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A cross-biome analysis of *Cedrela fissilis* Vell: Growth, age, and diameter class transitions

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ABSTRACT

The measurement of tree-rings of *Cedrela fissilis* was used to determine the variability of diametric and basal growth across three sites located in the Cerrado biome in Bolivia and one in the Atlantic Forest, Santa Catarina, Brazil. The growth variability in growth is particularly pronounced among sites when trees have smaller diameters and during the initial 50 years of their lives. Initial growth rates are generally higher in those sites recovered from agricultural to forest lands or highly impacted forests than those growing in well-established forests. Optimal basal growth for the four sites occurs between 60 and 80 years old. The estimated times required for *C. fissilis* trees to grow from a given diameter to the next one are longer at the JBA and LCH sites. Under optimal conditions, this species requires 12 years to grow from 1 to 10 cm in diameter at STA. Conversely, when growth is slower and the diametric size is larger, they need about 23 years to grow from 31 to 40 cm. The JBA and LCH sites require >100 years to reach diameters of 50 cm, the AAI (Average Annual Increase) of 0.83 cm for diameters of 1–10 cm corresponds to STA, while in this same diametric class, the lowest of 0.36 cm corresponds to LCH. In diametric sizes of 41–50 cm, the highest growth of 0.47 cm corresponds to INP and the lowest of 0.31 cm to STA. The average time necessary to grow diameters of 10 cm, the lowest is 19.2 years corresponding to the site of INP and LCH requires an average of 22.4 years.

The age of the trees required to be part of the deck, in order to achieve optimal growth, is dependent on to site-specific factors, such as light and soil nutrients. By combining this information with data on passage times, it is possible to project forest management based on an understanding of the specific events in which trees of this species change their growth dynamics within a given site or biome.

1. Introduction

The tropical and subtropical forests of South America are regarded as the most vulnerable biomes, largely due to the low regeneration capacity and slow radial growth of tree species (Fredericksen and Mostacedo, 2000). The deforestation and selective, unsustainable logging practices driven by the high commercial demand of local and international markets have resulted in significant alterations to the composition and dynamics of these ecosystems (Kant, 2004). Species such as *Swietenia macrophylla* King, were intensely and selectively exploited for many years to the point that currently, it is difficult to find any native remnants in these biomes (Gullison et al., 2008). Among other commercially overexploited species are *Cedrela fissilis* Vell and *Amburana cearensis* (Allemão) A.C.Sm. In 1980, the highest volume of extraction was recorded, and from 2000, this condition decreased due to the reduction of their adult populations (ITTO, 2005). This decrease was mainly marked by the selective extraction of healthy specimens and straight trunks, including those with characteristics and potential for seed trees (Bolfor, 2003).

In some remaining forests with conservation categories, whether National Parks, Forest Reserves, and Private or Municipal Conservation Areas driven by recommendations, it was possible to conserve species such as *C. fissilis* and others in danger of extinction (CITES, 2023). However, in the past, even these areas were subject to selective logging of the best specimens, mainly the oldest and healthiest trunks. As a result of these activities, today, most of these forests with the presence of *C. fissilis* are young and have few old specimens that do not exceed 100 years old. On the other hand, today many of the forests with the presence

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of *C. fissilis* originated from plantations, reforestation, restoration of degraded areas, and are mainly intended for conservation and as carbon storage sources.

Forest management, regardless of the objective, necessitates an understanding of the entire life cycle of a tree, from its modes of reproduction, survival, and growth across different ecological phases (Fredericksen et al., 2001) to large-scale factors influencing development, such as climate change (Locosselli et al., 2020). By dating and measuring the width of tree-rings throughout a tree's lifespan, dendrochronology enables the extraction of a wealth of ecological and environmental information that is applicable in a range of scientific fields (Fritts, 1976). In forestry management, dendrochronology has been employed to inform sustainable management practices, assess the effectiveness of these practices, understand the history of forest disturbances, and guide forest restoration and conservation efforts (Brienen and Zuidema, 2006; Brienen et al., 2016; López et al., 2019). It provides access to precise data on forest dynamics and individual growth performance for species, contributing to public policies focused on sustainable forest management and biodiversity conservation (Schöngart, 2008). Nevertheless, given the considerable diversity of tropical tree species, research utilizing this method is still in its early stages of development. Furthermore, tree growth rates are subject to a number of factors, including management practices , competition for resources, and environmental conditions (e.g., altitude, soil, light availability) (Fritts, 1976; King et al., 2013). Thus, the growth rate of the same species can vary along its distribution gradient (King et al., 2013), especially in species with a broad distribution, necessitating different management and conservation strategies for the same species. In this context, this study aims to investigate the variation in the radial growth rate of *C. fissilis* in the Cerrado and Atlantic Forest biomes, considering environmental influences and inferring about management and competition for resources, to understand growth patterns and promote conservation practices and sustainable management of the species. To achieve these goals, we propose to: a) analyze the temporal variability of diameter growth in *C. fissilis* across different study sites; b) identify the age and specific sites where *C. fissilis* achieves optimal basal growth; c) determine the time necessary for the species to reach and transition between diameter classes in sites within the two biomes.

