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Carbon stocks and changes in tropical secondary forests of southern Mexico

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ABSTRACT

The role of tropical secondary forests in carbon accumulation has been widely acknowledged, but the rates of changes in carbon stocks still remain uncertain. The aim of this study was to analyze the changes in carbon pool sizes and accumulation rates associated with growth, recruitment and mortality of trees at different ages of forest succession in semi-evergreen tropical forests and relate these to the age of the secondary vegetation and prior land use intensity. The study was carried out in a chronosequence of secondary and mature forests around Calakmul Biosphere Reserve in southern Yucatan Peninsula, Mexico. Permanent monitoring plots were established and measured in 2011 and 2012 to account all carbon stocks and changes due to tree increments, establishment of new trees and tree mortality in different age classes of secondary forests. We found that carbon stocks in living tree biomass increased rapidly in the early stages and decreased in the older secondary forests. The annual carbon dynamics of trees were higher in younger secondary forest compared to older forests due to higher tree growth and recruitment. Growth functions predict that the secondary forests recover live aboveground biomass carbon stocks to pre-disturbance levels (99.56 Mg C ha^{-1}) at the age of about 125 years or more, while the basal area (33.2 m^2 ha^{-1}) regains this level at the age of about 85 years. The longer carbon recovery time can be explained by the fact that mature forests are dominated by hardwood species whereas secondary forests are composed of softwood species and that species composition turnover during succession is relatively slow. Secondary forests of 35 years look similar to mature forests in terms of basal area, but this is located in large number of small and medium sized trees, whereas in mature forests, most of the basal area is in trees of >20 cm diameter. In addition, the intensity of slash and burn agriculture can negatively alter the velocity of carbon accumulation. These findings have important implications for national forest carbon monitoring systems, greenhouse gas emission inventories and regional level REDD+ strategies.

1. Introduction

Tropical secondary forests play an important role in global carbon cycle (Canadell et al., 2010; De Jong et al., 2010; Pan et al., 2011) because of their fast growing nature and accumulation of atmospheric carbon (Bonan, 2008; Chazdon et al., 2005, 2007; Raupach et al., 2007). Successional mosaics of secondary forest have been increasing rapidly in the tropics due to shifting cultivation and abandonment of agricultural lands or grasslands, which currently cover about 57% of world's tropical forest area (Brown and Lugo, 1990; FAO, 2010a; Guariguata and Ostertag, 2001; Ostertag et al., 2008). In Mexico, secondary and degraded forests occupy about 64% of the total lowland forest cover (FAO, 2010b).

Understanding the carbon dynamics of successional forests is becoming critical for the development of tropical forest conservation and management strategies as well as for REDD+ intervention potentials (Asner, 2011; Edwards et al., 2010; Pan et al., 2011; Purves et al., 2008; Wright, 2005). The current estimations of carbon stocks and stock change of tropical secondary forests still have a high level of uncertainty (Asner, 2011; De Jong et al., 2010; Houghton, 2010; Chazdon et al., 2005; Drake et al., 2011; Pregitzer and Euskirchen, 2004). Although there are some studies related to carbon stocks in Yucatan Peninsula of Mexico (Eaton and Lawrence, 2009; Cairns et al., 2003; Urquiza-Haas et al., 2007), carbon dynamics derived from tree recruitment, growth and mortality has not yet understood.

Carbon stock changes in live tree biomass within a certain period of time after abandoning cultivation is the aggregated

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outcome of growth of existing trees plus recruitment of new individuals minus mortality (Chazdon et al., 2005; Lebrija-Trejos et al., 2010; Prach and Walker, 2011; Van Breugel et al., 2006). Tree establishment, growth, mortality, and longevity vary according to the species and stage of forest succession, which in turn also influences carbon dynamics (Huston and Smith, 1987; Martínez-Ramos and García-Orth, 2007; Mascaro et al., 2011; Noble and Slatyer, 1980; Pickett et al., 1987; Tilman, 1985).

Dramatic changes in vegetation structure and composition occur during the first few years of succession in tropical regions, as woody species rapidly colonize abandoned fields (DeWalt et al., 2003; Guariguata and Ostertag, 2001; Marín-Spiotta et al., 2008; Oliver and Larson, 1990). Due to transition in canopy dominance from light-demanding pioneer trees to shade tolerant species, secondary forests are expected to exhibit rapid changes compared to mature forests (Brown and Lugo, 1990; Chazdon et al., 2005; Purves et al., 2008). Considering the asymptotic behavior of most successional trends, we would predict a decreasing rate of carbon turnover with successional age, i.e., community dynamics decrease with forest age (Lebrija-Trejos et al., 2010; Van Breugel et al., 2007; Vargas et al., 2008). We also expect that under asymmetric competition, growth concentrates in the larger individuals and smaller individuals suffer higher mortality rates, resulting in declining tree density and an increasing average carbon stock per tree (Huston and DeAngelis, 1994; Van Breugel et al., 2006) although variations between species responses may be high.

