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Tree basal area increment models for *Cedrela*, *Amburana*, *Copaifera* and *Swietenia* growing in the Amazon rain forests

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ABSTRACT

Little is known about sustainable forest management and tree growth in the Amazon forest. Reliable growth data from trees are very important in the context of forest management. Tree-characteristics such as architecture and competition are associated with diameter growth. Previous studies analyzing tree growth have indicated that these variables can describe these effects for temperate and boreal forests. However, the role of these effects for the growth of tropical trees needs to be enhanced for forest management practices. Here, we reconstructed the periodic annual basal area increment (BAI_i cm^2 yr^{-1}) of four long-lived timber species from the Amazon forest of Brazil: (i) *Cedrela odorata,* (ii) *Amburana cearensis,* (iii) *Copaifera pauper* and (iv) *Swietenia macrophylla* to investigate the growth development. The study focuses on (i) drivers important for individual tree growth, (ii) calibration of an individual tree basal area increment model for each of the four species, and (iii) assessing the practical implementation of our findings for enhancing sustainable forest management of these four tree species in the Amazon rainforest. The results exhibit a significant relationship between increasing basal area increment versus increasing crown length and decreasing competition expressed by Hegyi's index. Trees sampled in densities greater than 25 m^2 ha^{-1} had their *BAI%* significantly reduced. For *Cedrela* an additional negative impact on basal area increment from liana load is evident. Our findings reinforce the importance of release trees to obtain better crown exposure.

1. Introduction

The Amazon forest in South America comprises one of the world's largest biodiversity pools, and considerable efforts have been put in place to protect this forest. Nevertheless deforestation is still the major threat mainly because of the lack of knowledge in sustainable forest management (Godar et al., 2012).

The Brazilian Forest Service has established norms addressing sustainable forest management by ensuring biodiversity and conservation issues as well as providing saw-timber for commercial use (IBAMA, the agency responsible for forest policy and law enforcement, Normative Instruction 5, 2006). A practical guideline provides management practices by using a Minimum Cutting Diameter (*MCD*) of 50 cm, a cutting cycle of 25–35 years and an average reference increment rate of 0.86 m^3 ha^{-1} yr^{-1} for all commercial forest tree species. This regulation serves as a minimum harvesting requirement to avoid overcutting within the forest. It is important because the Amazon rainforest is comprised of a large number of tree species, but only some of them are of commercial interest for the timber industry (nowadays an average of 20 species are usually harvested).

The practical problem of these regulations is that no information on species-specific changes in volume growth over time is available which limits sustainable forest management. This may lead to over cuttings or even an exploitation of high value tree species within such forests even if the "increment-reference-system" with a cutting cycle of 25–35 years (see IBAMA/Normative Instruction 5, 2006) is applied (Schöngart, 2008). This suggests that a species-specific silvicultural management and controlling system is needed to ensure sustainable wood production but also to address conservation issues of the forests.

A first step is to enhance our understanding of the annual increment rates by tree species, site, as well as stand conditions and implement these findings in simple species specific growth models to guide the Amazon forest management.

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In temperate forests, annual increment rates and thus tree and stand age, are easy to determine due to the distinct seasonality and the appearance of the tree rings. However, within rainforests, tree rings may follow a different pattern and therefore they may not be usable as a measure of annual growth rates (Lieberman and Lieberman, 1985). This makes the determination of annual increment rates by tree species and stand age much more difficult. Previous studies on individual tree-growth in the Amazon forest were questioned due to this problem (e.g. Lieberman and Lieberman, 1985), while recent research based on tree ring analysis has proven that annual tree rings exists for trees growing in the Amazon forest (Worbes, 1995). Tree rings are caused by the occurrence of a specific annual dry season (Brienen and Zuidema, 2005; Schöngart, 2008). This change from a wet to dry season evokes changes in wood anatomy and wood density (early wood, late wood) and turn the tree-ring more visible allowing for a measure of the annual diameter or individual tree basal area increment rates (da Cunha, 2009, Fig. 1). Based on these findings, growth data collection and interpretation for developing growth models are possible for some trees of the Amazon forest.