2. Material and methods

2.1. Study sites

The study sites are located across two large South American biomes: the Cerrado and the Atlantic Forest (Fig. 1). Within the Cerrado biome, the sites La Chonta (LCH, 15° 38′ 33.68′’; 62° 46′ 56′’), Santa Anita (STA, 6° 32′ 12′’; 61° 119 55′ 33′’), and Inpa (INP, 16°21′28″; 61°68′07″) are situated. This biome is one of the largest in the world, extending from central-northern Brazil to eastern Bolivia and northeastern Paraguay (Fig. 1, Table 1).

According to (Cabrera and Willink, 1973), this biome is also referred to as the Cerrado Province. The Cerrado is known for its vast territorial range and high biodiversity, characteristic of seasonal tropical environments (Table 1). Its forests lie between humid tropical formations and their transition areas (Chaco-Amazon) to the wet savannas of the Pantanal and the deciduous forests of the Chaco (Killeen et al., 1993). The Cerrado sites experience a dry season of six months (April-September), with average temperatures ranging from 26.0 to 24.2 °C and annual precipitation between 1246 −1144 mm, according to Guarayos meteorological stations located 40 km from LCH and 50–60 km from STA and INP, respectively. LCH and INP are forestry concessions for timber extraction, while STA is a community-managed forest area for both timber and non-timber products.

The other biome, the Joaçaba Site (JBA), is federally owned by the Ministry of Agriculture and was previously an Agricultural Station, combining agricultural crops, livestock, and conserved forest remnants (Raimundo, 2003). Since 1985, a conservation concession has been granted to the municipality of Joaçaba, which is currently undergoing an advanced stage of natural regeneration. Located on the Southern Brazilian Plateau, a subtropical region in the Midwest of the State of Santa Catarina, specifically within the Parque Natural Municipal do Vale do Rio do Peixe preservation area (27° 9′50″S; 51°34′51″W, Fig. 1, Table 1). In the biogeographic classification of Cabrera y Willnk (1973), this area is termed the Paranense Province and is part of the Atlantic Forest biome, a highly diverse and endangered tropical forest biome with a long history of deforestation and degradation (Ribeiro et al., 2009; Joly et al., 2014). The Atlantic Forest spans the eastern, northeastern, southeastern, and southern parts of Brazil, as well as parts of Paraguay and the Misiones province in Argentina (Galindo-Leal and

