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Uncovering the First Reforestation Project in the 19th-Century Brazilian Atlantic Rainforest: Insights from Wood Anatomy and Historical Analysis

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Abstract

The arrival of the Portuguese Court in Rio de Janeiro in 1808 intensified wood extraction, compromising the city's water supply. The Tijuca massif—largely deforested by 19th-century coffee cultivation—subsequently became the target of urgent imperial reforestation efforts, which resulted in one of the world's earliest large-scale successful reforestation programs and established the Tijuca Forest as the largest planted tropical urban forest. Despite its scientific and cultural significance, the locations of early silvicultural experiments and the species employed had remained unidentified until recently. In this study, tree-ring dating combined with cartographic, ecological, and historiographic analyses was used to recover 19th-century planting data. This approach mapped trees planted from 1862 onward, based on growth-ring analysis of *Cedrela odorata* L., *Copaifera lucens* Dwyer, and *Lafoensia glyptocarpa* Koehne. The results highlight the value of wood anatomy and dendrochronology for reconstructing the historical development of Brazilian forests—methods seldom applied for this purpose. Identifying trees planted more than 150 years ago provides a basis for future research on climate change and urbanization in Rio de Janeiro and supports forest management strategies amid the global climate crisis, underscoring the urgent need for ecological restoration across Brazilian ecosystems.

Keywords

Wood Anatomy, Tropical Forestry, Urban Ecology, Environmental History, Atlantic Forest

1. Introduction

The use of timber resources as a component of the human evolutionary process predates the Holocene, long before forests were greatly impacted by the First Industrial Revolution (Kaplan et al., 2009). Fast forward to today and the use of trees and their products remains highly prized for societies. Moreover, and most concerning is that there is now a renewed and heightened interest in the potential of building with wood on a scale previously unimaginable (Ramage et al., 2017). In the case of Brazil, its processes of occupation and colonization were directly associated with the extensive extraction of brazilwood (*Paubrasilia echinata* (Lam.) Gagnon, H.C.Lima & G.P.Lewis), as well as the culling of various other species that culminated in various manner and scale of impact. Much of this commenced during the 16th century, mainly in the Atlantic Forest (Dean, 1996; Cabral, 2008).

The magnitude with which the existing forests on the Brazilian coast were deforested thus influenced the establishment and growth of populations in colonial cities, including Rio de Janeiro, in southeastern Brazil. The cutting of forests, purposed for selection of noble woods for construction and woodworking, as well as numerous other activities, culminated in extensive deforestation where land was principally occupied to cultivate agriculture and to breed livestock, thus replacing the native forests (Dean, 1996).

During the 19th century, the reduction of forests in the city of Rio de Janeiro impacted the springs and compromised the population’s water supply. This situation demanded protective measures, which were subsequently initiated in 1817 by D. João VI, who prohibited the cutting of trees near the Carioca River, which at the time was the main watercourse of the city. From the 1860s onward, D. Pedro II implemented a reforestation program on former coffee plantations acquired by the Empire, targeting degraded areas of the Tijuca Massif. This initiative included the establishment of the Tijuca Forest—still regarded today as the world’s largest urban planted forest—as well as other national forests (Drummond, 1988; Heynemann, 1995; Sales & Guedes-Bruni, 2023; Sales & Guedes-Bruni, 2024).

The location of these planted areas remained largely unknown for over a century, and with the passing of time, the reforested zones became indistinguishable from those undergoing natural regeneration. This overlap complicates investigations based solely on ecological, geographical, or historical approaches. The aim of this study is to therefore, identify trees planted in the 19th century by employing integrative methodologies grounded in wood anatomy, to analyze their role in environmental history and to uncover a hidden legacy of tropical forest recovery dynamics—as vividly exemplified by this case study in Brazil’s most emblematic urban forest. In this way, the approach enables delineation of the experimental area and evaluation of intentional species selection.

