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LIDAR-based estimation of bole biomass for precision management of an Amazonian forest: Comparisons of ground-based and remotely sensed estimates

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ABSTRACT

Based on airborne LIDAR data on canopy morphology and height of Amazon forest trees, we developed allometric models to estimate dry biomass stored in the boles of dominant and co-dominant individuals and compared these results with those from equations based on traditional variables such as diameter at breast height (DBH). The database consisted of 142 trees of interest for logging in a forest under management for timber in Brazil's state of Acre. The trees chosen for study were selected through proportional sampling by diameter class (ranging from 45 to 165 cm DBH) in order to properly represent the dominant and co-dominant tree populations with diameters appropriate for harvest. Subsequent to LIDAR profiling of these trees, they were felled, subjected to a battery of dimensional measurements and sampled for wood-density determination. A set of models was generated, followed by model selection and identity testing in order to compare groups of basic wood density (low, medium and high). The morphometric variables of the crown had high explanatory power for bole biomass independent of whether the allometric equations included DBH. When calculating bole biomass with equations that include basic wood density, the best estimate is obtained using variables for both DBH and crown morphology. To obtain an allometric equation that encompasses species in all three classes of basic density, one should either use only independent variables representing crown dimensions or complement these with variables for basic density (BD) and total height (Ht). The study demonstrates the feasibility of using ground-based measurements to calibrate biomass models that include only LIDAR-based variables, allowing much larger areas to be surveyed with reasonable accuracy. The present study is designed to produce data needed for forest management, but the methods developed here can be adapted to studies aimed at reducing the uncertainty in biomass estimates of whole forests (not just harvestable trees) for use in quantifying carbon emissions from forest loss and degradation.

1. Introduction

In recent years great advances have been made in the planning and implementation of forest-management operations in Brazil's Amazon region using precision management techniques (Figueiredo et al., 2007). Precision management integrates the use of geographical positioning system (GPS) and geographical information system (GIS) technology. Airborne LIDAR (Light Detection And Ranging) technology has recently been shown to have wide application in precision management of tropical forests, allowing information on relief and hydrographic structure to be obtained with sub-meter accuracy over large tracts of forest (d'Oliveira et al., 2012). Dubayah et al. (2010), Stark et al. (2012), Sullivan et al. (2014) and Palace et al. (2015) have described LIDAR's potential in modeling forest carbon stocks, while Hunter et al. (2013) proposed corrective measures to improve estimates of forest biometric parameters using LIDAR. Use of laser profiling improves the quality of planning for infrastructure (such as the network of roads, storage yards and skid trails in the monitoring of forest operations) and in estimating the volume and biomass of managed forests.

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Despite technological advances in optical physics, remote sensing, GIS and computing (Hudak et al., 2012; Lim and Treitz, 2004; Næsset and Gobakken, 2008; Simbaña et al., 2016), it is still necessary to further develop basic knowledge of forest components, such as the understanding of plant biomass. Biomass estimates are considered to be empirical since the models used to describe a response variable do not identify the causes or explain the phenomena that affect the behavior of this variable (Clark and Clark, 2000; Scolforo et al., 2004, 2008; Vanclay, 1994; Whittaker and Woodwell, 1971). Allometric equations used to estimate volume, biomass and carbon stocks in forests have usually been prepared based on destructive plots, correlating measurements of whole trees with two variables that are possible to measure in the field: height and diameter at breast height measured 1.3 m above the ground or above any buttresses (DBH) (da Silva, 2007; Higuchi et al., 1998).

Morphometric variables of the crown have high correlations with dendrometric parameters of the bole such as DBH and height (Durlo and Denardi, 1998; Orellana and Koehler, 2008; Wink et al., 2012). However, estimating the values of these variables by measuring individual trees in tropical forests is a major challenge. Even for measuring diameter and height, the dense understory, crooked trunks and the presence of roots in strut or tabular form are obstacles to making precise measurements. Especially for variables that cannot be measured directly in the field (i.e., height) the gain produced by inclusion of the variable in the model should not be smaller than the error associated with its measurement in the field (d'Oliveira et al., 2012). In this environment, it is difficult, from a practical standpoint, to obtain morphometric variables for the canopy in conventional forest inventories (Ferraz et al., 2015; Wulder et al., 2012). However, LIDAR data allow measurements of total height and morphological variables for the canopies of co-dominant and dominant trees to be obtained with great precision.

The aim of the present study is to develop allometric equations for estimating stem biomass of dominant and co-dominant trees under precision forest management. A combination of field-based measurements and LIDAR-derived estimates of canopy geometry was used to estimate bole biomass. The equations are based on morphometric variables for the canopy obtained from LIDAR, together with traditionally employed variables such as DBH, total height (Ht), and the apparent density (AD) and basic density (BD) of the wood. Identity was also assessed for groups of models of wood density.