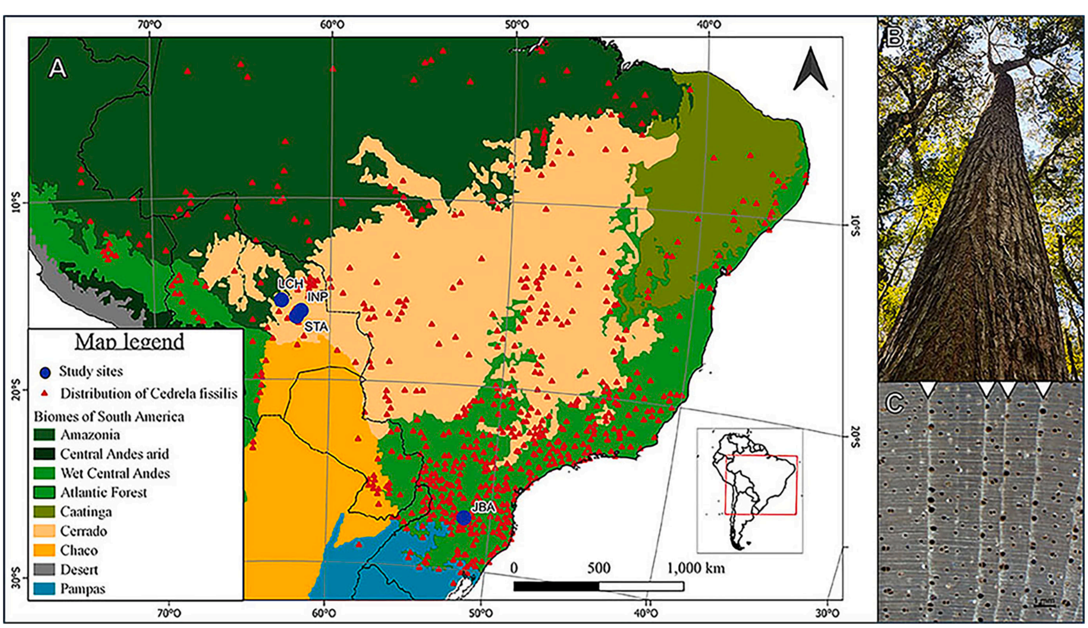

Fig. 1. Location of the study sites and the distribution of *Cedrela fissilis* in South America (A). Typical tree of *C. fissilis* (B). Characteristics of tree-rings (arrows, bar = 1 mm) (C). *A* = Source: http://www.splink.org.br/ and https://www.discoverlife.org/.

Table 1
Characteristics and overview of the current use of forests in the four study sites.

Study sites	Altitude (m a.s.l.)	Average annual temperature (°C)	Total annual precipitation (mm)	Predominant soil type	Biome and forest type	Forest use domain
La Chonta (LCH)	250	26,0	1298	Gneiss derivatives and granites, neutral PH	Cerrado Wet	Permanent production forest (timber harvesting)
Santa Anita (STA)	430	24,8	1304	Loamy to sandy loam to clayey, humic cambisol pH neutral	Cerrado Dry	Community forestry management (Native communities)
Inpa (INP)	503	24,2	1148	Clay loam, leptosols and cambisols, pH neutral	Cerrado Dry	Permanent production forest (timber harvesting)
Joacaba (JBA)	810	17,4	1818	Bruno Nitisol, high clay content, acidic pH	Atlantic Forest Subtropical	Advanced stage of secondary succession

Câmara, 2005). Specifically, the phytophysionomy of the JBA site belongs to the Mixed Ombrophilous Forest subgroup, found in high-altitude regions (~800–1800 m.a.s.l.) mainly in the subtropical region of Brazil and characterized by the presence of the conifer *Araucaria angustifolia* (Bertol.) Kuntze. The mean annual temperature at JBA is 17.4 °C, with precipitation of 1818 mm (1969–2022), experiencing a six-month period (April-September) of colder temperatures and a little decrease in rainfall (Instituto Nacional de Meteorologia (INMET), 2023). This subtropical part of Brazil frequently experiences frosts and occasional snowfall in winter (Scipioni et al., 2021). The soil is characterized as Bruno Nitisol, with high clay content and acidic pH (Bündchen et al., 2013).

2.2. Species and distribution

The neotropical species *Cedrela fissilis* Vell. (Meliaceae) is widely distributed in Argentina, Brazil, Bolivia, Colombia, Costa Rica, Ecuador, Panama, Paraguay, Peru, Suriname, Uruguay, and Venezuela (Toledo et al., 2008; Backes and Irgang, 2009) (Fig. 1A). Its habitat spans from tropical and subtropical moist and dry forests to cloudy mountain ecosystems, savannas, and drier areas (Killeen et al., 1993; Muellner et al., 2010). *C. fissilis* trees grow in highly varied environments ranging from sea level up to 1800 m a.s.l., with precipitation ranging from 750 mm (Morro do Chapéu) to 3700 mm (Serra de Paranapiacaba) and can withstand very low temperatures, where the average minimum of the coldest month is below 6 °C, with a record of absolute minimums of −11.6 °C (Santa Catarina) to where the average maximum of the hottest month is 27.5 °C in Pará (Carvalho, 2003; Toledo et al., 2008). In both biomes, *C. fissilis* has emergent trees with heights from 20 to 40 m, and in some sites, diameters of 60 cm up to 3 m for mature trees have been reported (Killeen et al., 1993; Lorenzi, 2002) (Fig. 1B).

