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Fire records in tree rings of *Moquiniastrum polymorphum*: potential for reconstructing fire history in the Brazilian Atlantic Forest

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ABSTRACT

Fire disturbance affects the composition, structure and dynamics of vegetation. Historical records of fire events exist in some places, but they are generally limited in temporal and spatial extent. Tree-ring research is a useful tool for fire history reconstruction and can contribute important long-term ecological data. We tested the hypotheses that *Moquiniastrum polymorphum* (Less.) G. Sancho, a widespread species in Brazil that occurs in burnt areas of Atlantic Forest, produces annual growth rings and that its wood can record fire incidence by datable fire scaring. Our results corroborate these hypotheses and indicate that the species has potential for fire history reconstruction.

Keywords: Camará, Cambará, dendrochronology, fire history, fire scars, *Gochnatia polymorpha,* growth rings, *Moquiniastrum polymorphum*, pyrochronology

Introduction

Fire disturbance can be the result of natural factors or human activity and affects the composition, structure and dynamics of vegetation (Thonicke *et al*. 2001). Dendrochronology is useful for the reconstruction of fire history (pyrochronology) and has been used in this way in both temperate and tropical forests (Worbes 1995; Grau *et al*. 2003; Lopez *et al*. 2012; Mundo *et al*. 2013; Rink & Thompson 2014). In tropical regions many species are known to produce distinct growth rings with potential for dendroecological research (Worbes 2002; Brienen *et al*. 2009; Rozendaal & Zuidema 2011). In the Atlantic Forest, growth ring research has helped to understand individual growth and species development, as well as the associated factors (Callado *et al*. 2001; Brandes *et al*. 2011; 2015; Andreacci *et al*. 2014; Shimamoto *et al*. 2014; Costa *et al*. 2015). Dendrochronology offers a temporal and spatial record of fire disturbance that is useful for understanding historical ecologies in this complex biome.

Historically, fire has been a common practice for clearing forest in the Atlantic Forest, a practice known as slash-and-burn (Dean 1996). Fire events remain frequent in the Atlantic Forest, with more than 136,000 outbreaks being recorded from 2007 to 2016, 37 % of which have been in the last three years (INPE 2017). Therefore, impacts of fire at the community scale, such as decreases in tree species richness and abundance (Melo & Durigan 2010; Sansevero *et al*. 2017), may be underestimated since fire data are restricted to a few places and over a short time span. Tree-ring analysis could expand the temporal and spatial extent of fire records. In trees and shrubs, the occurrence of fire produces scaring, which is preserved in woody tissue. In long-lived woody species with distinct annual growth rings, these scars have proven useful for dating fire occurrence

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and periodicity (McBride 1983; Fritts & Swetnam 1989; Worbes 1995; Stahle 1999).

Moquiniastrum polymorphum (Asteraceae) (new combination for *Gochnatia polymorpha*), is a shrub or small tree that is widely distributed in Brazil, having been reported from the Northeast, Central-West, Southeast and South regions of the country. It occurs in the Atlantic Forest and Cerrado biomes, more precisely in cerrado (*lato sensu*), gallery forest, seasonal forest and ombrophilous forest vegetation types (*Moquiniastrum* in Flora do Brasil 2020 em construção 2017). Popularly known as Camará and Cambará, the national conservation status for the species is "Least Concern" (CNCFlora 2017), although regionally it is considered "Vulnerable" according to the red list of threatened plants for the state of Rio Grande do Sul (State Decree number 42,099 from December 31, 2002). The species dominates some early regeneration stages in areas previously covered by ombrophilous forest that have been disturbed by deforestation, slash-and-burn practices and fire (Uhlmann *et al*. 2014; Sansevero *et al*. 2017). It is also freeze resistant (Brando & Durigan 2005) and survives fire (Kolb 1993; Sánchez-Tapia 2011) due to its thick bark. Its wide distribution, local relative abundance and fire resistance make *M. polymorphum* a good candidate for pyrochronological study in the Atlantic Forest.

