Forest Ecology and Management 397 (2017) 1–9

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Decomposition rates of coarse woody debris in undisturbed Amazonian seasonally flooded and unflooded forests in the Rio Negro-Rio Branco Basin in Roraima, Brazil

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A R T I C L E I N F O

Article history:
Received 25 November 2016
Received in revised form 15 April 2017
Accepted 20 April 2017
Available online 29 April 2017

Keywords:
Carbon flux
Dead biomass
Roraima
Undisturbed forests
Wood density
Wood fragmentation

A B S T R A C T

Estimates of carbon-stock changes in forest ecosystems require information on dead wood decomposition rates. In the Amazon, the lack of data is dramatic due to the small number of studies and the large range of forest types. The aim of this study was to estimate the decomposition rate of coarse woody debris (CWD) in two oligotrophic undisturbed forest formations of the northern Brazilian Amazon: seasonally flooded and unflooded. We analyzed 20 arboreal individuals (11 tree species and 3 palm species) with distinct wood-density categories. The mean annual decomposition rate of all samples independent of forest formation ranged from 0.044 to 0.963 yr^{-1}, considering two observation periods (12 and 24 months). The highest rate (0.732 ± 0.206 [SD] yr^{-1}) was observed for the lowest wood-density class of palms, whereas the lowest rate (0.119 ± 0.101 yr^{-1}) was determined for trees with high wood density. In terms of forest formation, the rates values differ when weighted by the wood-density classes, indicating that unflooded forest (0.181 ± 0.083 [SE] yr^{-1}; mean decay time 11–30 years) has a decomposition rate ~19% higher than the seasonally flooded formations (0.152 ± 0.072 yr^{-1}; 13–37 years). This result reflects the dominance of species with high wood density in seasonally flooded formations. In both formations 95% of the dead wood is expected to disappear within 30–40 years. Based on our results, we conclude that the CWD decomposition in the studied area is slower in forests on nutrient-poor seasonally flooded soils, where structure and species composition result in ~40% of the aboveground biomass being in tree species with high wood density. Thus, it is estimated that CWD in seasonally flooded forest formations has longer residence time and slower carbon release by decomposition (respiration) than in unflooded forests. These results improve our ability to model stocks and fluxes of carbon derived from decomposition of dead wood in undisturbed oligotrophic forests in the Rio Negro-Rio Branco Basin, northern Brazilian Amazon.

1. Introduction

Greenhouse gases are emitted from tropical forests not only from deforestation but also from standing forests, both disturbed and undisturbed. Emissions from standing forest have received much less research attention than deforestation. The December 2015 Paris Accords on climate change (UNFCCC, 2015) make it critical to gain better understanding of emissions from standing forest, including the time path of these emissions. The Paris Accords call for preventing mean global temperature from passing a limit "well below" 2 °C the pre-industrial mean, and to "pursue efforts" to keep mean temperature within 1.5 °C of the pre-industrial level.

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http://dx.doi.org/10.1016/j.foreco.2017.04.026
0378-1127/© 2017 The Authors. Published by Elsevier B.V.

This means that the net total of all greenhouse gas fluxes, whether anthropogenic or not, must be reduced within a period of approximately 20 years such that the atmospheric concentrations are held close to their present levels (e.g., Rogelj et al., 2016). This requires faster action and greater attention to the time path of emissions than the previous criterion, which defined the limit in terms of a longterm "stabilization" of greenhouse gas concentrations (UNFCCC, 1992, Article 2).

One of the major ways that standing tropical forests emit greenhouse gases is by the death and decomposition of trees, which may be caused by disturbances such as logging, forest fires, invasion by plants such as lianas and bamboos, or by extreme droughts or floods. These disturbances may be either "directly human induced" (in the terms of the Kyoto Protocol: UNFCCC, 1998) or not, as in extreme events influenced by climate change. Coarse woody debris (CWD, diameter ≥ 10 cm) represents a key forest ecosystem compartment in carbon fluxes from standing forest. The carbon stock in this compartment is also important in quantifying the emissions of deforestation, and cannot be simply defined away on the bases of 'necromass' not being considered to be 'biomass' (e.g., IPCC, 1997); as was done in Brazil's first and second inventories of greenhouse gases (Brazil-MCT, 2004; Brazil-MCTI, 2010). In the standing forest, the carbon stock in CWD and its decomposition rate will determine the annual carbon budget from this compartment (Harmon et al., 1986).

The CWD decomposition rate (k) is an important biological metric. It is influenced by environmental conditions, wood density and the quality of the soil substrate (Li et al., 2007; Harmon et al., 2011; Russell et al., 2015). Due to slow decomposition and sporadic mortality of trees in forest environments, few studies have addressed the variability in CWD decomposition rates, although this process is a great source of uncertainty in the context of forest dynamics (Harmon et al., 1995; Chambers et al., 2001; Palace et al., 2012). Accurate measurements of CWD decomposition rates are important for determining the magnitude of the carbon stock and the residence time in this forest compartment, providing crucial data for accurate modeling of the effects of climate change on these stocks and on global carbon fluxes (IPCC, 2006; Zell et al., 2009; Bradford et al., 2014).