Its trees have well-defined annual growth rings marked by bands of marginal axial parenchyma and vessels distributed in circular to semicircular patterns of larger diametric size in the earlywood (Marcati et al., 2006) (Fig. 1C). In some sections of the wood, traumatic ducts caused by insect damage to the cambial part and clusters of narrow rings located mainly in the sapwood have been reported, which has made the correct dating to the year of formation difficult (Dünisch and Baas, 2006). Despite these difficulties reported in some trees, the growth rings of *C. fissilis* have been used in many ecological and dendroclimatic studies in South America (Paredes-Villanueva et al., 2016; Ortega Rodriguez et al., 2023). The wood is lightweight with a density ranging from 0.47 to 0.61 g/cm^3, and in Brazil, it is classified for more diversified uses, being surpassed only by the wood of *Araucaria angustifolia* in the Atlantic forests (Baker et al., 2017).

2.3. Sample collection

The sampling of woody from *C. fissilis* trees was carried out using two techniques, destructive and non-destructive. In the LCH, STA, and INP sites with forests designated for logging, cross-sectional sections of the trunk of the trees being cut to obtain timber were collected. The samples were obtained from opposite radii of 25 cm with the pith from the same tree with the help of a chainsaw. Having cross-sectional or wedge sections of the trees allows for a better view of the woody plane, increasing the precision in the determination and measurement of the thickness of the growth rings (López, 2011). Most of the samples were taken at trunk heights ranging from 1.5 to 2 m, depending on the reach of the buttresses on the trunk and the logging processes. The non-destructive sampling method employed in JBA consisted of using a manual increment borer (Haglöf) 40–60 cm in length and 5.1 mm in diameter, with which 20 trees were sampled, two to four radii per tree at a height of one to 1.30 m from the ground.

2.4. Sample processing

The cross-sectional samples at radii were polished and visually dated following the criteria established in dendrochronology (Stokes and Smiley, 1968). Meanwhile, the cores were mounted on wooden supports and fixed with wood glue. In both cases, the samples were sanded with sandpaper of different grain sizes (80–1500 grit) until the tree-rings were fully visible. Subsequently, the samples were dated under a stereomicroscope following the convention for the Southern Hemisphere, where the calendar year is assigned to the growth ring according the year in which its formation began (Schulman, 1956). The trees used in JBA were dated to the year of formation and their annual growth was also verified by radiocarbon dating (Fontana et al., 2024). While for the LCH, STA and INP sites, the correlations in some sectors or decades were low, so we resorted to the technique used in (López and Villalba, 2016). A method consisting of dating the same number of rings on two opposite radii of the same tree. If the number of rings determined on one radius was not the same as on the opposite radius, the radii were re-examined until the number of rings on both radii of the same cross section coincided. Once the age of the trees for each site was determined, the thickness of the growth rings was measured using a Velmex UniSlide tablet connected to a Metronics Quick–Chek QC–10 V digital counter with a precision of 0.001 mm. Core samples that included the pith were selected; these were scanned at high resolution (1200 DPI, Epson 12000XL scanner) and the measurement of the growth rings was performed in an image software (CooRecorde®, versión 9.8.1) with a precision of 0.001 mm (Larsson, 2014a). The dated series were integrated into an average series in the CDendro program (Larsson, 2014b).