2. Material and Methods

The Tijuca Forest is located in the Tijuca Massif within the city of Rio de Janeiro, RJ, Brazil. It is part of the Tijuca National Park, which together with the adjacent forests, constitutes one of the largest urban forests in the world, extending to approximately 4000 hectares (**Figure 1**). This mountain range is covered by remnants of the Atlantic Forest (**Figure 2**), specifically Dense Ombrophylous Forest, submontane and montane types (Sales & Guedes-Bruni, 2023).

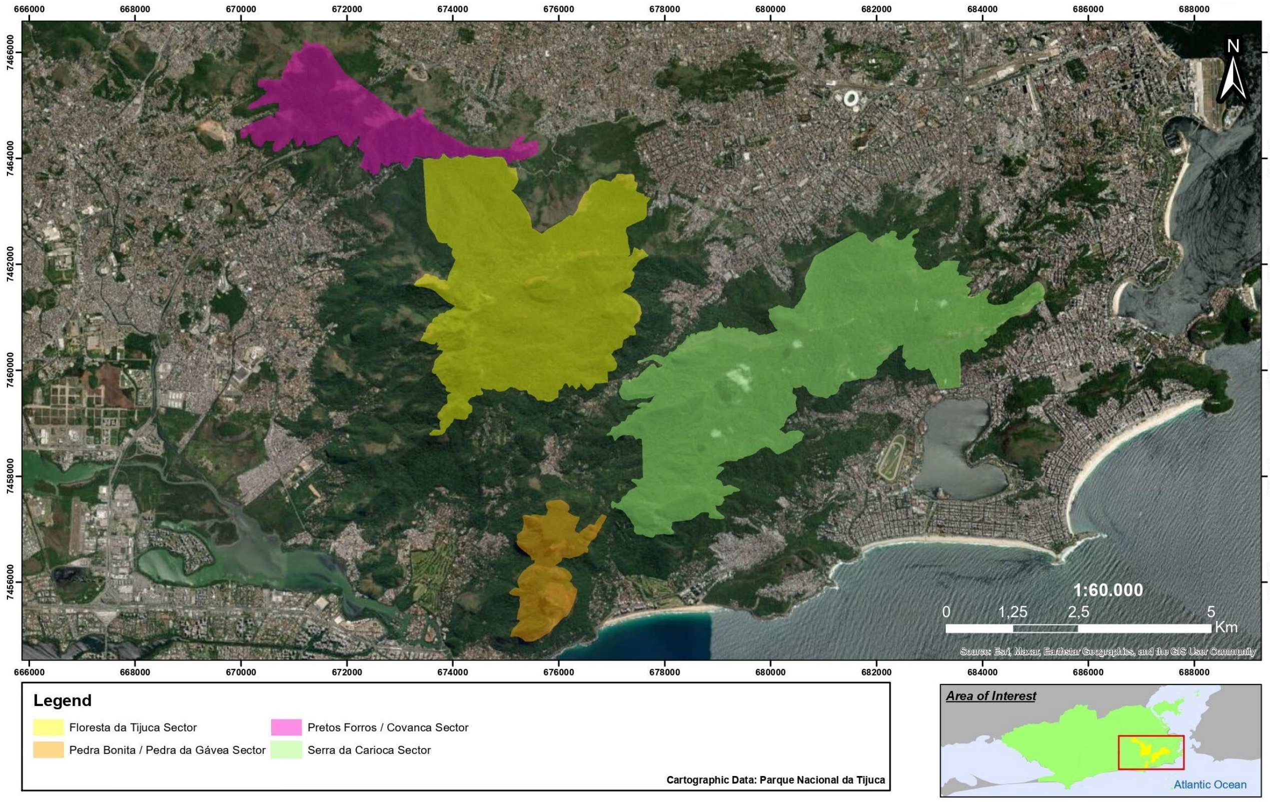

Figure 1. Map showing the localization of the Tijuca National Park in Rio de Janeiro, Brazil, emphasizing its four sectors. The sector known as the Tijuca Forest is showed in yellow.