The paucity of data on CWD decomposition is particularly acute in Amazonia due to the small number of studies, the vastness of the region and the huge range of forest types determined by different environmental conditions and land uses (Chambers et al., 2000; Hérault et al., 2010; Fearnside, 2016). Most studies in undisturbed forests in Amazonia have assumed a steady-state between production and CWD decomposition in order to estimate residence time, stocks and input of carbon through dead tree biomass (Chao et al., 2008; Silva et al., 2016). However, this steady-state has been altered by direct human activity (e.g., selective logging: Keller et al., 2004; Palace et al., 2008), and indirect effects (e.g., increased frequency of surface fires: Alencar et al., 2015; Barni et al., 2015). In both cases, prolonged droughts associated with extreme weather events can maximize the imbalance (Phillips et al., 2009; Vasconcelos et al., 2013).

Selective logging and deforestation provide an increased stock of residual wood pieces and non-commercial trees that are killed as a result of logging (Fearnside, 2000; Aguiar et al., 2016). In this case, the decomposition rates associated with carbon emissions are highly dependent on the replacement landscape (e.g., pastures and secondary forest), with most CWD being considered missing after the first years following deforestation (Buschbacher, 1984; Barbosa and Fearnside, 1996; Fearnside, 2008). In contrast, prolonged drought and surface fires increase tree mortality, reducing standing biomass and dramatically increasing the amount of CWD in undisturbed ecosystems (Brando et al., 2014; Doughty et al., 2015). This imbalance has a direct influence on the residence time of carbon fixed in the living biomass and its subsequent emission from CWD decomposition in undisturbed forests, and it can become part of a positive feedback process with global climate change (Galbraith et al., 2013). Because the Amazon supports forest formations with high species diversity and large carbon reservoirs (Nogueira et al., 2015), it is crucial to estimate CWD decomposition taking into account specific wood attributes (e.g., wood density) associated with the environmental conditions, and the community structure and species composition of the different forest types (Toledo et al., 2009). This provides a weighted calculation of CWD decomposition rates in terms of forest type, avoiding the use of simple averages that do not represent the ecosystem as a whole.

The Rio Negro-Rio Branco Basin (~600,000 km^2; Montero and Latrubesse, 2013) lacks information on CWD stocks and carbon flows (Barbosa and Ferreira, 2004; Chao et al., 2009; Silva et al., 2016). This region is characterized by a remarkably variable hydrological regime (different hydro-edaphic restrictions) that shapes vegetation mosaics among seasonally flooded and unflooded forest formations (Junk et al., 2011; Targhetta et al., 2015; Barni et al., 2016). Flooded and unflooded forest types are distinct in community structure and species composition (Hawes et al., 2012), as well as in abiotic characteristics. The present study offers an opportunity to determine the relative importance of taxonomic groups and wood-density classes on CWD decomposition rates in different forests in the Amazon. This approach will improve our understanding of CWD decomposition in undisturbed Amazon forests, especially in ecosystems where distinct hydro-edaphic restrictions can determine differences in the natural decomposition rates.

This study aims to investigate the CWD decomposition rates of different species that occur in undisturbed oligotrophic forests in the Rio Negro-Rio Branco Basin in the Northern Amazon. Our goal was to estimate CWD decomposition rates in two forest formations (seasonally flooded and unflooded) that naturally occur in this region, based on observations made on species in different wood-density classes over two time periods (12 and 24 months). It is expected that CWD decomposition rates in seasonally flooded formations are lower because this type of environment supports tree species with higher wood density and resistance to natural processes of fragmentation (Parolin and Worbes, 2000; Wittmann et al., 2006). The specific objectives of the study were (i) to estimate annual CWD decomposition rates of different taxonomic groups and wood-density classes, (ii) to estimate decomposition rate for each forest formation considering taxonomic groups and wood-density classes weighted by the dominance of individuals (structure) and species (composition) of each formation, and (iii) to estimate the residence time (decay time = number of years for the wood piece to completely lose its physical integrity) and carbon emissions to the atmosphere associated with the annual CWD production in each forest formation. The decomposition rates given here are the first for the oligotrophic forests of the northern Brazilian Amazon.

2. Materials and methods

2.1. Study area

Sampling for CWD decomposition rates was performed in the PPBio (Biodiversity Research Program) research grid in Viruá National Park (1°36′N, 61°13′W); a federal protected area (215.917 ha) located in the state of Roraima (Fig. 1). Viruá is part of the Rio Negro-Rio Branco basin, an ecoregion of the Amazon where the vegetation structure is directly related to the hydro-edaphic restrictions determined by different topographical features, soils and flooding levels (Cordeiro et al., 2016). Viruá is set