2.5. Age estimation and growth rates

From the radial measurements of the growth rings' width, the growth data expressed in millimeters (excluding the bark) were converted to diameter (in cm) and basal area growth (expressed in m^2). This last process was carried out with the aim of reducing the biological tendency that visually indicates that the initial rings grow larger than the later ones near the bark. For this process, the program (AGE) for tree growth by age from the Dendrochronology Program Library (DPL) (Holmes, 1983) was used. The current and mean diametric growths result from averaging the radial values corresponding to two radii (usually opposite) within the same cross-section or radius. The diametric growth per site was determined by averaging the individual growths considering the biological age of each series and not its calendar date. In the initial stage of the process the central ring (in contact with the pith) was designated for the first year in each cross-section. In this way, the average current diametric growth was obtained by averaging the values from each of the individuals taking into account the biological age of each sample. The standard error of estimation was obtained from the annual diametric increment of all the trees at a site for the same year. With the purpose of highlighting the long-term variation, the diametric growth series were adjusted with a cubic spline that reduces 50 % of the variance in a sinusoidal wave with a periodicity of 15 years (Cook and Peters, 1981). The average annual increment (AAI) differences by diameter class (1–10 cm, 11–20 cm, 21–30 cm, 31–40 cm, and 41–50 cm) for each site were evaluated up to 50 cm in diameter, in which the number of individuals was as high as possible based on the total number of individuals collected. Finally, for each diametric size, the elapsed and cumulative time required for *C. fissilis* trees to reach a certain size in both biomes was determined.

3. Results

The diametric growth of *C. fissilis* trees in the Cerrado and Atlantic forests varies between sites, especially in the first 50 years old. During these initial 50 years, the sites with the highest growth were STA and JBA, while LCH and INP recorded the lowest diametric growth, mainly in the first 30 years. After 50 years, the differences in growth between sites were less pronounced. Between 50–60 years old, the diametric growth of *C. fissilis* tends to stabilize to a point where variability between sites is minimal. From this point, where the diametric growth in all four sites is almost similar, growth tends to increase for some years and then continues with the decreasing trend until the end of the time analyzed (Fig. 2).

The variation in basal growth indicates that the STA and JBA sites have the highest growth, while LCH and INP have the lowest, especially during the first 60 years old. After 60 years, this species at both sites seems to reach optimal basal growths. In all four sites, after 70–80 years, there is a reduction in basal growth, with JBA at this age showing the highest growth (Fig. 3).

When growth conditions are optimal, this species needs 12 years to grow from 1 to 10 cm in diameter at the STA site, whereas when growth is slower and the diametric size is larger, they need about 23 years to grow from 31 to 40 cm. On the other hand, the sites that require >100 years to reach diameters of 50 cm are JBA and LCH. The highest AAI of 0.83 cm achieved in the diameter sizes of 1–10 cm corresponds to the STA site, while in this same diametric class, the lowest of 0.36 cm corresponds to the LCH site. In diametric sizes of 41–50 cm, the highest diametric growth of 0.47 cm corresponds to INP and the lowest of 0.31 cm to STA. Regarding the average time necessary to grow diameters of 10 cm, the lowest is 19.2 years corresponding to the INP site, while LCH requires an average of 22.4 years (Table 2).

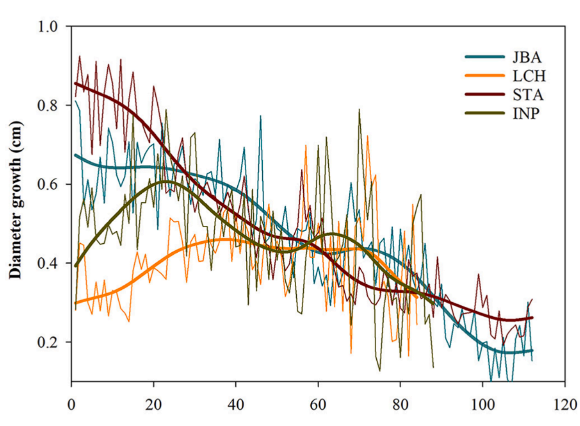

Fig. 2. Variation in diametric growth over the analyzed time period at the four study sites. To highlight the long-term variations in diameter increment, thicker lines show a cubic smoothing spline that highlights low-frequency variations close to 15 years (Cook and Peters, 1981).

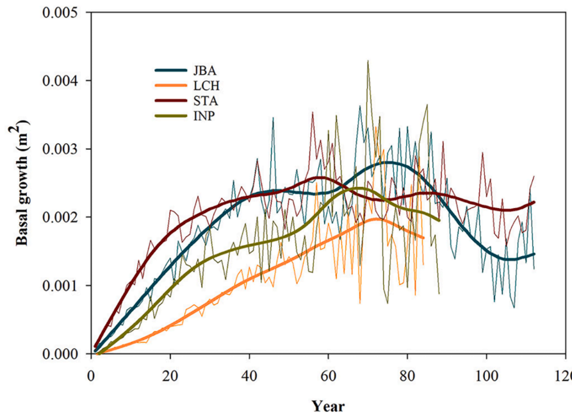

Fig. 3. Variation in basal growth (m^2) in fine lines and a 25-year spline indicating low-frequency variation.

