Journal of Environmental Management 171 (2016) 42–51

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Conversion from forests to pastures in the Colombian Amazon leads to differences in dead wood dynamics depending on land management practices

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ARTICLE INFO

Article history:
Received 26 November 2015
Received in revised form
26 January 2016
Accepted 29 January 2016
Available online 11 February 2016

Keywords:
Colombian Amazon
Coarse woody debris
Dead wood carbon pool
Forest-to-pasture conversion
Grazing intensity
REDD+

ABSTRACT

Dead wood, composed of coarse standing and fallen woody debris (CWD), is an important carbon (C) pool in tropical forests and its accounting is needed to reduce uncertainties within the strategies to mitigate climate change by reducing deforestation and forest degradation (REDD+). To date, information on CWD stocks in tropical forests is scarce and effects of land-cover conversion and land management practices on CWD dynamics remain largely unexplored. Here we present estimates on CWD stocks in primary forests in the Colombian Amazon and their dynamics along 20 years of forest-to-pasture conversion in two sub-regions with different management practices during pasture establishment: high-grazing intensity (HG) and low-grazing intensity (LG) sub-regions. Two 20-year-old chronosequences describing the forest-to-pasture conversion were identified in both sub-regions. The line-intersect and the plot-based methods were used to estimate fallen and standing CWD stocks, respectively. Total necromass in primary forests was similar between both sub-regions (35.6 ± 5.8 Mg ha^{-1} in HG and 37.0 ± 7.4 Mg ha^{-1} in LG). An increase of ~124% in CWD stocks followed by a reduction to values close to those at the intact forests were registered after slash-and-burn practice was implemented in both sub-regions during the first two years of forest-to-pasture conversion. Implementation of machinery after using fire in HG pastures led to a reduction of 82% in CWD stocks during the second and fifth years of pasture establishment, compared to a decrease of 41% during the same period in LG where mechanization is not implemented. Finally, average necromass 20 years after forest-to-pasture conversion decreased to 3.5 ± 1.4 Mg ha^{-1} in HG and 9.3 ± 3.5 Mg ha^{-1} in LG, representing a total reduction of between 90% and 75% in each sub-region, respectively. These results highlight the importance of low-grazing intensity management practices during ranching activities in the Colombian Amazon to reduce C emissions associated with land-cover change from forest to pasture.

1. Introduction

Deforestation in the tropics generates 7–14% of the total carbon dioxide (CO_2) emissions globally (Harris et al., 2012) becoming the second most important source of greenhouse gases (GHG) after fossil fuel combustion (Don et al., 2011). Conversion from forest to pasture is the most common land-cover change in the Amazon basin (Fearnside and Barbosa, 1998; Asner et al., 2004; Desjardins et al., 2004), although the area dedicated to agriculture activities, particularly soybean crops, has increased since the 2000s (Nepstad et al., 2008; Pacheco et al., 2012). After cutting the forest, management practices to establish pasture in Amazonia may include: the use of fire to eliminate the maximum amount of plant material left by deforestation or to control the expansion of secondary vegetation (Fearnside et al., 1993; Kauffman et al., 1995, 1998; IPCC, 2006; Aragão and Shimabukuro, 2010), implemented once or more times depending on burning efficiency of dead wood (Fearnsidea et al., 1999, 2001); the use of machinery to remove unburned woody debris (Murty et al., 2002; Marin-Spiotta et al., 2009); the introduction of improved pastures and legume species (Alarcón

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http://dx.doi.org/10.1016/j.jenvman.2016.01.037
0301-4797/

and Tabares, 2007; Mosquera et al., 2012), or the use of fertilizers and lime to improve pasture productivity (Jiménez and Lal, 2006; Fisher et al., 2007). Management practices implemented during pasture establishment are as important as land-cover changes in determining carbon (C) dynamics and GHG emissions/removals (Fearnside and Barbosa, 1998; Dias-Filho et al., 2000; Berenguer et al., 2014; Luyssaert et al., 2014), and among them, grazing intensity can significantly contribute to increase or reduce C stocks (Uhl et al., 1988).

Coarse dead wood, also called coarse woody debris (CWD), is one of the C pools defined by the Intergovernmental Panel Climate Change (IPCC) to report on C stocks changes and GHG emissions/removals associated with land-use changes within the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006). CWD includes standing and fallen dead trees and all dead wood pieces with diameter ≥10 cm that together store on average ~30% of the total C stored in the aboveground C pools in tropical forests (Harmon et al., 1995; Clark et al., 2002; Creed et al., 2004; Rice et al., 2004; Baker et al., 2007; Palace et al., 2007). CWD is also an important component in many ecological processes in the forest as it provides a habitat for some micro- and macro-organisms (Gibbs et al., 1993; Eggleton et al., 1995; Grove, 2002; Pedlar et al., 2002), participates in nutrient cycling and influences the energy flux within the ecosystem (Harmon et al., 1986; Chao et al., 2008).

