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Secondary vegetation in central Amazonia: Land-use history effects on aboveground biomass

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ABSTRACT

Growth of secondary forest (*capoeira*) is an important factor in absorption of carbon from the atmosphere. Estimates of this absorption vary greatly, in large part due to the effect of different land-use histories on the estimates available in the literature. We relate land-use history to aboveground biomass accumulation of secondary vegetation in plots on land that had been used for agriculture (unmechanized manioc and maize) and for pasture in small rural properties in the Tarumã-Mirim settlement near Manaus in central Amazonia, Brazil. We evaluated influence of (a) age of the second growth vegetation, (b) time of use as agriculture or pasture and (c) number of times the area was burned. Biomass data were obtained by destructive sampling of all plants with diameter at breast height >1 cm in 24 parcels of secondary vegetation ranging from 1 to 15 years of age in abandoned pasture ($n = 9$) and agriculture ($n = 15$). As compared to secondary vegetation in abandoned agricultural fields, vegetation in abandoned cattle pasture (the predominant use history for Amazonian secondary vegetation) grows 38% more slowly to age 6 years. Number of burns also negatively affects biomass recovery. Applying the growth rates we measured to the secondary forests reported in Brazil's Second National Communication to the United Nations Framework Convention on Climate Change suggests that carbon uptake by this vegetation is overestimated by a factor of four in the report.

1. Introduction

The growth rates of secondary forest represent important inputs for calculating net emissions of greenhouse gases from land-use change (e.g., Fearnside, 1996, 1997, 2000) and for the productivity and sustainability of agriculture that depends on fallow periods between periods of cultivation (e.g., Silva-Forsberg and Fearnside, 1997). Secondary vegetation growth has a significant role in national accounts of greenhouse-gas emissions, but uncertainty in these accounts is very high. Brazil's first inventory under the United Nations Framework Convention on Climate Change claimed that secondary vegetation in Brazil's Amazonia biome was absorbing 34.9×10^6 Mg C year^{-1} for 1988–1994 (Brazil, MCT, 2004, p. 147). Information presented in the second inventory indicates an absorption of 9×10^6 Mg C year^{-1} for 1994–2002 in the Amazonia biome and 10.9×10^6 Mg C year^{-1} in all of Brazil, the reduction being due to a smaller estimated area of secondary vegetation (Brazil, MCT, 2010, p. 242 & 248). Despite the magnitude of these numbers, the estimates are not based on any actual measurements of secondary-forest growth (Fearnside, 2013).

Brazil's Legal Amazon region, which occupies 5×10^6 km^2 or about 60% of the country, has a wide variety of different land uses replacing natural forest, each with different implications for secondary-forest growth. Mechanized agriculture, primarily for soybeans, is almost all located along the southern edge of the region, especially in the state of Mato Grosso (Fearnside, 2001). Cattle pasture is the predominant land use in the remainder of the region, including the Manaus area in central Amazonia. Pasture is planted by actors of all sizes: large (defined in Brazil as >1000 ha) and medium (101–1000 ha) ranchers and small ($\leqslant$100 ha) farmers (Fearnside, 2005, 2008). Large and medium landholders have long been the main agents of deforestation and pasture planting in Brazilian Amazonia (e.g., Fearnside, 1993). However, a comparison of data from 2002 and 2009 indicates a marked decrease in the average size of clearings (Rosa et al., 2012) and an increase in relative terms in the role of small farmers. The large overall decrease in Brazil's deforestation rate that began in 2005 was disproportionately among larger actors, especially since 2008 (Godar et al., 2014). The number of small farmers has

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steadily increased, as has the number of government-sponsored settlement projects; by 2013 they totaled 3325 projects. Considering the 2738 of these for which data are available, deforestation in the projects totaled 161,833 km^2 through 2013, or 21% of the total by that year in Brazil's Legal Amazon region (Yanai et al., 2015).

Large ranchers almost always plant pasture directly after clearing the forest, while small farmers often plant annual crops such as manioc and maize for several years before the area is converted to pasture. These farms may have areas under fallow between use periods under annual crops. This is similar to swidden or shifting cultivation, such as that practiced by indigenous and other traditional peoples whose cultural traditions include use of fallows as part of a cycle that can sustain production indefinitely (e.g., Nye and Greenland, 1960). In the case of small farms in Amazonian settlement projects, no such long-term adjustment has taken place, and cropping is most commonly supplanted by pasture after a few years, the continued planting of annual crops depending on continued advancement of clearing into the remaining forest (e.g., Fearnside, 1986). We refer to this form of agriculture as "slash-and-burn." This paper only considers secondary vegetation derived from slash-and-burn agriculture and from cattle pasture (in small-farmer lots in both cases).

