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# Carbon stock classification for tropical forests in Brazil: Understanding the effect of stand and climate variables

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## ABSTRACT

Forest ecosystems play an important role in the global carbon cycle and with this there is an increasing need for quantifying carbon at large scales. The aim of this research was to develop a system for classifying tropical forests in Brazil into carbon stock classes, applicable to large areas, emphasizing different sets of stand and climate variables. We used data from forests inventoried in two Brazilian biomes: Atlantic Forest and Savanna. We applied discriminant analysis to generate a classification rule by biome. Three types of variables were used: climatic (mean annual temperature and precipitation, or MAT and MAP), geographical (latitude and longitude), and stand variables (density of trees, mean height or $\bar{h}$, mean square diameter or *dg*, and basal area or *G*). We combined these into three scenarios for analysis: (1) all variables; (2) all variables, except $\bar{h}$; (3) all variables, except $\bar{h}$, *dg*, and *G*, to determine their contribution to classifying carbon stocks. We also assessed each set of variables in the presence/absence of MAP and MAT, used simultaneously or not. The best classification rules resulted in 83.9% and 98.5% of correct classifications for Atlantic Forest and Savanna biomes, respectively. Stand variables contributed significantly to successful classification; for the Atlantic Forest biome, *dg* and G contributed from 36% to 42% and $\bar{h}$ from 2% to 5%, yet for the Savanna biome the gains ranged from 31% to 42% and 6%–9%, respectively. For the climate variables, the simultaneous use of MAT and MAP played an important role in the classification in all cases in the Atlantic Forest biome, contributing up to 9.2% for the classification. In the Savanna biome, we found significant positive gains by the simultaneous use in the absence of $\bar{h}$, *dg*, and *G*, on the other hand, the simultaneous use exerted negative effects when $\bar{h}$ was used. We concluded that climate variables are most helpful when stand variables are not included in the analysis. In terms of carbon stock variation, the Atlantic Forest biome tended to be more sensitive to both MAT and MAP, whereas the Savanna biome had no significant climatic dependence in the classification. The variable $\bar{h}$ exerted a greater effect in the Savanna biome than in the Atlantic Forest, however, basal area and mean square diameter were the most important in both biomes.

## 1. Introduction

Many scientists associate greenhouse gas (GHG) emissions, especially carbon dioxide, as contributing to global climate change. However, many issues regarding carbon sequestration and emission potential from forests are not well understood, including how above-ground carbon stocks are spatially distributed (Saks et al. 2007, Baccini et al. 2012).

Brazil is one of the five biggest carbon dioxide emitting nations globally and its emissions are mostly caused by land-use changes and

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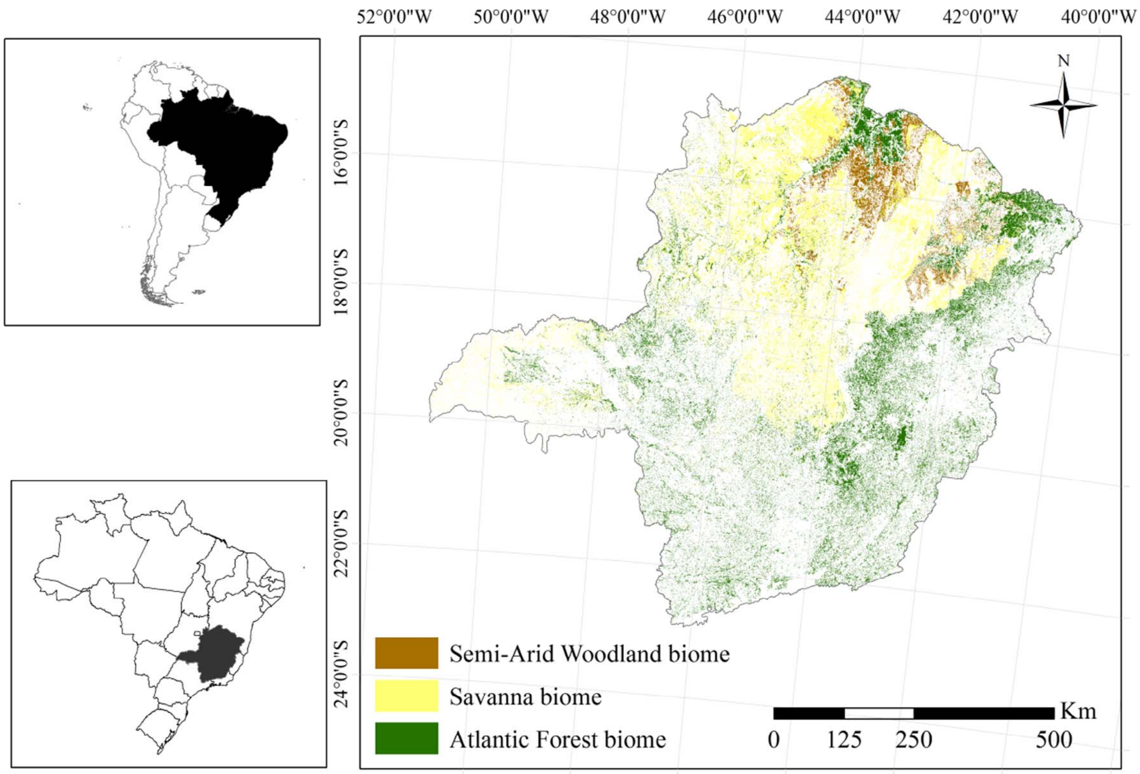


