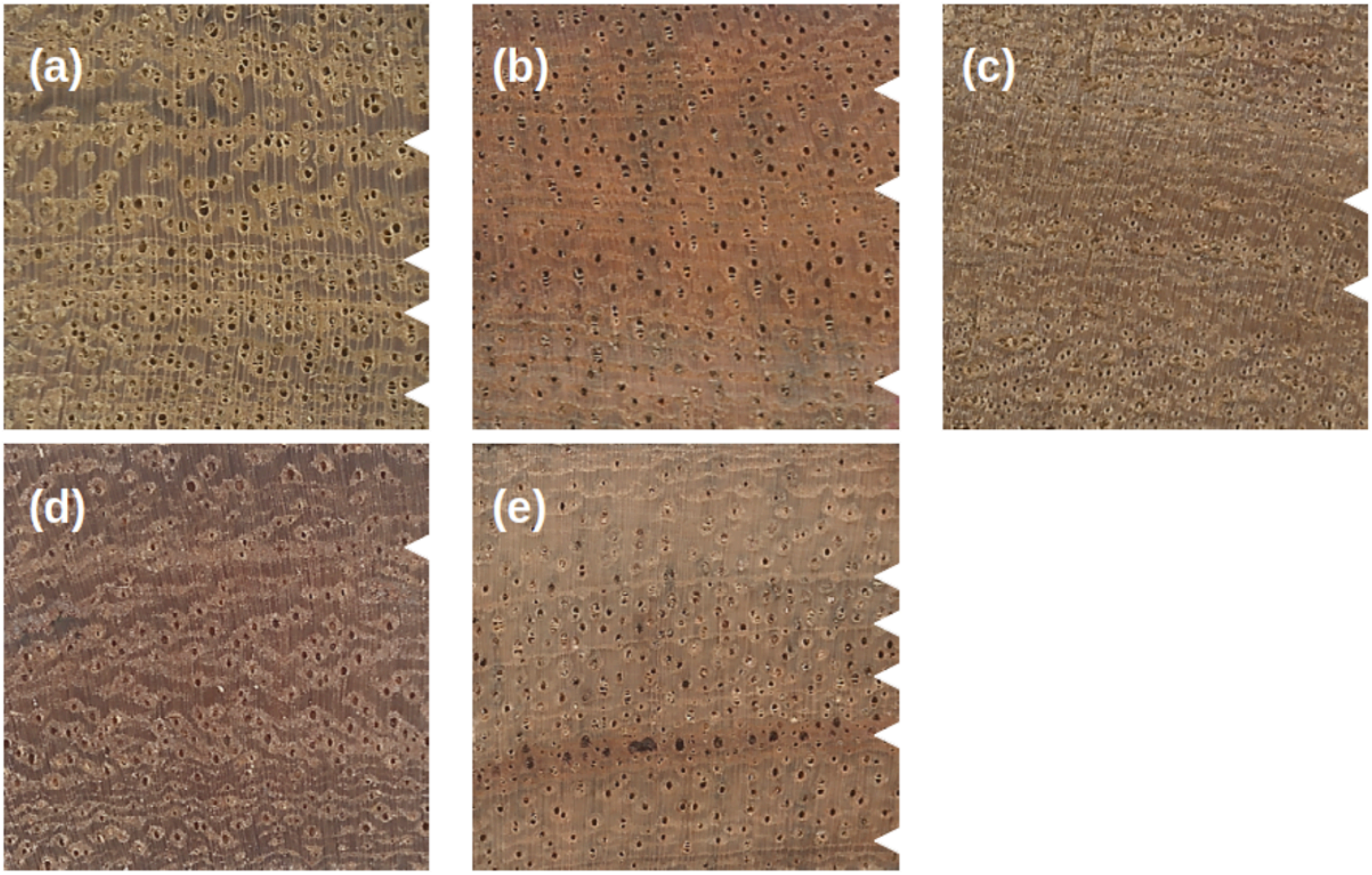

Figure 2

Transverse sections of: (a) *Senegalia nigrescens*, (b) *Brachystegia boehmii*, (c) *Combretum molle*, (d) *Combretum zeyheri* and (e) *Julbernardia globiflora*.