4. Discussion and conclusions

This study presents the variability of diametric and basal growth of *Cedrela fissilis*, a species with a wide distribution across the four studied sites at different ages and diametric sizes. Upon reviewing studies that address the average annual radial increase of *C. fissilis* through dendrochronology (Table 3), it becomes evident that the growth of the species varies significantly across its distribution range, with lower growth averages in more arid sites and higher in sites without water deficit, such as the Mixed Ombrophylous Forest. This variability can also be linked to the species' successional stage, which is often described as a long-lived pioneer too early to late secondary (Reitz, 1978; Santos et al., 2006), featuring an aggressive growth strategy in the first years of life, where growth rates can reach up to 1 cm/year (Cusatis et al., 2013).

Trees of *C. fissilis* in the forests of the Cerrado and Atlantic show varying diametric growth among sites, mainly during the 20–30 cm diameter range, corresponding to the first 50 years old. There are limited studies adopting a class increment approach. Barbosa et al. (2018) examined the growth trajectory of *C. fissilis* in five fragments of a seasonally dry tropical forest, where trees also exhibited significant variation within this diameter class (20–30 cm). Specifically, the JBA site, a previously agricultural area recovered and designated for conservation, and STA with a highly impacted communal management forest, have the highest growth rates during this period. These characteristics suggest that *C. fissilis* trees in these two sites were established in open areas with greater exposure to light and clearly focused their energy and resources on greater growth at smaller diameters. As a light-demanding, pioneer to long-lived secondary species (Reitz, 1978; Carvalho, 2003; Santos et al., 2006), 50 years is likely the time required for establishment, and their higher growth rate is a response to the low competition during their establishment and development. Meanwhile, the LCH and INP sites, with forested areas and a covered canopy, previously used for selective logging, seem to have trees that were established in small clearings within the forest. In these sites, the low growth rates during the first 30 years until the trees reached diameters of about 30 cm indicate that light conditions and high competition limited their growth. It can germinate in both light and shaded environments, but it grows at a slower pace in the shade until gaps in the forest canopy allow for faster growth (Santos et al., 2006). The growth dynamics over the

Table 2
Radial growth by diameter class and the elapsed and cumulative times required for *Cedrela fissilis* to move from one diameter class to the next. The number of specimens included is reported for each site, and an average is given at the end. AAI = Average Annual Increment.

Study site		Diameter class (cm)					Average
		1–10	11–20	21–30	31–40	41–50	
LCH							
	AAI (cm)	0.36	0.45	0.43	0.45	0.42	0.422
	Time required (years)	27	22	23	22	18	22.4
	Accumulated time (years)	27	49	72	94	112	
	Number of trees	20	14	14	14	9	14.2
STA							
	AAI (cm)	0.83	0.72	0.56	0.44	0.31	0.572
	Time required (years)	12	14	18	23	31	19.6
	Accumulated time (years)	12	26	44	67	98	
	Number of trees	27	27	25	20	18	23.4
INP							
	AAI (cm)	0.46	0.55	0.62	0.54	0.47	0.528
	Time required (years)	24	18	16	16	22	19.2
	Accumulated time (years)	24	42	58	74	96	
	Number of trees	25	22	22	16	14	19.8
JBA							
	AAI (cm)	0.64	0.64	0.58	0.44	0.33	0.526
	Time required (years)	15	16	17	22	30	20
	Accumulated time (years)	15	31	48	70	100	
	Number of trees	20	20	20	17	10	17.4

Table 3
Average annual increment (AAI) for the species *Cedrela fissilis* at different altitudes and phytophysiognomes in tropical and subtropical forests. For uninformed altitude, Google Earth data was used considering the information available about the study site.