Figure 2. View of the Tijuca Forest, highlighting its mountains and forests.

The field investigation employed multiple tools, integrating methodological processes from varying fields of knowledge. For purposes of herbage sampling, areas of similar vegetation-type were selected, and the quadrant point method (Martins, 1991) was implemented, thus adopting the inclusion criterion of DBH (diameter at breast height) ≥ 15 cm. Samples of vegetative branches were collected for taxonomic identification and inclusion in the Herbário Friburguense (FCAB) collection of PUC-Rio.

Following the taxonomic identification, the 44 trees with the largest recorded diameters—representing 12 different taxa—were selected for wood sampling. These samples were collected between May 2019 and January 2023 by incorporating non-destructive techniques with a Pressler increment borer. Between two and four radial cores were extracted from each tree at 1.30 meters above ground level. The samples were air-dried and progressively polished using sandpaper with grits ranging from 60 to 1200 (Roig, 2000). They were then examined under a Bel Photonics® stereomicroscope and scanned at 1200 DPI using an HP Deskjet 3510 scanner. Cores that did not attain pith or failed to include the innermost growth rings were excluded from the analysis. The samples were then deposited at the Xiloteca Dra. Cecília Gonçalves Costa (HUENFw) of the Darcy Ribeiro State University of Northern Fluminense (**Table 1**).

Table 1. Tree planted during the Tijuca Forest planting period (1862-1894), along with their respective botanical identifications, voucher numbers (HUENFw), diameter at breast height, estimated height, estimated age, and estimated year of planting.

Family	Species	Voucher (HUENFw)	DBH (cm)	Height (m)	Age (yr)	Year of planting
Meliaceae	*Cedrela odorata*	891	75.0	24	130	1894
Meliaceae	*Cedrela odorata*	892	51.6	22	144	1880
Lythraceae	*Lafoensia glyptocarpa*	893	82.0	24	143	1881
Fabaceae	*Copaifera lucens*	894	37.7	18	135	1889
Meliaceae	*Cedrela odorata*	895	83.8	30	155	1869
Meliaceae	*Cedrela odorata*	896	107.0	16	130	1894
Meliaceae	*Cedrela odorata*	897	51.6	22	148	1876
Meliaceae	*Cedrela odorata*	898	83.8	30	147	1877
Meliaceae	*Cedrela odorata*	899	155.0	30	137	1887
Meliaceae	*Cedrela odorata*	900	96.1	19	154	1870
Meliaceae	*Cedrela odorata*	901	139.3	22	147	1877
Meliaceae	*Cedrela odorata*	902	87.0	20	153	1871

Post examination of the wood samples, five species exhibited a high degree of growth ring distinctiveness. However, for the purposes of age estimation, only twelve trees (forty-eight radii) from three species were included in the analysis, as these are well documented within scientific literature as forming distinct and annual growth rings in southeastern Brazil. This characteristic of the three species had previously been underscored via classical dendrochronological studies and, in some cases, corroborated by investigation into cambial activity (Lisi et al., 2008; Costa et al., 2013; Costa et al., 2015; Gaspar et al., 2016; Costa et al., 2024). Consequently, seven taxa were excluded because they did not exhibit growth rings sufficiently distinct for reliable dating, and two species were excluded because the periodicity of the growth rings observed in their wood cross-sections has not yet been established. The principle of cross-dating was applied solely to compare growth ring widths between differing radial cores taken from the same tree (Roig, 2000). This enhanced the accuracy of ring counts and assisted in minimizing errors such as the omission of narrow rings or the inclusion of false rings. Accordingly, the comparison between the number of growth rings observed in the wood samples and historical records of plantation establishment enabled a direct correlation between ring count and tree age (Worbes, 1995).

