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Spatial modeling of primary and secondary forest growth in Amazonia

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Abstract

A stand level growth model for primary and secondary forest in the Amazon region is presented. The approach is empirical and relies on an extended amount of forest inventory data for model calibration. We used a total of 368 sample plots with 469 ha from primary forest and 330 sample plots with 30.8 ha from secondary forest. The data come from eight countries and are distributed over tropical forests in all of Amazonia. We interpolated primary forest descriptors spatially in virtue of their dependence on biophysical conditions. Secondary forest parameters were described by a set of differential equations, in which the primary forest functioned as asymptotes of the growth processes. A state-space approach to growth modeling allowed for derivation of other forest parameters from models for state variables by auxiliary relationships. The fitted models offer a spatially explicit description of growth and increment over all the tropical forests in Amazonia on a large scale. As a function of biophysiology and of forest age, the models specify individual secondary forest growth curves at the level of grid cells. We calculated grids for forest parameters and their increments in primary and secondary forests of various ages. In primary forest, total basal area ranged between 22 and 33 $m^2\ ha^{-1}$, top height was 10–35 m, there were 400–850 individuals per hectare, and standing alive above-ground biomass ranged between 110 and 370 $t\ ha^{-1}$. The biomass model was validated by comparing predictions at various successional stages from different locations in Amazonia against independent reference data. Despite a small negative bias, the RMSE for standing alive above-ground biomass amounted to only 38 $t\ ha^{-1}$.

Keywords: Amazon; Biomass; Carbon; Growth model; Increment; Primary forest; Secondary forest; State-space

1. Introduction

The growth of the Amazon forest and its dynamics receive scientific attention both in the context of forest management (Silva et al., 1996), and of ecology and global change (Moorcroft et al., 2001; Zarin et al., 2001). For some regions growth models have been proposed (Neeff and dos Santos, 2005; da Silva et al., 2002; Silva et al., 1996) and efforts are being undertaken to unify data sources (Malhi et al., 2002). However, science is still far from achieving accurate

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and comprehensive description of forest conditions and dynamics over the vast and diverse Amazon region.

Biomass and its spatial distribution are key variables for carbon budget estimation. The scientific community recognizes the need for accurate methods to determine biomass in the Amazon (Schimel et al., 2001; Houghton et al., 2000). Vegetation models are considered indispensable, because common remote sensing data sources are incapable to directly measure biomass (Houghton et al., 2001). While remote sensing could provide information on distribution and extension of vegetation types, models of vegetation characteristics are required that would describe potential biomass stocks and dynamics for a forest of a given type and a certain age at a specific location (Neeff et al., 2005). Forest growth models provide means to accurately estimate forest biomass and carbon sequestration rates when linked to data on primary and secondary forest cover (Moorcroft et al., 2001).

In this paper, we venture to describe the growth and increment of tropical forests in the Amazon region. This research largely represents a generalization of methods developed by Neeff and dos Santos (2005), who applied a standard approach for stand level forest growth modeling. Empirical models that base on biophysical parameters were adjusted to a large dataset of forest inventories. The presented growth model encompasses the major descriptors of tropical forests across Amazonia at arbitrary successional stages. In a larger research effort, we intend to link the growth model to large-scale remote sensing results and a land-use change model (Neeff et al., in press). Our ultimate goal is to extend methods for carbon budgeting applied by Neeff et al. (2005) to all of Amazonia in order to describe the carbon balance arising from forest dynamics during the last decades in a spatially explit way.

2. Material

2.1. Collection of forest inventory data

The classical experimental design to collect data for forest growth modeling consists of permanent forest plots, that are inventoried periodically over an extended period of time (Vanclay, 1994). Such data are not easily available for the case of tropical primary and secondary forest (Vanclay, 1994). Therefore, we used a collection of plots from several sites, various years, and of different sizes. All of them were measured, adopting similar methods in field work, and all of them represent tropical forests in Amazonia. We compiled a dataset of primary and secondary forest inventories from a variety of different sources, both published forest inventory results and original forest inventory data were collected (see Appendix A).

A major problem in using published forest inventory results is the incompatibility of the methodologies for field work and data processing applied by the researchers. Differing minimum measured diameters, varying treatments of dead trees or nontree species, and differing allometric equations can be an additional source of variance and potentially introduce bias into the analysis. Therefore, an effort was undertaken to collect original tree-by-tree data from forest inventories conducted by many researchers in Amazonia. Additionally, a number of sample plots were compiled from literature. Here, we had less control over forest measurement methodology, but we felt it was necessary to complement the original tree-by-tree data with data from other sources (see Appendix A).

A number of datapoints were excluded from the analysis for one of the following reasons: minimum diameters from field measurements were too high, the plots were too small to compute the standard forest parameters (particularly top height), the plot did not correspond to a forest ecosystem, or supposedly primary forest underwent logging before. In total, the database on forest growth, that we deemed appropriate for calibration purposes, contained 60.7 ha (172 plots) of primary forest inventories on a tree-by-tree basis and 385.9 ha (186 plots) from other sources. Secondary forest inventories amounted to a total of 16 ha (230 plots) on a tree-by-tree basis and 5.3 ha (64 plots) from other sources. Validation data, where only biomass measurements were conducted, were available for 22.4 ha (10 plots) of primary forests and for 9.5 ha (36 plots) of secondary forests. The data were collected from the 1950s till present. The data come from almost all countries that share the Amazon forest: Bolivia, Brazil, Colombia, Ecuador, French Guiana, Peru, Suriname, and Venezuela; the plots were widespread over Amazonia (see Fig. 1).

Different minimum diameters are commonly applied when dealing with forests at different ages.