In Amazonia, biomass accumulation rates of secondary vegetation (known as "*capoeira*" in Brazil) can be limited by factors related to land-use history (Buschbacher et al., 1988; Fearnside and Guimarães, 1996; Finegan, 1996; Moran et al., 2000; Steininger, 2000; Uhl, 1987; Uhl et al., 1988). Intensity of prior land use is reflected in natural regeneration and is related to: 1 – type of previous land use at the site, such as slash-and-burn agriculture, cattle pasture, tree planting or exploitation of charcoal; 2 – age of secondary vegetation (time since abandonment); 3 – time that the area remained under agriculture and ranching activity prior to abandonment; 4 – method used for removal of vegetation (preparation of the soil) such as burning versus mechanical clearing and grinding; and 5 – frequency of occurrence of disturbances such as burning and weeding.

Fearnside and Guimarães (1996) observed that secondary forests with a pasture use history accumulate less biomass than do stands established in abandoned agricultural areas in Altamira, Pará. Brazil. Pasture use also results in secondary vegetation with floristic compositions that differ from those in areas without this history, as shown by studies in the Manaus Free Trade Zone Agriculture and Ranching District (DAS) in Brazil's state of Amazonas (Longworth et al., 2014; Mesquita et al., 2001). Uhl et al. (1988) observed that secondary vegetation developed from pasture with lighter use intensity accumulated 40% more biomass than did stands of the same age, but with more intensive use history in Paragominas, Pará. Moreira (2003) noted that the number of burns negatively influences biomass inventory of natural regeneration in areas that had been used for pasture, agriculture and rubber plantations north of Manaus. Annual rate of biomass accumulation decreases with increase in age of secondary vegetation (e.g., Lucas et al., 1996).

Based on data from destructive measurements in the Venezuelan Amazon, Uhl (1987) established a practical model to estimate biomass stock in secondary vegetation using time since abandonment as the only independent variable, but did not include variables related to land-use history. Zarin et al. (2005) developed models to estimate biomass with wide applicability in Amazonia, including soils with a range of sand and clay contents. In addition to the age of the secondary vegetation, these authors considered climatic data (such as temperature and the duration of the dry season), but they did not include variables related to land-use history. Silver et al. (2000) also developed model estimates for biomass in different rainfall regimes in tropical regions and for different land-use types using age as the independent variable, but not including the time the site was used and number of burns.

Stocks and accumulation rates of biomass need to be quantified in Amazonian secondary vegetation in order to better understand successional processes so that appropriate management can be proposed. Here we develop models based only on land-use history factors, making these models more practical, although less precise, than either direct measurement by destructive sampling or estimates requiring allometric data and species identifications (*e.g.*, Wandelli and Fearnside, manuscript).

Secondary-vegetation growth rates have major implications for the net emissions of carbon from land use and land-use change in Amazonia. We examine the implications of our results for the carbon uptake calculated in Brazil's national inventory of greenhouse-gas emissions reported in the country's second national communication to the United Nations Framework Convention on Climate Change.

2. Materials and methods

2.1. Study area

Our study was carried out in secondary vegetation in rural properties in the Turumã-Mirim agrarian reform project, located to the northwest of the city of Manaus, Amazonas, Brazil (Fig. 1). The original forest is classified as dense *terra firme* (unflooded upland) forest (Braga, 1979) and the soil is predominantly allic yellow latosol (Oxisol) with high clay content (Brazil, IPEAAOc, 1971). The climate is Ami in the Köppen system, with mean annual rainfall around 2200 mm and a three-month dry season.

The Turumã-Mirim Agrarian Reform Project was established in 1992 for 1042 families, each with a 40-ha lot. The area is described by de Matos et al. (2009) and Coelho et al. (2012). Since the area is located approximately 35 km by road from the city of Manaus (population ~2 million), it is influenced by urban markets for charcoal, manioc flour and meat.

2.2. Direct destructive assessment of biomass

Aboveground biomass (AGB) of each of 24 secondary-vegetation stands between 1 and 15 years of age was measured directly by destructive sampling, and individual plant measurements and weights were obtained with diameter at breast height (DBH) $\geqslant$ 1 cm (DBH = diameter 1.3 m above the ground) for developing allometric equations. A total of 2268 plants in 146 species were weighed and height and diameter at breast height (1.3 m above the ground) were measured. Water contents and dry weights were obtained for trunks, branches and leaves of 3–5 individuals (if present) of each species in each 100-m^2 plot. Each of 24 stands had a single plot laid out as a 10 × 10 m square randomly positioned within each stand but located at least 10 m from the edge of the secondary-vegetation stand and at least 50 m from the edge of the forest.

Information about land-use history of secondary vegetation in each lot was obtained through interviews with various members of the family that owned the lot (Table 1). This information was supplemented and validated through interviews with neighbors who could remember when the vegetation was cut and burned because they had collaborated in collective work exchanges (*mutirões*) in the lot or because they were concerned about uncontrolled fire entering their own fields. Inventories and destructive measurements of biomass were only made in secondary-vegetation stands where information about use history was consistent with our observations of remains still present in the area and where this coincided with the opinions of all informants.