Due to its importance within the tropical forests, C emissions from CWD potentially contribute a considerable amount of total CO_2 emissions associated with deforestation (Palace et al., 2008). However, information on CWD stocks and variation with land-cover and land-use changes is scarce (Baker et al., 2007; Palace et al., 2012). Recently, two studies were published on the impact of forest degradation on dead wood C pool in primary forests in eastern Brazilian Amazon (Berenguer et al., 2014) and Malaysia (Pfeifer et al., 2015) with the potential to improve GHG emissions accountability. However, there are no studies assessing the impact of the land-cover change from forest to pasture on CWD stocks and C dynamics.

Strategies to mitigate CO_2 emissions associated with deforestation such as REDD + require reporting of emission factors, defined as the emissions/removals of all important GHG associated with land-cover conversion in all relevant C pools (i.e. total changes in C stocks), and activity data, referring to the size of a deforested or degraded area (Verchot et al., 2012). Both emission factors and activity data should be included within the forest reference emission levels (FREL) that countries willing to access result-based payments through REDD+ activities must submit to the UNFCCC, as benchmarks for assessing country's performance (FAO, 2014). Due to lack of information, dead wood C pool was not included in any of the FRELs recently submitted to the UNFCCC by Brazil, Colombia, Ecuador, Guyana, Malaysia and Mexico (Conafor, 2014; GFC, 2014; MADS, 2014; MAE, 2014; MMA, 2014; MNRE, 2014). Colombia, in particular, included the above- and below-ground biomass C pools in forests within its FREL, but neither the dead wood C pool nor their change after conversion from forest to any post-deforestation land-use category were included (MADS, 2014). Nonetheless, under the UNFCCC Stepwise Approach (UNFCCC, 2012), countries have the option to improve their initial FRELs by incorporating high-quality data, improved methodologies and additional C pools developed from country- or region-specific information and field measurements following an IPCC Tier 3 approach.

Here we present new Tier 3 information and emission factors on dead wood C pool and its dynamics during 20 years of forest-to-pasture conversion under different management practices in the Colombian Amazon. In this study we addressed the following general question: to what extent land-cover change from forest to pasture and subsequent land management practices affect dead wood C pool in the Colombian Amazon? Therefore, we aimed to better quantify CWD stocks and changes with forest-to-pasture conversion in the Colombian Amazon in support of REDD + initiatives. Specifically, our objectives were to:

1. Quantify the volume, wood density and necromass of CWD in primary forests of the Colombian Amazon.
2. Quantify the changes in CWD stocks in two sub-regions of the Colombian Amazon and describe the influence of the high- and low-grazing intensity management practices after 20 years of forest-to-pasture conversion on the dead wood dynamics.
3. Determine the emission factors of dead wood C pool in both sub-regions according to IPCC (2006), by applying region-specific equations developed in this study describing the CWD dynamics along 20 years of forest-to-pasture conversion.

2. Materials and methods

2.1. Site description

The study was carried out in two sub-regions of the Colombian Amazon where management practices after forest-to-pasture conversion differ in terms of grazing intensity. According to Mahecha et al. (2002), the carrying capacity of pastures in the Colombian Amazon is 0.8–1.0 heads of forage-fed livestock (HFFL) per hectare. Therefore, for this study we defined the high- and low-grazing intensity areas (hereafter HG and LG, respectively) as those pastures in which the number of HFFL per hectare is above and below a threshold of 1.0 head of livestock ha^{-1}, respectively (Fig. 1). High-grazing intensity management practices are evident in most of the pasture areas located in HG, where pastures cover ~662,000 ha (3.6%) from a total area of 18,237,519 ha (Ideam, 2014) and cattle density by 2013 was 1,777,549 heads of forage-fed livestock (HFFL), giving an average of 2.7 HFFL ha^{-1}, according to the National Livestock Inventory of Colombia (Fedegan, 2013). In contrast, pastures in LG in 2013 covered ~45,000 ha (0.2%) from a total area of 23,387,251 ha (Ideam, 2014), and cattle density by the 2013 was 5328 HFFL (Fedegan, 2013), averaging 0.1 HFFL ha^{-1}. HG and LG also coincide with the division of the Colombian Amazon made by government, as high- and low-deforestation risk sub-regions, respectively (González et al., 2014). Pastures are the predominant post-deforestation land cover across the whole Colombian Amazon and are mostly located in HG (Cabrera et al., 2011). According to Bowman et al. (2012), up to 80% of the pasture area in the Colombian Amazon is occupied by farms implementing the extensive cattle ranching system. However, whereas in HG farmers tend to manage their pastures by planting *Brachiaria humidicola* or *B. decumbens*, or by mixing these species with legume species such as *Arachis pintoi* or *Desmodium ovalifolium* (Alarcón and Tabares, 2007; Mosquera et al., 2012), in LG it is common to find pasture areas where grasses (C4 vegetation) are mixed with shrubs and trees (C3 vegetation). The use of fire is a commonly-used management practice in both sub-regions to eliminate the remnant dead wood and other non-readily-decomposable material left after deforestation. However, whilst in HG the implementation of machinery to remove most of the residual dead wood not consumed completely by fire and to eliminate the secondary vegetation growing in the pasture matrix is a frequent practice, the use of machinery in LG is reduced or absent due to the limitation to transport heavy equipment to remote areas within the forest of this sub-region.

HG is located in the west of the Colombian Amazon where the major land forms are low-gradient foot slopes and dissected plains,