**Fig. 1.** Forest coverage for different biomes in the state of Minas Gerais, Brazil.

deforestation (MALFS 2010, Baccini et al. 2012, Matthews et al. 2014). The reason for this is related to the high levels of terrestrial carbon stocks found in Brazil's forest ecosystems, especially in the Amazon and Atlantic Forest biomes (Nogueira et al., 2015, Delpierre et al. 2012, Domke et al. 2012). For example, in the state of Minas Gerais, which has large areas of Savanna and Atlantic Forest types, land-use changes and deforestation are responsible for 54% of the total GHG emissions (Malfs 2010).

The role of forest carbon in the global climate highlights the importance of public polices to control carbon emission and sequestration, which in turn depend on accurate methods for measurement and verification of carbon stocks (Liski et al. 2006, Mackey et al. 2013, Morais et al. 2013, Scolforo et al. 2015). Brazil and many other countries have conducted National Forest Inventories (NFIs) aiming to, among other things, quantify biomass and carbon stocked in their forests. Due to the low sampling intensities generally used in regional and national forest inventories, forest carbon stock estimates are often only available at large scales. Modelling forest biomass and carbon at finer scales is of particular importance to forest management because management decisions are made at local or regional scales (Wilson et al. 2013).

There is a need in Brazil, which has recently began its NFI, for efficient methods for extrapolating data to finer scales. Wilson et al. (2013) suggest disaggregating large scale estimates into maps which can improve strategic forest management plans by providing information on spatial variability in forest carbon stocks. This information is critical for countries committed to climate agreements such as UNFCCC (United Nations' Convention Climate Change) and COP (Conference of the Parties); such agreements require assessment and reporting of forest carbon stocks and emissions, including losses from forest carbon pools (Cienciala et al., 2008; Domke et al., 2012; Wilson et al. 2013).

In a large nation like Brazil, it is necessary to understand how forest biomass and its associated carbon vary relative to local climate and geographic location, because there should be differences among biomes, where weather and broad plant community types are sharply contrasted (Baraloto et al. 2011). Scolforo et al. (2015) showed correlations between forest carbon and geographical variables (latitude and longitude, in degrees), which is expected due to their relation with the global temperature (Keyser et al. 2000, Wit et al. 2014). At local scales, stand variables (e.g. mean stem diameter, basal area, mean height) reflect the collective dimensions of tree trunks, branches, and crowns, and are necessarily crucial to accurately estimating forest carbon stocks (Pan et al., 2011, Chave et al. 2004, Chave et al. 2005, Baraloto et al. 2011, Woodall et al. 2011). Climate variables should also help to explain local carbon stock variations from regional models (Baraloto et al. 2011, Delpierre et al. 2012, Jantz et al. 2014). However, carbon-climate interactions can be complex. For example, it has been observed that increasing temperatures could affect forest carbon sequestration either positively or negatively (Lindroth et al. 1998, Kueppers and Harte 2005, Raich et al. 2006, Saks et al. 2007, Grosso et al. 2008). Precipitation should have a strong influence on forest carbon stock potential. For example, the discrepancy in carbon stocks found in Brazilian rainforests versus Semi-Arid forests is related to the higher levels of rainfall in the rainforests (Schuur 2003, Grosso et al. 2008, Ciais et al. 2009).

For this research, we used data from the Forest Inventory of the State of Minas Gerais, Brazil and discriminant analysis to classify tropical forests based on their carbon stock per unit area. We examined three types of variables: location, climate, and stand variables to develop a general rule, applicable to large areas, for classifying tropical forests into classes of aboveground forest carbon stocks. We emphasized the stand and climate effects in order to understand their impacts on carbon stocking.

## 2. Material and methods

### 2.1. Study area and data collection

The study area included the Brazilian state of Minas Gerais, which has a total area equal to 586,528 km$^2$ and a forest coverage close to 35%, distributed in three biomes: Atlantic Forest, Savanna, and Semi-