In the present study, we demonstrate that *M. polymorphum* produces annual growth rings and that when exposed to the fire, fire scars appear and the year of these events can be determined. These results have important implications for detecting past fire events and for understanding the ecological resilience and shifts in species composition of communities subjected to fire in the Brazilian Atlantic Forest, a global biodiversity hotspot.

Materials and methods

Research was conducted at Poço das Antas Biological Reserve (PABR), (22°30'-22°33'S 42°15'-42°19'W) in the state of Rio de Janeiro, Brazil. This reserve occupies approximately 5,160 hectares that include forest and non-forest phytophysiognomies (Lima *et al*. 2006). Non-forest formations with anthropic interference have a significant presence in the study area (47.9 %). Anthropic actions, including wood exploitation, fire, artificial drainage and river course modification, have contributed to the attrition of forest species in these areas (Lima *et al*. 2006). Fire has been reported to have been frequent in recent decades (Lima *et al*. 2006). Since 1990, PABR has recorded and mapped all fire events by official technical reports. Topography of the area is characterized by plains and undulations with hills and hillocks with rounded profiles varying from 19 to 200 m in elevation and separated by flat-bottom floodplain wetlands. The climate is of the Aw type according to the Köppen-Geiger system (tropical with a dry season in winter). Average annual rainfall is 1,995 mm and the average annual temperature is 25.5 °C (Lima *et al*. 2006; Moraes *et al*. 2006).

Moquiniastrum polymorphum (Less.) G. Sancho is a representative species of the floristic composition of secondary forests and areas in early regeneration in PABR (Lima *et al*. 2006). In disturbed areas, the species occurs in high densities and appears to play an important ecological role in post-fire succession (Neves & Peixoto 2008; Sánchez-Tapia 2011; Prieto *et al*. 2017), due to its ability to survive and resprout quickly following fire.

We sampled 53 individuals in sites where we had historical records of fire, according to PABR technical reports, with burning marks at the base and with or without externally visible wounds. Stem samples were collected from plants in areas with recorded incidence of fire in the winter: 1990, 14 samples; 2002, 17 samples; 2005, 2 samples; 2002 and 2005, 5 samples; and 2010, 15 samples (Tab. 1). Samples were collected in July 2007 and April 2012 from the main stem using a hacksaw and chisel (section, 31 samples), and an increment borer (22 samples). We collected samples from where external wounds were visible (nine samples) and, when external wounds were not visible, from where the bark appeared more burnt (44 samples). The wood samples were deposited in the wood collection of the Herbário de Niterói (NITw).

Collected samples were polished with the help of a razor and/or an orbital sander using sandpaper with progressively finer grit to facilitate the observation of, and clear distinction between, growth rings. Observations were performed with a stereoscopic microscope (Leica). Dating of growth rings followed Schulman's (1956) convention for dendrochronological research in the Southern Hemisphere. We evaluated the presence of fire scars for the recorded fire dates. The annual periodicity of growth ring formation was evaluated by the correspondence of fire scars with the known dates of fire (Worbes 1995; Lopez *et al*. 2012).

For anatomical description of the growth rings in bright-field microscopy, samples were softened in boiling water and glycerin, 12 to 30 µm-thick sections were made in transversal plain using a Spencer 860 sliding microtome. After cleaning, they were stained with safranin and astra blue (Bukatsch 1972), dehydrated, and mounted on Entellan resin in permanent slides. Slides were observed using a Primo Star Zeiss microscope, and images were captured with ZEN software for Windows linked to the microscope through a Media Axiocam ERC 5s video camera.

Results and discussion

Moquiniastrum polymorphum produces annual growth rings, which can exhibit visible scars from fire events such as pith flecks, traumatic canals and external wounds that expose wood. We observed such scars in 17 individuals that corresponded with the dates of fires reported by PABR

Table 1. Sample number, year of fire incidence, year of collection, method of collection, and the presence of fire scars in the year of fire incidence. *** = Individual with externally visible wound.