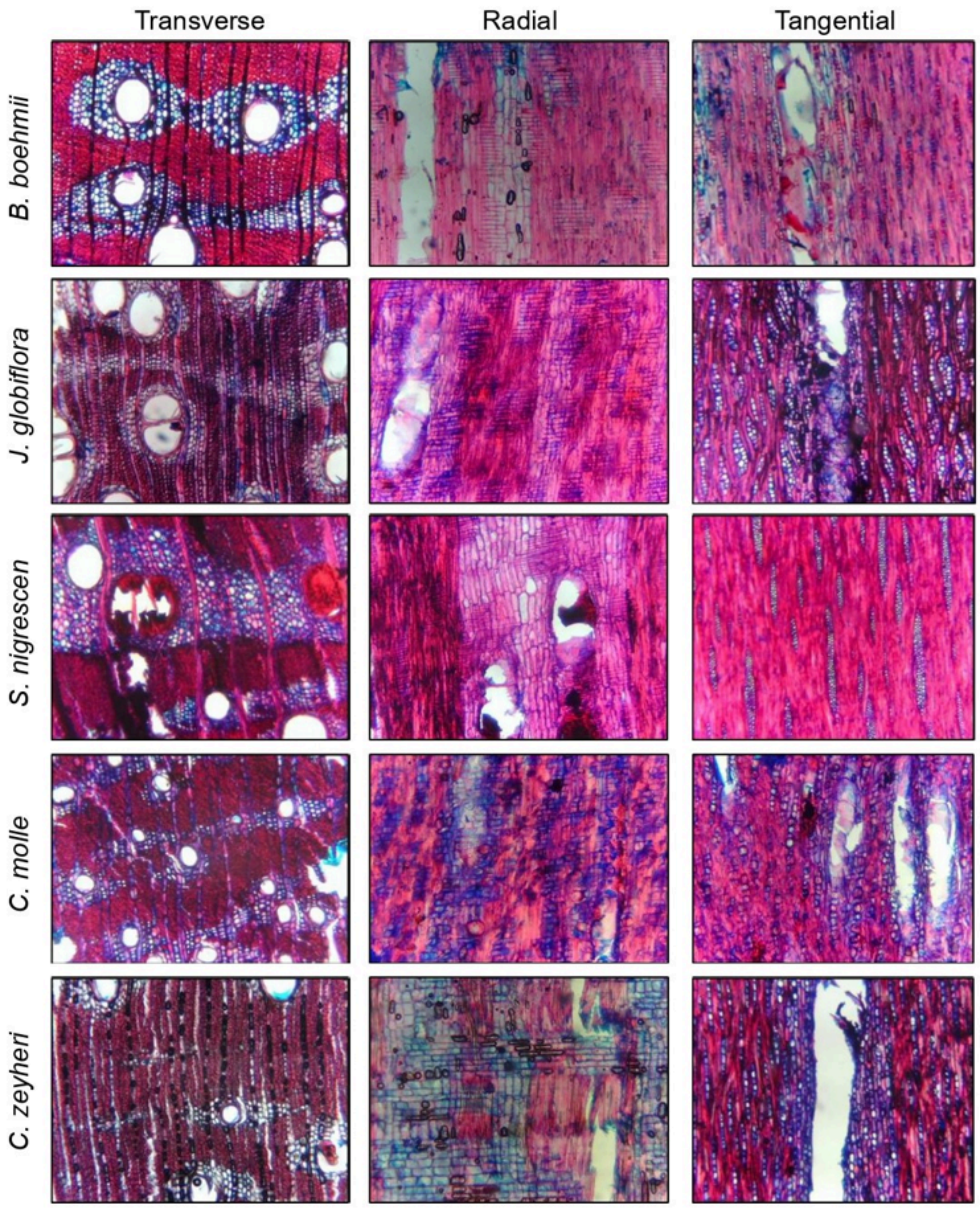

Figure 3

Transverse, radial and tangential longitudinal light microscope sections of the studied Miombo tree species showing vessel distribution, ray width, and ray composition.