3. Results and Discussion

Twelve taxa were analyzed for the growth rings distinctiveness in the wood: *Clethra scabra* Pers. (Clethraceae); *Terminalia acuminata* (Allemão) Eichler (Combretaceae); *Joannesia princeps* Vell. (Euphorbiaceae); *Copaifera lucens* Dwyer, *Centrolobium tomentosum* Guillem. ex Benth. and *Pseudopiptadenia contorta* (DC.) G.P.Lewis & M.P.Lima (Fabaceae); *Lafoensia glyptocarpa* Koehne (Lythraceae); *Ceiba crispiflora* (Kunth) Ravenna and *Sterculia apetala* (Jacq.) H.Karst. (Malvaceae); *Cedrela odorata* L. (Meliaceae); *Eucalyptus robusta* Sm. (Myrtaceae) and *Pradosia kuhlmannii* Toledo (Sapotaceae). Only five of these species exhibited growth rings with a high to excellent degree distinction: *Cedrela odorata* exhibited growth ring boundaries marked by marginal parenchyma and semi-porous distribution of vessel elements in the earlywood; *Centrolobium tomentosum* revealed growth ring boundaries marked by thick-walled fibers in the latewood associated with marginal parenchyma bands; *Lafoensia glyptocarpa* showed growth ring boundaries marked by marginal parenchyma; *Copaifera lucens* indicated growth ring boundaries marked by marginal parenchyma; and *Pseudopiptadenia contorta* exhibited growth ring boundaries marked by marginal parenchyma.

The anatomical characterization of growth rings in wood is the first step towards a heightened understanding of tree growth dynamics (Jacoby, 1989; Worbes, 1995; Callado et al., 2001; Lisi et al., 2008). Analysis of these rings provides the determination of tree age, species lifespan, wood production and quality, and factors influencing individual growth. These studies can prove of significant value for the management of commercially important species focused on conservation or forest restoration (Jacoby, 1989; Worbes, 1995; Albuquerque et al., 2019).

There exists a great diversity of biotic and abiotic factors within tropical forests that induce and control the periodicity of radial growth and, consequently, the formation of distinct and annual growth rings (Worbes, 1995; Callado et al., 2013; Andreu-Hayles et al., 2023). This diversity requires assessments of cambial activity to verify just how annual growth rings are formed. As such, this study focused purely on species with clearly distinct growth rings and for which there was already the available research that confirmed the annual periodicity of growth ring formation (Lisi et al., 2008; Costa et al., 2013; Gaspar et al., 2016). Among the species studied, only *Cedrela odorata* (**Figure 3(a)**), *Lafoensia glyptocarpa* (**Figure 3(b)**), and *Copaifera lucens* (**Figure 3(c)**) have studies on the annual periodicity of growth ring formation in the southeastern region of Brazil (Lisi et al., 2008; Costa et al., 2013; Costa et al., 2015; Gaspar et al., 2016; Costa et al., 2024).