Sample number	Collection year	Collection method	Fire year	Fire scar
NITw909	2007	section	2002	present***
NITw910	2007	section	2002	present
NITw911	2007	section	2002	present
NITw912	2007	section	2002	present
NITw913	2007	section	2002	present
NITw914	2007	section	2005	present
NITw915	2007	section	2005	present
NITw916	2007	section	2005 / 2002	present***
NITw917	2007	section	2005 / 2002	present
NITw918	2007	section	2005 / 2002	present
NITw919	2007	section	2005 / 2002	present***
NITw920	2007	section	2005 / 2002	present***
NITw921	2012	increment borer	1990	
NITw922	2012	increment borer	1990	
NITw923	2012	increment borer	1990	
NITw924	2012	increment borer	1990	
NITw925	2012	increment borer	1990	
NITw926	2012	increment borer	1990	
NITw927	2012	increment borer	1990	
NITw928	2012	increment borer	1990	
NITw929	2012	increment borer	1990	
NITw930	2012	section	1990	
NITw931	2012	section	1990	
NITw932	2012	section	1990	
NITw933	2012	section	1990	
NITw934	2012	section	1990	
NITw935	2012	increment borer	2002	
NITw936	2012	increment borer	2002	
NITw937	2012	increment borer	2002	
NITw938	2012	increment borer	2002	
NITw939	2012	increment borer	2002	
NITw940	2012	section	2002	present***
NITw941	2012	section	2002	present***
NITw942	2012	section	2002	
NITw943	2012	section	2002	
NITw944	2012	section	2002	
NITw945	2012	section	2002	
NITw946	2012	section	2002	
NITw947	2012	increment borer	2010	
NITw948	2012	increment borer	2010	
NITw949	2012	increment borer	2010	
NITw950	2012	increment borer	2010	
NITw951	2012	increment borer	2010	
NITw952	2012	increment borer	2010	
NITw953	2012	increment borer	2010	
NITw954	2012	increment borer	2010	
NITw955	2012	section	2010	present***
NITw956	2012	section	2010	present***
NITw957	2012	section	2010	present***
NITw958	2012	section	2010	
NITw959	2012	section	2010	
NITw960	2012	section	2010	
NITw961	2012	section	2010	

(Tab. 1). In individuals where fire damaged a wide area of the vascular cambium, an external wound would be present where new wood was not produced and which would contrast with adjacent areas where the cambium remained productive (Fig. 1A). In samples where fire had damaged a more limited area of the vascular cambium, pith flecks and traumatic canals were produced, while the vascular cambium reestablished continuity to produce secondary xylem and secondary phloem (Fig. 1B).

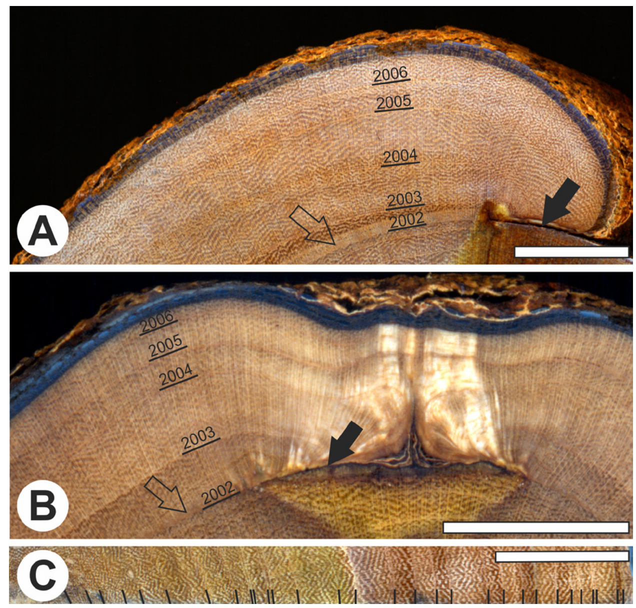

Figure 1. Transverse sections (stereomicroscopy) of *M. polymorphum*. **A.** Sample with externally visible wound. Fire incidence in 2002. **B.** Sample without externally visible wounds. Fire incidence in 2002. **C.** Sample collected with increment borer without fire scars. Bars indicate growth ring boundaries. Black arrow indicates fire scar. Clear arrow indicates differentiated early wood. Scale bars = 1 cm.

