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Drought and climate change incidence on hospot Cedrela forests from the Mata Atlântica biome in southeastern Brazil

Alejandro Venegas-González [a, b, c, *], Fidel A. Roig [d], Claudio S. Lisi [e], Alci Albiero- Junior [c], Clayton Alcarde Alvares [f], Mario Tomazello-Filho [c]

[a] *Facultad de Ciencias, Escuela de Ingeniería Forestal, Universidad Mayor, Camino La Pirámide, Huechuraba, Santiago, 5750, Chile*
[b] *Instituto de Geografía, Pontificia Universidad Católica de Valparaíso, Avenida Brasil, Valparaíso, 2241, Chile*
[c] *Departamento de Ciências Florestais, Universidade de São Paulo, Avenida Pádua Dias 11, Piracicaba, 13418-57, Brazil*
[d] *Laboratorio de Dendrocronología e Historia Ambiental, IANIGLA, CCT-CONICET Mendoza, CC 330, Mendoza, M5502IRA, Argentina*
[e] *Departamento de Biologia, Universidade de Sergipe, Avenida Pádua Dias 11, Piracicaba, 13418-57 2, Brazil*
[f] *IPEF - Instituto de Pesquisas e Estudos Florestais, Via Comendador Pedro Morganti, Piracicaba, 3500, Brazil*

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ABSTRACT

The Atlantic Forest is a Neotropical biome encompassing mainly Brazil's coastline and parts of Paraguay, Uruguay, and Argentina, but today surviving largely in small degraded patches and protected areas. Being a region under threat of extinction of its biological components, little is known about how climate change could influence the biodiversity, dynamics, and stability of this ecosystem. Here, we analyze the response of tree-growth dynamics to regional climate variability and drought, both in temporal and spatial scale. For this purpose, five *Cedrela* spp forest sites located in the biogeographic region '*Serra do Mar*' (AFSM) in southeastern Brazil was considered. This region contains the best-preserved secondary forests of the Atlantic Forest biome, a fact that represents a natural laboratory to ascertain the environmental influence on the tree development through large spatial scales. Correlation and regression analysis were used to explore the relationship between growth and rainfall, air temperature, and a drought index. Results indicate that tree growth performance is highly dependent to the dry season rainfall amounts in the most humid sector of the gradient, while sites settled in areas of lower summer temperatures, rainfall during the warm-rainy season is the main determining factor influencing tree-growth dynamics. This implies that the same environmental factor (rainfall) affect differentially the growth of *Cedrela* sites depending on the sector in the gradient in which they are. We found that the population located at the highest-altitude site experienced a growth decline in recent decades linked to increases of winter regional warming, being more sensitivity to long periods of drought (6–10 years). In summary, the seasonal response of cambium activity in AFSM trees to rainfall varies across a climatic gradient. These results are crucial to understand how the present and future global change may differentially impact on tree population dynamics of montane Neotropical forests.

* Corresponding author. Facultad de Ciencias, Escuela de Ingeniería Forestal, Universidad Mayor, Camino La Pirámide, 5750, Huechuraba, Santiago, Chile.
E-mail addresses: alejandro.venegas@umayor.cl (A. Venegas-González), froig@mendoza-conicet.gob.ar (F.A. Roig), cslisi@ufs.br (C.S. Lisi), albierojunior@usp.br (A.A. Junior), caalvares@yahoo.com.br (C.A. Alvares), mtomazel@usp.br (M. Tomazello-Filho).

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1. Introduction

The Atlantic Forest biome, or Mata Atlântica, is one of the largest areas of tropical ecosystems and biodiversity in the World (Myers et al., 2000). It is distributed in Brazil almost as a continuous strip in the Atlantic coastal plains although discreetly extend inland to encompass the foothills, the slopes and the highlands of Serra do Mar. Fragments of this forest are also found in Paraguay and the NE of Argentina (Rodrigues et al., 2009). The Atlantic Forest is considered a threatened biome due to the devastation that suffered during centuries by human occupation (pastures, crops and higher urban growth) and intensive exploration of its resources (mainly timbers) (Dean, 1996). Currently the Atlantic Forest is highly fragmented and it is reduced to less than 16% of its original area (Ribeiro et al., 2009). For these reasons the Atlantic Forest was declared as a Biosphere Reserve by UNESCO and has received the status of conservation hotspot (Myers et al., 2000).