2. Materials and methods

2.1. Study site

The studies were conducted in a 315-ha area of forest management in the Antimary State Forest (68° 01′ to 68° 23′W; 9° 13′ to 9° 31′S) under SmartWood Certification No. SW-FM/COC-1670 and Environment Institute of Acre (IMAC) Operating License No. 530/2008 (renewal). This protected area is located in the municipalities of Bujari and Sena Madureira, Acre state, Brazil (Fig. 1).

The area encompassing the Antimary State Forest has an average annual rainfall of 2000 mm and average temperature of 25 °C (Acre, 2000). A dry season from June to September is the period when the logging is performed. The forest consists of three main types: dense, open, and open with bamboo. These three forest types occur intermittently in the study area. The predominant soils are dystrophic and yellow latosols

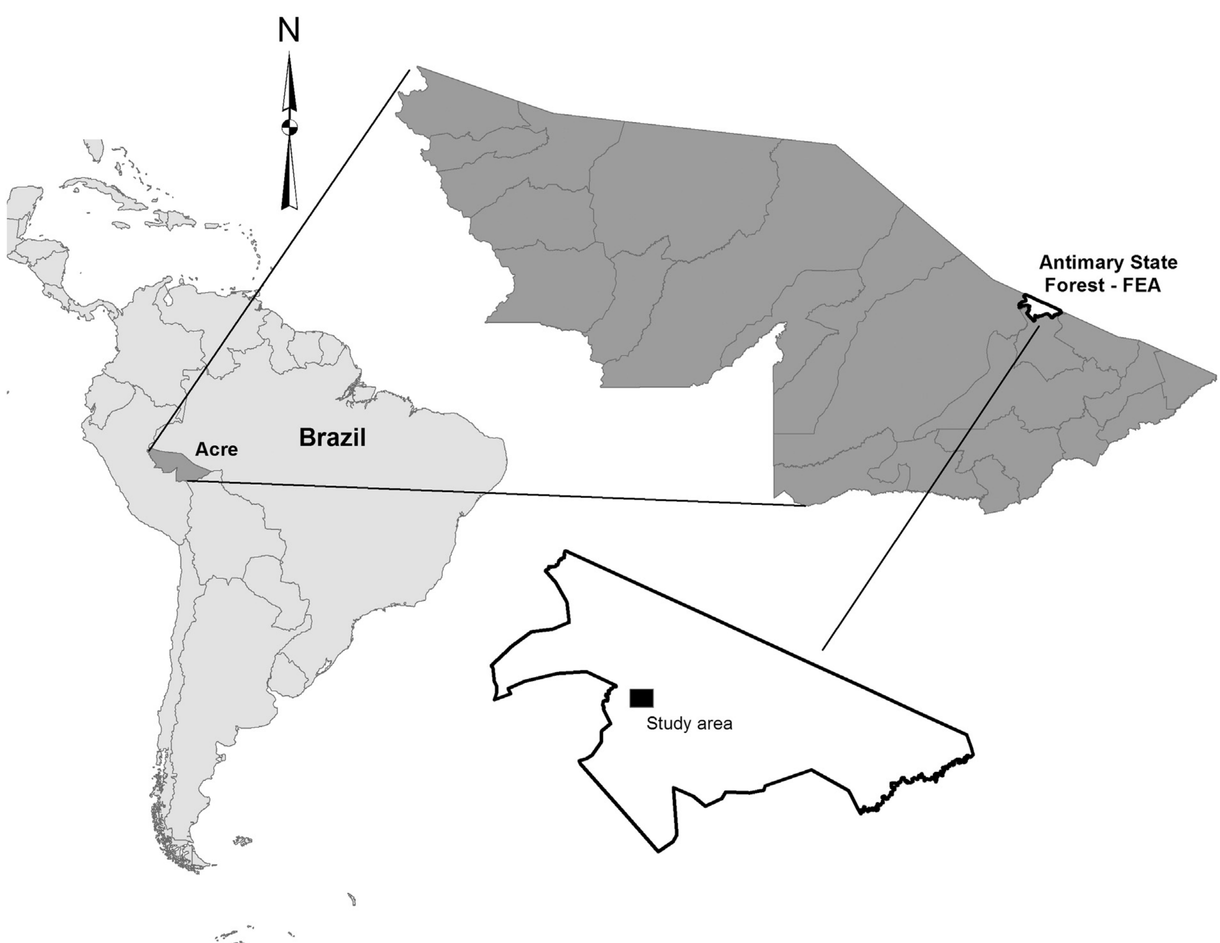

Fig. 1. Location map of Antimary State Forest, Acre, Brazil.