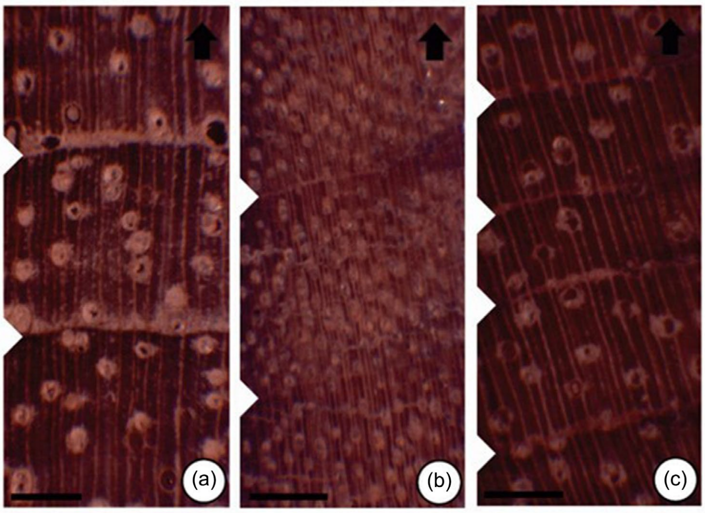

Figure 3. Cross-section of wood with distinct and annual growth rings. (a) *Cedrela odorata*—marked by marginal parenchyma (arrowhead) and semi-porous distribution of vessel elements in the earlywood. (b) *Lafoensia glyptocarpa*—marked by marginal parenchyma (arrowhead). (c) *Copaifera lucens*—marked by marginal parenchyma (arrowhead). Arrows = boundaries between consecutive growth rings; Scale bars = 1 mm.

The annual periodicity of growth rings was validated through the correspondence between the number of rings observed in the wood samples and the recorded planting dates-evidence reported by Tschinkel (1966) and later consolidated in the review by Worbes (1995), which addresses "How to measure growth dynamics in tropical trees—a Review". This approach has been successfully applied to studies that involve trees from plantations of known age across forests in both temperate and tropical zones, including the Atlantic Forest of southeastern Brazil (Estrada et al., 2008; Costa et al., 2015; Brandes et al., 2016; Albuquerque et al., 2019; Olmedo et al., 2025), thus reinforcing the method's reliability. That said, advanced-age plantings—both in Brazil and abroad—are not readily accessible, which places limitation to long-term studies (Worbes, 1995) and further underscores the importance of this study conducted on the slopes of the Tijuca massif, being most notably, the first and oldest reforestation project undertaken in Brazil.

Growth rings continue to prove a decisive field of research in uncovering historical processes involving plants, vegetation, and society. Various studies dissected: the past structure of European forests during the Roman and medieval periods (Haneca et al., 2005); the species used in the construction of monasteries (Makris et al., 2021) and ships (Daly, 2007); craft farming tools from the 19th and first half of the 20th century in Czech Republic (Filková et al., 2015); as well as the creation of sculptures and paintings on wooden panels (Bauch, 1978; Bauch & Eckstein, 1981); the recognition of architectural styles (Crone & Fawcett, 1998; Hanke, 2012); and even the selection of species for constructing military trenches (Haneca et al., 2018; McNeill, 2004). Such approaches, however, remain rare in Brazil.

In relation to Brazilian forests, research has focused notably on the Atlantic Forest and within conservation units in the state of Rio de Janeiro. Such analyses, utilizing growth rings, have identified populations of relatively young tree species, with individuals not exceeding 150 years of age, thus providing analytical perspectives on past uses and conservation and forest management actions (Brandes et al., 2021; Costa et al., 2021; Macedo et al., 2021).

Whilst being a controversial topic, it was decided to acknowledge that tree age and trunk diameter possess a positive correlation, as the tree ages and the cambium adds new layers of wood, thus increasing the stem diameter (Bowman et al., 2013; Pretzsch, 2020). Based on this relationship, various attempts have been undertaken to estimate age from trunk diameter, tree height, or crown width (O'Brien et al., 1995; Kalliovirta & Tokola, 2005; Silva et al., 2017).

Furthermore, tree age proves necessary for analyses of plant community structure and silviculture (Kalliovirta & Tokola, 2005; Wittmann et al., 2011), by applying diameter at breast height, which is a readily obtainable and low-cost data point. Yet, the results obtained in this study corroborate previously recorded analyses in the Atlantic Forest in the state of Rio de Janeiro, where no positive relationship between diameter and age was established (Costa et al., 2015; Costa et al., 2021). This relationship varies greatly amid locations, species and individuals and some trees with a smaller diameter may indeed be older than those with a larger diameter, as observed between 895 and 899 trees of *Cedrela odorata* (**Table 1**).