Growth models predict tree growth over time based on relationships between increment rates and potential drivers. Commonly such drivers are crown attributes, as a surrogate for the assimilation surface of a tree (Hasenauer and Monserud, 1996), competition variables for determining the competitive situation of a given tree versus its neighbors (Monserud and Sterba, 1996),

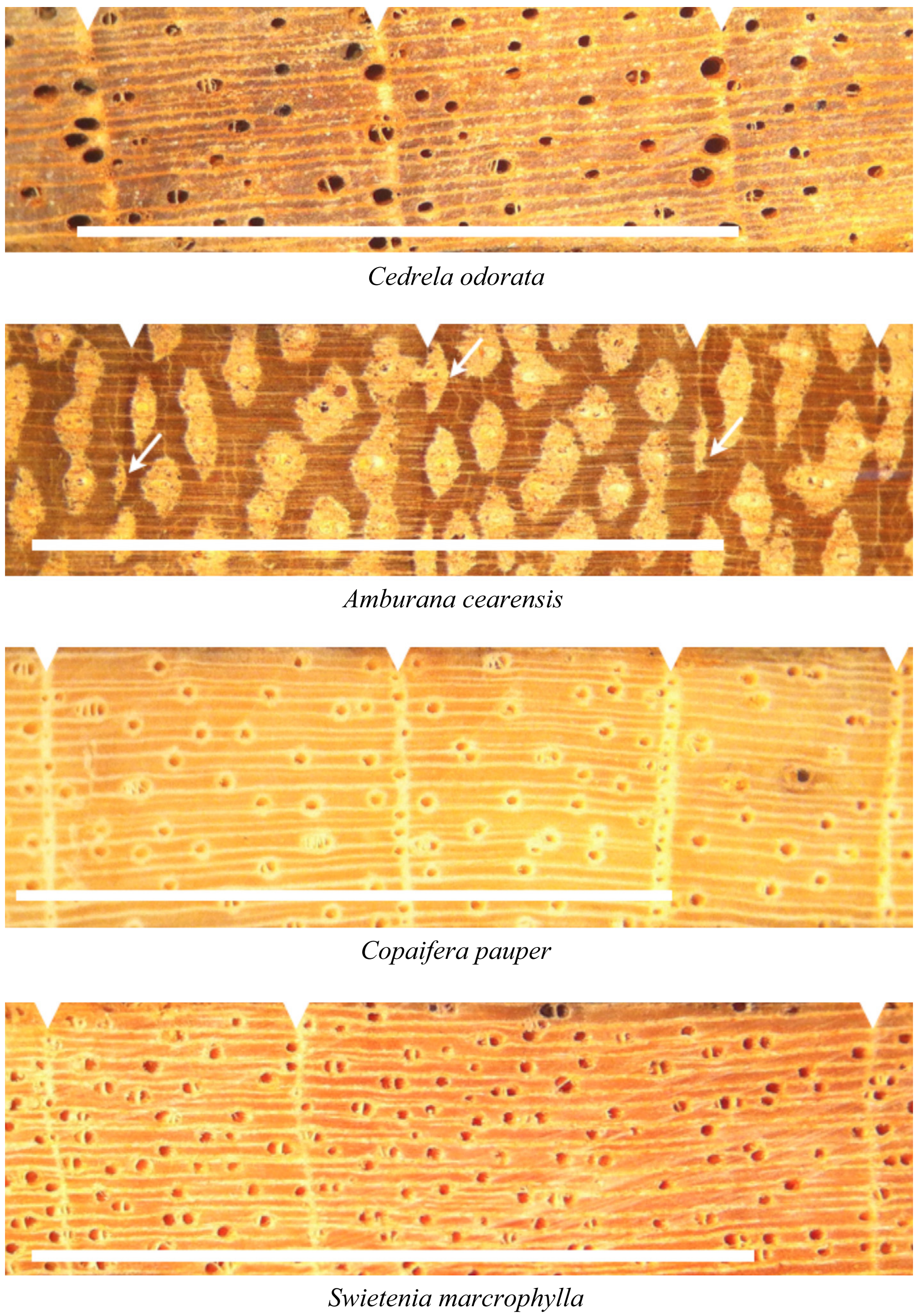

Fig. 1. Macroscopic wood anatomy of object trees species showing ring boundaries (cava). For *Cedrela* marginal porous band occur at the beginning of the growth phase and presents diminution in vessel diameter with the proximity of the cambial dormancy. *Swietenia* clear differ from *Cedrela* due uniform vessel diameters without marginal parenchyma bands. Tree rings characterized by alternating fiber bands with aliform paratracheal parenchyma turning narrow at the end of the growth phase (Arrows) in *Amburana*. Horizontal bars indicated 10 mm length. *Copaifera* presents axial parenchyma that contains axial porous from where canals secret oil-resin located in the late wood.