Tropical forests in southern México have suffered from different cycles of anthropogenic and natural disturbances such as slash and burn agriculture, selective logging, clearance for pasture establishment, forest fires and hurricanes (Klepeis et al., 2004; Ochoa-Gaona et al., 2007; Schmook, 2010; Turner et al., 2001). The recovery rates of successional forests after abandonment may also vary according to the age and the former intensity of land use in terms of frequency and duration of previous fallow periods versus cultivation cycles (Levy-Tacher and Rivera, 2005; Ochoa-Gaona et al., 2007; Schmook, 2010). Despite the attempts to develop ecological succession models that formulate generalized interpretation for any ecosystem, there is still a need for theoretical modeling based on long-term monitoring of recruitment, growth and mortality of trees in successional stages of tropical forest ecosystems to understand the vegetation dynamics in these forests along the whole succession gradient (Lebrija-Trejos et al., 2010; Rees et al., 2001). In this study, we aim to analyze the effect of successional age and shifting cultivation intensity on all carbon pool sizes and accumulation rates that occur from tree growth, mortality and recruitment in semi-evergreen tropical secondary forests of southern Mexico. In this paper, we examine the following research questions: (i) carbon stocks changes evenly among the C pools with forest age? (ii) how do tree recruitment and mortality influence carbon dynamics during secondary forest succession? (iii) does previous land use intensity affect carbon accumulation in secondary forest after slash and burn agriculture? and (iv) how long does it take for secondary forests to recover forest structure and carbon stocks of mature forests after slash and burn agriculture? Based on the research questions, we tested the following hypotheses: (i) carbon stocks changes differently among pools during secondary forest succession; (ii) carbon stock changes due to tree growth, recruitment and mortality are relatively higher in younger stages of forest succession than in older stages; (iii) increasing land use intensity (in terms of number of cultivation years and frequency of cropping cycles) reduces carbon accumulation rates in secondary forests; and (iv) carbon stocks in live biomass recover slower than forest structure (expressed in basal area) during forest succession.

2. Methods

2.1. Study sites

The study was conducted in four localities around Calakmul Biosphere Reserve, situated in the south of Yucatan Peninsula, Mexico. Sampling sites were located in four communities: Cristóbal Colon, El Carmen II, Narciso Mendoza and Nuevo Conhuas (Fig. 1). The region is composed of rolling limestone hills and ridges

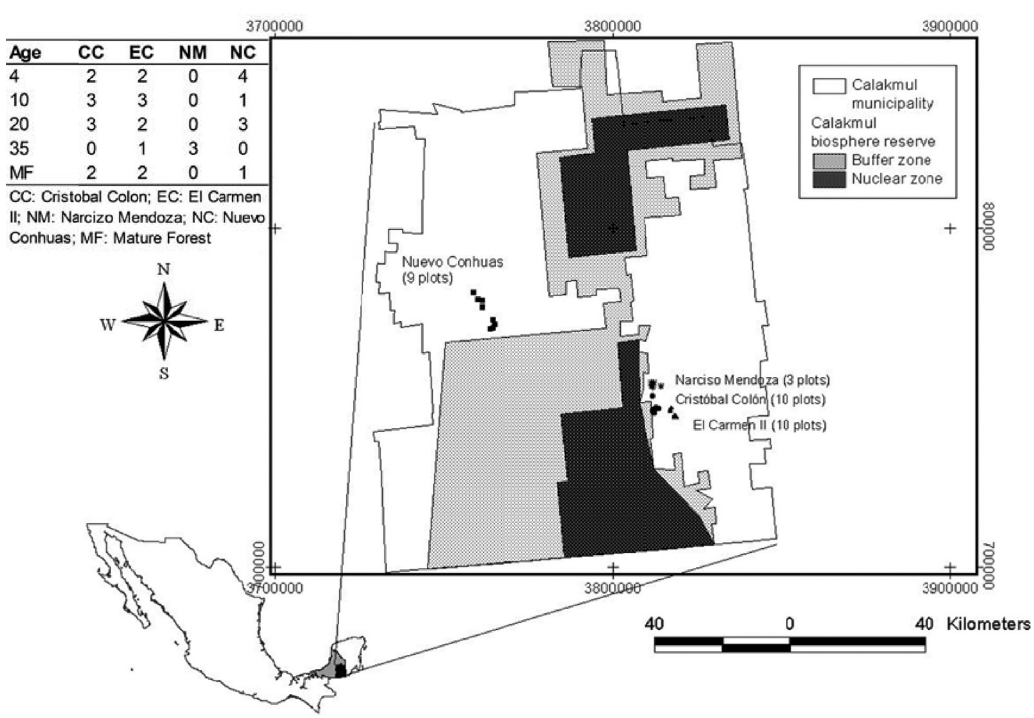

Fig. 1. Location of study area and sampling plots in Campeche, Mexico.