Moquiniastrum polymorphum can be regarded as fire resistant because 36 of the individuals exposed to fire did not show scars (Tab. 1), which may be related to its thick bark (Sansevero 2013). This finding is in agreement with *in situ* observations made by several researchers (Neves & Peixoto 2008; Sánchez-Tapia 2011) but represents the first anatomical observational confirmation of fire resistance for the species. Bark thickness has been shown to be an important feature for stem survival through fire (Lawes *et al*. 2011).

None of the samples collected with the increment borer showed fire scars (Fig. 1C, Tab. 1), but it is unclear whether these individuals were undamaged by fire or whether the limited sample-size obtained by the increment borer failed to obtain tissue from fire-wounded areas of the stem. In some samples, differentiated early wood was detected that was similar to the early wood observed adjacent to fire scars (Fig. 1A-B), which was characterized by abundant axial parenchyma (Fig. 2A-B), however, these were not considered fire scars.

The annual growth rings of this species are delimited by tangentially arranged early wood vessels and radially flattened late wood fibers (Fig. 3A-B). The anatomy of growth rings match with features described by Sonsin *et al*. (2014). Tomazello-Filho *et al*. (2004) described *M. polymorphum* as having scarcely distinct annual growth rings, but in our samples we detected distinct rings regardless of the collection method.

This result indicates that *M. polymorphum* has potential for reconstructing fire history. Grau *et al*. (2003) suggest that pyrochonology may be useful in the reconstruction of historic fire regimes when three important features are present, specifically, the fire must have been abundant in the system; indicator species must be damaged by fire so as to produce visible scars, but yet survive fire damage; and fire scars must be datable. Previous studies in PABR have reported the persistence of *M. polymorphum* after fire (Neves & Peixoto 2008; Sánchez-Tapia 2011), indicating that many individuals of this species did not die as a result. We sampled live individuals with datable fire scars and post-fire growth. Technical reports from PABR report an incidence of fire (size and duration of events) sufficient to produce a historical record. Populations of *M. polymorphum* in PABR appear seem to meet the requirements necessary for establishing a dendrochronological record of fire regimes in this ecosystem.

The number of scars in the stems of *M. polymorphum* may not represent the total number of fire episodes, given that fire scars were not always recorded after fire passage. The intensity of fire, fire type (surface fire, crown fire and ground fire) and other environmental conditions would affect the fire record (Taylor & Skinner 2003; Speer 2010). Lack of scars in some trees does not indicate that fire event does not wounded other trees on nearby sites and does

