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Wood decomposition in Amazonian hydropower reservoirs: An additional source of greenhouse gases

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ABSTRACT

Amazonian hydroelectric reservoirs produce abundant carbon dioxide and methane from large quantities of flooded biomass that decompose anaerobically underwater. Emissions are extreme the first years after impounding and progressively decrease with time. To date, only water-to-air fluxes have been considered in these estimates. Here, we investigate in two Amazonian reservoirs (Balbina and Petit Saut) the fate of above water standing dead trees, by combining a qualitative analysis of wood state and density through time and a quantitative analysis of the biomass initially flooded. Dead wood was much more decomposed in the Balbina reservoir 23 years after flooding than in the Petit Saut reservoir 10 years after flooding. Termites apparently played a major role in wood decomposition, occurring mainly above water, and resulting in a complete conversion of this carbon biomass into CO_2 and CH_4 at a timescale much shorter than reservoir operation. The analysis of pre-impounding wood biomass reveals that above-water decomposition in Amazonian reservoirs is a large, previously unrecognized source of carbon emissions to the atmosphere, representing 26–45% of the total reservoir flux integrated over 100 years. Accounting for both below- and above-water fluxes, we could estimate that each km^2 of Amazonian forest converted to reservoir would emit over 140 Gg CO_2-eq in 100 years. Hydropower plants in the Amazon should thus generate 0.25–0.4 MW h per km^2 flooded area to produce lower greenhouse gas emissions than gas power plants. They also have the disadvantage to emit most of their greenhouse gases the earliest years of operation.

1. Introduction

Hydroelectric reservoirs, particularly those that flood tropical forests, in which the stores of organic carbon are among the highest in the world, emit greenhouse gases (GHGs) to the atmosphere (Galy-Lacaux et al., 1997; St Louis et al., 2002; Delmas et al., 2001; Abril et al., 2005; Guérin et al., 2006; Kemenes et al., 2007, 2011; Barros et al., 2011). Furthermore, anoxic conditions and high concentrations of CO_2 and CH_4 resulting from intense microbial activity have been consistently observed in Amazonian reservoirs (Galy-Lacaux et al., 1997; Abril et al., 2005; Kemenes et al., 2007, 2011). The flooded soil and litter rapidly decompose underwater to GHGs, which reach the atmosphere through four distinct pathways (Abril et al., 2005): (1) ebullition (mainly of CH_4), from shallow areas of the reservoir; (2) diffusion of CO_2 and CH_4 from the reservoir surface; (3) degassing at the turbines and immediately below the dam; and (4) degassing from downstream rivers. As the carbon pool from the flooded soil and biomass is progressively consumed, the emissions decrease with time (Abril et al., 2005; Guérin et al., 2008). Most information available from the literature are gross GHG emissions and very few studies attempt to quantify net emissions, that is the difference between pre-impounding and post-impounding fluxes (Delmas et al., 2001; Guérin et al., 2008). Even though projections at a 100-year horizon are approximates, they suggest that lowland Amazonian reservoirs with a low power density (the ratio between the energy produced and the flooded area) could emit amounts of GHGs similar to or even higher than those from a gas power plant (Delmas et al., 2001). However, all these estimates have only considered the gross fluxes from waters upstream and downstream from dams, and the fate of the standing

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dead wood has been ignored (Fearnside and Pueyo, 2012). In this paper, we attempt to describe the decomposition of wood that occurs above water in reservoirs, and to quantify its significance in terms of greenhouse gases emissions.

2. Material and methods

We studied two Amazonian reservoirs: Balbina in Brazil, flooded in October 1987, and Petit Saut in French Guiana, flooded in January 1994. Flooded area in both systems was dominated by tropical forest growing on the dissected Guianense Complex Formation (Fearnside, 1989; Galy-Lacaux et al., 1997). We base our qualitative analysis on observations and photographs taken during numerous cruises at different years, which correspond to different post-flooding ages of the wood in the reservoirs: one year (1995) and 9 years (2003) at Petit Saut, and 23 years (2010) at Balbina. Such analysis allowed us assessing the fate of flooded wood in tropical reservoirs over time. Concerning the quantitative approach, the transient character of the GHG emissions of reservoirs makes it difficult to compare reservoirs with thermal power plants. Because of the limited field data, no completely satisfactory method exists for the extrapolation of measured gas emissions during 100 years of reservoir operation (Delmas et al., 2001). We based our analysis on the comparison of two scenarios of “low” and “high” above- and below-water CO_2 and CH_4 emissions in Balbina, where GHG fluxes were measured in 2005 (Kemenes et al., 2007, 2011) and in Petit Saut, which has been intensively monitored since impounding (Galy-Lacaux et al., 1997; Abril et al., 2005). We first applied the 100-year extrapolation method previously developed at Petit Saut to both reservoirs; this method is based also on data from older African reservoirs and provides net GHG fluxes (Delmas et al., 2001). This model incorporates the pre-impounding fluxes from natural tropical forest and soils, and includes the assumption that the gross flux of CH_4 will remain significant over 100 years, based on the fueling by organic material carried by rivers and produced by the aquatic system itself. The model developed at Petit Saut was applied to Balbina by simply correcting for the reservoir surface area. A second type of estimates was derived by extrapolating the few available fluxes measured in the field (Abril et al., 2005; Kemenes et al., 2007, 2011) to a 100-year period. At Petit Saut, we applied the observed fluxes during the first 10 years (Abril et al., 2005). We assumed that the emissions of the reservoir would be 10-fold lower during the subsequent 90 years, consistently to the observed decreasing time course of emission (Abril et al., 2005). At Balbina, we assumed that, during the first 20 years, the reservoir had emitted at the rates measured at year 18 (Kemenes et al., 2007, 2011) and for the next 80 years, we applied fluxes that were 10-fold lower. Balbina’s emission calculated that way is probably an underestimate of gross emission, as it does not account for the strong ebullition probably occurring the first 2 years after impounding (Fearnside and Pueyo, 2012).

The above-water emissions were computed as a loss of biomass, assuming a total decomposition of the wood above the water table, consistent with our qualitative observations (see Results). The above water wood biomass in each reservoir was calculated from the regional carbon density given by Saatchi et al. (2007), an average canopy height of 30-m as reported by Helmer and Lefsky (2006), and the reservoirs depths and the surface areas. The relative proportions of CO_2 and CH_4 produced were calculated from the reported rates of wood decomposition by termites (Seiler et al.,

Fig. 1. Above-water wood decomposing in tropical reservoirs. A: Aerial view of the Petit Saut Reservoir one year after complete flooding, showing the initial density of dead trees. Living, green trees remain only on the islands. B: Flooded dead forest in the Petit Saut Reservoir 9 years after flooding. C: A termite nest on a standing tree in the Petit Saut Reservoir 9 years after flooding. D: Flooded dead forest in the Balbina Reservoir 23 years after flooding, showing a broken hollow bole (diameter ~2 m) resulting from decomposition by termites. The trees generally break near the water level, whereas the submerged wood decomposes more slowly (6). E: Beached boles in the Balbina Reservoir, 23 years after flooding; falling wood can continue to float for months in the reservoirs but is finally transported by wind and decomposes on the reservoir banks. Photo credits: A: Hydreco, Kourou, B to E: G. Abril.