Reference	Study site	Altitude m. a. s.l.	Phytophysiognomy	Number of trees	AAI (cm)	Age (minimum-maximum)
(Barbosa et al., 2018)	Southeastern Brazil	457–520	Seasonally Dry Tropical Forest	28	0.48	44–180
(Blagitz et al., 2019)	Southern Brazil	500–600	Seasonal semi-deciduous forest	5	0.29	44 (24–83)
(Cusatis et al., 2013)	Southern Brazil	850–970	Mixed Ombrophylous Forest	28	1.10	28 (21–37)
(Figueiredo Filho et al., 2017)	Southern Brazil	850	Mixed Ombrophylous Forest	24	0.42	20–48
(López et al., 2013)	Northeastern Bolivia	426	Cerrado	27	0.60	130 (40–130)
(Marcon et al., 2019)	Southern Brazil	950	Mixed Ombrophylous Forest	26	0.64	74 (43–127)
(Paredes-Villanueva et al., 2016)	Northeastern Bolivia, Concepción	497	Dry Chiquitano	12	0,21	88
	Northern Bolivia, Guarayos	247	Chiquitano transitional Amazonian	11	0.19	84
(Stepka et al., 2021)	Caçador, SC (Southern Brazil)	1140	Mixed Ombrophylous Forest	30	0.44	104 (41–171)
	Irati, PR (Southern Brazil)	850	Mixed Ombrophylous Forest	30	0.40	109 (27–231)
	Sao Francisco de Paula, RS (Southern Brazil)	915	Mixed Ombrophylous Forest	20	0.53	50 (25–71)
(Venegas-González et al., 2018)	Southeastern Brazil	1600	Dense Ombrophylous Forest	10	0.21	77
	Southeastern Brazil	680	Dense Ombrophylous Forest	23	0.24	45

analyzed time show a common point in both sites between 50 and 60 years, where growth rates become similar and converge. There is no information on the time *C. fissilis* trees require to establish themselves or reach the upper canopy of a forest. It will undoubtedly depend on many variables, including ecological, environmental, and site quality factors, particularly light and soil nutrients (Hartshorn, 1980). However, the growth of this species and the dasonomic variables are mainly modulated by the horizontal structure of each site. In the four studied sites, it can be inferred that they need between 50 and 60 years old to establish themselves. Although after this age, periods with some releases in growth rates are observed, this is probably due to some impacts on the forest by logging, wildfires, especially in the INPA and LCH sites where these activities intensified in the last three decades (Rojas et al., 2003).

Analyzing the variations in basal growth where the biological trend is removed, we can observe the age at each site where *C. fissilis* trees reached their growth optimum. These times vary between sites, but generally, the age at which periods of maximum basal area production are observed remains between 60 and 80 years. Having this information and knowing the age trees need to become part of the canopy, reach their growth optimum, and achieve maximum seed production is essential. This data, combined with the passage times, will allow for projecting forest management based on the knowledge of specific events in which the trees of this species change their growth dynamics at a particular site or biome. Furthermore, understanding a site like LCH, where the annual diametric growth is 0.42 cm, the slowest growth occurs between 1 and 10 cm, and to reach a diameter of 50 cm, on average, requires 112 years. Or simply STA, where *C. fissilis* reaches the highest diametric growth during its initial stage, with an average of 0.57 cm, and requires 98 years to reach 50 cm.

This variability in the dynamics of growth rates, ages, and more fragile diameters where *C. fissilis* trees grow less could be reinforced with certain silvicultural treatments to improve growth and survival. The times to reach a certain diameter indicate the need to develop and adopt new forest management strategies that can adapt to climate variability and the ecological growth capacity of species in each biome. Tropical and subtropical forest ecosystems are experiencing very marked short-term structural changes and directional climate changes such as habitat fragmentation, wildfires, and the emergence of pests and/or exotic species (Millar and Stephenson, 2015). Using species like *C. fissilis* to recover degraded areas and simultaneously as carbon storage is crucial to mitigate the effects of climate change, project sustainable management in the long term, and conserve native forests.

Finally, the information presented in this study will undoubtedly help project the maintenance and continuous renewal of *C. fissilis* stands currently under immense pressure due to use of soils. Understanding how forest development, the largest terrestrial carbon sink, will respond to a changing climate is fundamental to predicting the alterations that will occur in forest ecosystems under the new climatic conditions simulated for the 21st century. The study demonstrates the complexity of tree growth rates and the influence of factors such as management, the quality conditions of each site and competition for resources in radial growth, emphasizing the need for a nuanced approach to forest conservation and management in the face of global environmental challenges.

CRediT authorship contribution statement

Lidio López: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Cláudia Fontana:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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