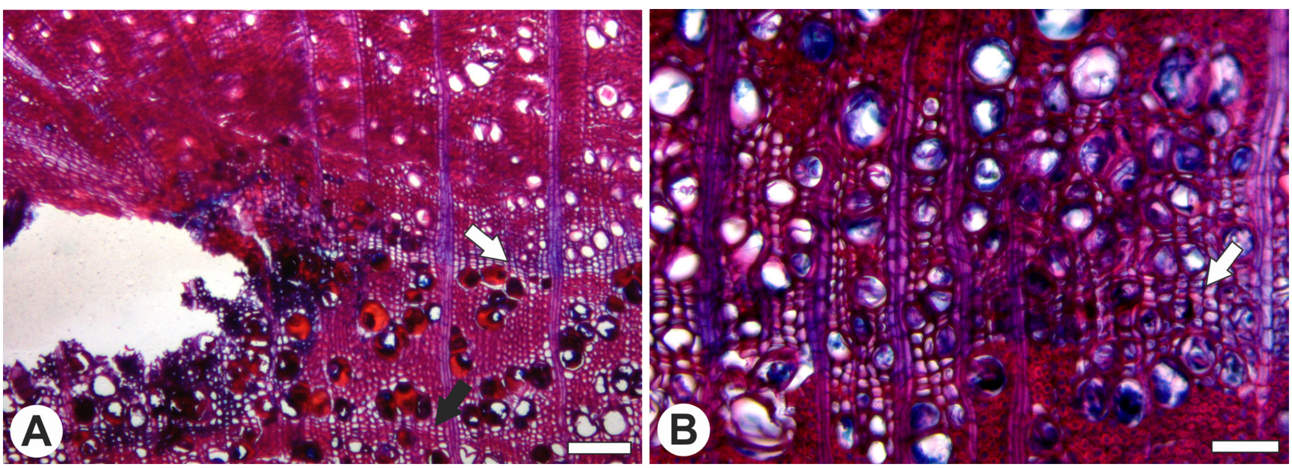

Figure 2. Transverse sections (bright-field microscopy) of *M. polymorphum*. **A.** Fire scar and adjacent differentiated early wood with abundant axial parenchyma. Scale bar = 200 μm. **B.** Differentiated early wood with abundant axial parenchyma. Scale bar = 100 μm. Clear arrow indicates differentiated early wood. Black arrow indicates growth ring boundary.

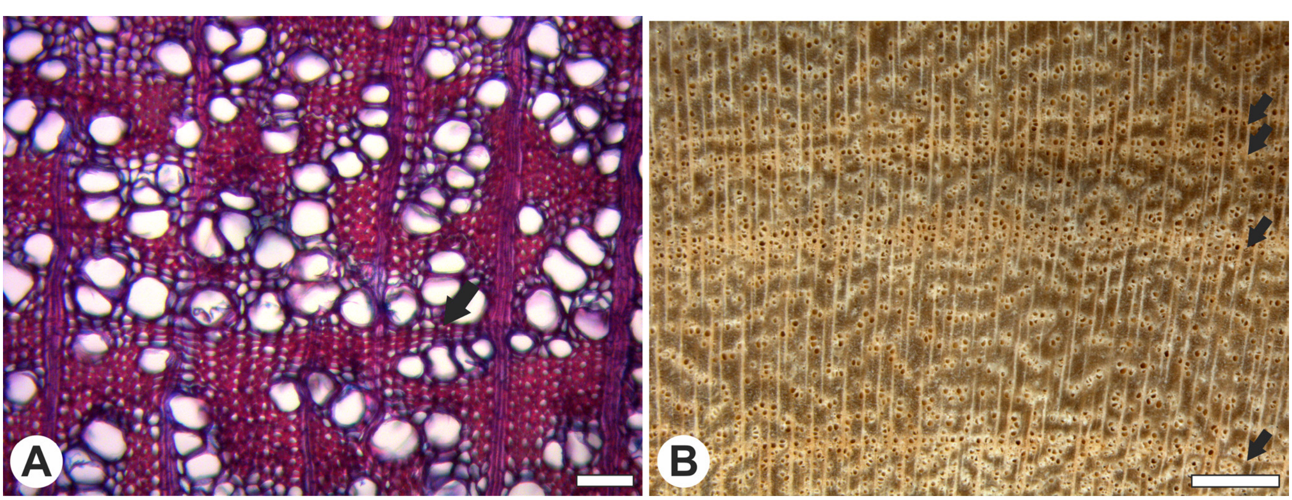

Figure 3. Transverse sections of *M. polymorphum* with growth ring boundaries delimited by tangentially arranged early wood vessels and radially flattened late wood fibers. **A.** Bright-field microscopy. Scale bar = 100 μm. **B.** Stereomicroscopy. Scale bar = 1 mm. Black arrows indicate growth ring boundaries.

not reduce the potential of the species for reconstructing fire history. To overcome this condition, researches for reconstruction of fire histories perform collection of many trees and individuals with externally visible fire scars (Grau *et al*. 2003; Taylor & Skinner 2003; Horne & Fulé 2006; Everett 2008). In the present study all individuals with visible external wound recorded fire events.

We conclude that *M. polymorphum* produces annual growth rings and seems to produce datable fires scars that can be used in the reconstruction of fire history. Considering the widespread distribution of *M. polymorphum* (two different biomes in Brazil) our results have important implications for future research that investigates fire events on a broad scale. For future research using this approach we recommend that individuals with externally visible fire scars be selected and that sections, as opposed to increment borer samples, be used for sampling wood.

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