Tree age, when applying ring counting, is determined by the cambial activity and dormancy cycles, whilst the diameter of each tree is influenced by various factors that either accelerate or slow down growth rates during the period of cambial activity. These factors can be both endogenous, such as hormonal and genetic rates (Savidge, 2000), and exogenous, specific to each site, such as shading, clearing openings, resource competition, soil composition, insect attacks, climatic factors, and even local biodiversity (Swaine et al., 1987; Dobbertin, 2005; Andrés et al., 2018).

Thus, it must be acknowledged that the initial sampling strategy, which prioritized trees with the largest recorded diameters, may represent a methodological limitation of this study. This criterion may have biased the sample towards faster-growing individuals, potentially obscuring a positive relationship between diameter and age. Consequently, larger diameters in the sampled population do not necessarily reflect greater age but may instead be indicative of higher growth rates driven by species-specific traits or favorable local environmental conditions. This sampling bias should therefore be considered when interpreting the absence of a clear diameter-age relationship, and highlights the importance of incorporating a broader range of size classes in future dendrochronological studies.

Cedrela odorata, *Lafoensia glyptocarpa*, and *Copaifera lucens* exemplify how the timber value of species was central to the criteria for selecting species for planting (Brasil, Ministério da Agricultura, Comércio e Obras Públicas, 1881; Sales, 2021; Sales & Guedes-Bruni, 2023). Counting the growth rings within the wood of tree species noted in historical documents, the arrangement of individuals in the field—arranged in rows with spacing similar to that reported at the time of planting, combined with the referencing of maps stored in archives and geographic information systems (GIS), provided identification to individuals planted in the 19th century (**Table 1**). These cross-referencing of information revealed scientific evidence that supports a new interpretation of this emblematic tropical reforestation project, such as the longevity of timber-valuable taxa in tropical rainforests and the identification of the different stages of this project, with the identification of planting dates of trees—ages ranging from 130 to 155 years—throughout the second half of the 19th century.

Such analysis indicates that the planting project not only prioritized species of high economic value but also succeeded in ensuring their survival and growth in a humid tropical forest environment over several generations. It is also worth noting that the younger trees found in the study highlight the success of the long-term planting project, as being the original specimens employed in the restoration of degraded areas. As such, these were not only maintained, but also, further increased their population through natural regeneration. By documenting the ages and characteristics of surviving trees, the study provides important insights into the reforestation practices and criteria of the time, revealing a strategy that is aimed at economic and ecological sustainability. By its very nature, the current study greatly contributes to a deeper understanding of historical reforestation methods and their impact on the current structure of the forest.

In this regard, it is important to reflect on the motivations underlying the reforestation efforts, as well as on the intellectual and technical influences that shaped how planting schemes were conceived and implemented during the second half of the nineteenth century—a process that ultimately contributed to the emergence of a national silvicultural. Undeniably, there was a clear understanding that, to address the city's worsening water supply crisis—intensified year after year, primarily because of deforestation associated with coffee cultivation—it was necessary to reforest degraded areas. However, these new forests were expected to be composed of carefully selected species, particularly native species with high timber value, regarded as genuine "forest treasures" that could potentially yield economic returns in the medium term (Sales, 2021; Sales et al., 2024).

Nevertheless, while at the outset of the second half of the nineteenth century the planted forest was envisioned as a future reservoir of timber for exploitation, these motivations gradually transformed over subsequent decades. As additional forest functions gained recognition—including social, recreational, and aesthetic values—the meaning and use of the planted forest shifted accordingly. The reforested landscape increasingly became a space for leisure, contemplation, and relaxation, and, more importantly, each planted tree came to be admired as a symbolic element, evoking ideals of nationalism and modernity (Sales et al., 2024).