Southeastern Brazil contains about 60% of the Brazilian sector of the Atlantic Forest (Rodrigues et al., 2009), and within this area, the São Paulo state shows the highest level of fragmentation and deforestation of this biome. Here, the Atlantic Forest is mostly concentrated in the coastal region, commonly named Serra do Mar (hereafter Atlantic Forest of Serra do Mar, AFSM; Colombo and Joly, 2010). The AFSM is characterized by a climatic gradient, ranging from 0 to 2000 m above sea level (m a.s.l.), involving changes in floristic composition and structure of the tree communities (Lacerda, 2001).

The AFSM represents the best-preserved identity of the Atlantic Forest biome, holding 36.5% of its original vegetation (Rodrigues et al., 2009). This includes populations of *Cedrela odorata* L. and *Cedrela fissilis* Vell., two Meliaceae trees considered among the most appreciated woods for their quality and aesthetics since the times of European colonization in South America (Dean, 1996). For this reason, they have been extensively exploited and today they are in a state of vulnerability and placed as target species in the red book of the Brazilian flora (Martinelli and Moraes, 2013). Both species have a similar crown and stem shape, wood anatomy, phenology, and autoecology (Muellner et al., 2010; Tomazello Filho et al., 2000).

Once a global warming has increased in the order of 0.07 °C per decade since 1900 (Jones and Moberg, 2003), and models predict an intensification during the 21st century (Pachauri et al., 2014), an increasingly frequency of warm nights and floods is expected in southeastern Brazil (Marengo et al., 2009), where AFSM occurs. This has been alerted as a worrying situation that compromises the plant diversity and sustainability of the Atlantic Forest (Colombo and Joly, 2010). Although many efforts have been made to identify how the ongoing global change affects the dynamics of different tropical tree species (e.g. Gea-Izquierdo and Cañellas, 2014; Mendivelso et al., 2014; Venegas-González et al., 2018; Allen et al., 2015), scarce is the knowledge about the effect of this global climate phenomenon on the Atlantic Forest.

The analysis of growth dynamics in environmental gradients is relevant to understand more in detail the synecology and resilience of forests. Since precipitation and air temperature may vary along a region, that change may finally be reflected in the growth of trees, giving the opportunity to identify the influence of stress factors along environmental gradients (e.g. Camarero and Gutiérrez, 2004, Lara et al., 2005). In this sense, environmental gradients can serve as potential natural laboratories to infer forest responses to global warming and climate change (Jump et al., 2009). However, the climatic response and drought sensitivity of Atlantic Forest along climatic gradients have been poorly documented up to now, a situation that can be reversed if we document what would be the reaction of these forests in face of climate change intensification. In this sense, the dendrochronology (the analysis of annual tree rings) allows us to evaluate forest growth and their association with climate variability and change at different spatial and temporal scales (Fritts, 1976). Previous dendrochronological studies in *Cedrela fissilis* and *Cedrela odorata* forests from the Neotropics showed that seasonal rhythms of radial growth are particularly influenced by rainfall amount at the end of the previous growing year (Brienen and Zuidema, 2005; Dünisch, 2005; Dunisch et al., 2003; Worbes, 1999). However, none of these studies considered a dendroecological vision under a biogeographic approach, considering the wide distribution of the genus. In the subtropical forests of Serra do Mar, moreover, the role of rainfall in annual xylem development of *Cedrela* spp. is poorly known, particularly under the influence of major droughts.

To partially solve the uncertainty of how long-term droughts and precipitation/temperature changes affects tree growth of Atlantic Forest remnants, we explored climate signals in *Cedrela* spp. tree rings at spatial and temporal scales along an environmental gradient. Based on the principles that tree rings can respond with differential intensity to climate variability (Fritts, 1976; Schweingruber, 1996) across environmental gradients (Jump et al., 2009), we first hypothesized that this phenomenon influence the ecology of the *Cedrela* forests in existing climatic gradients of Southeastern Brazil. Considering the divergences proven by different patterns of drought-growth responses in others Neotropical tree species, mainly in their long-term sensitivity (Mendivelso et al., 2014), we hypothesized that severe drought events linearly affects growth, even with delay effects in subsequent years of the event. Considering the ecological evidences of negative impacts by recent climate change on forest ecosystems in the World (Bonan, 2008; Walther et al., 2002), and the inverse relationship between climatic variables and elevation (Jump et al., 2009), we expect a negative growth resilience to rising global temperatures, mainly in sites located at higher altitudes, where trees are probably more adapted to lower temperatures.

2. Material and methods

2.1. Study sites and selected species

Five sites from southeastern Brazil containing populations of *Cedrela odorata* and *C. fissilis* were selected for this study (see Table 1). All sites are located in the center of the biogeographic subregion of the Atlantic Forest, the AFSM (22°-24°S), and all cases are represented by a secondary forest phytophysiognomy, recovering from past exploitations (Fig. 1). The subregion,