4. Closing Remarks

Growth ring studies provide a crucial role in better understanding the potential of timber among Brazilian tree species and hence, their commercial application within the market. In fact, their value extends far beyond such limits. They constitute a significant scientific field that addresses a multitude of knowledge gaps, which extend beyond the environmental realm. This encompasses historical and cultural values that, to some extent, have been neglected in their multiple potentials, when factoring in the country's biological diversity, whose flora comprises more than 50,000 species. The discovery of timber species selection for the Tijuca massif plantings, such as arariba (*Centrolobium* sp.), cedro-rosa (*Cedrela* sp.), guarajuba (*Terminalia acuminata*), jequitibá (*Cariniana* sp.), among others, redefines the project's objectives, which were previously understood to be limited to the restoration of springs and watercourses, which supply the city of Rio de Janeiro.

Conversely, growth ring analysis can reveal that cumulative effects from multiple disturbance vectors can indeed be greater than individual effects. This aspect is fundamental for a better understanding of forests, as it permits us to infer how a species reacts to changes in the landscape caused by anthropogenic incursion, for example, whether on a local scale or by climatic change on a global scale. These changes duly biological interaction, including herbivory and phytopathogenic diseases. Moreover, abiotic factors such as wind, floods, fire, and several other associated factors can be accounted for and indeed be further investigated from these rings of wood.

In relation to the silvicultural perspective, the conservation of timber species such as those found in the Tijuca Forest, being represented by individuals planted over 150 years ago, allows for the evaluation of these species' capacity to interact over time within their environment over time, as well as their strategic evolutionary process in one of Brazil's and Latin America's most densely populated cities. With its significant geomorphological and phytophysiognomic diversity, and as a historical reference in reforestation planning, the Tijuca Forest remains a barometer for: the development of management strategies for urban tropical forests, specifically those subjected to intense and uneven urban expansion. Furthermore, the conservation of its integrity and ecosystem services can be understood as a common good for city dwellers.

From the perspective of contemporary forest management, the identification of trees approximately 150 years old provides valuable insights for current conservation and restoration strategies. These individuals represent genetic lineages adapted to local conditions, with the potential to inform species selection in future restoration projects, while also serving as natural models for studying tree resilience to urban pollution and contemporary climatic stressors, as well as for populations of native species threatened with extinction. In this sense, a deeper understanding of past practices and legacies directly contributes to the development of more informed and effective strategies for the future of forests.

The planting of the Tijuca Forest, the first large-scale reforestation project in deforested areas carried out in Brazil, involved the use of at least one hundred species, with native species prioritized and selected according to rigorous criteria. This undertaking offers important lessons for contemporary environmental challenges, particularly concerning the ecological restoration of the Atlantic Forest. It is imperative to intensify conservation efforts of the remaining forested areas, as well as to promote the use of a wide diversity of native species, encompassing fast-, medium-, and slow-growth cycles. Considered the oldest and most emblematic silvicultural project in the country, the Tijuca Forest planting projects a legacy into the future, both within the realms of science, biological conservation, and culture and as a paradigm for a new model of environmental rationality in society. Whilst harking back has gone someway to explain the interactive processes between trees and their environment, the current climate emergency calls for public policies that prioritize the envision for the future of forests as proffering a possibility, just as the Tijuca Forest did for Major Archer, who was its very first administrator.

It is also important to emphasize that well-dated and long-term tree-ring chronologies may be used as robust indicators for reconstructing historical climate variability, as growth rings record, on an annual and continuous basis, the response of cambial activity to prevailing environmental conditions. When such precisely dated growth series extend over decades or centuries, they allow statistical analyses that relate ring width to recent instrumental climate records. Once this climate-growth relationship has been established, the chronologies can be applied retrospectively to infer climate variability prior to the onset of meteorological observations, enabling the reconstruction of historical patterns of precipitation, the occurrence of droughts, exceptionally wet years, and, in some cases, interannual temperature variability. Consequently, long chronologies derived from native tree species well adapted to the Atlantic Forest provide climate information at both local and regional scales, complementing data obtained from other paleoclimatic proxies. In this way, these trees function as high-resolution natural archives, essential for understanding past climate dynamics and for placing contemporary climate change into a broader historical context.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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