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Impacts of land-use and land-cover change on stream hydrochemistry in the Cerrado and Amazon biomes

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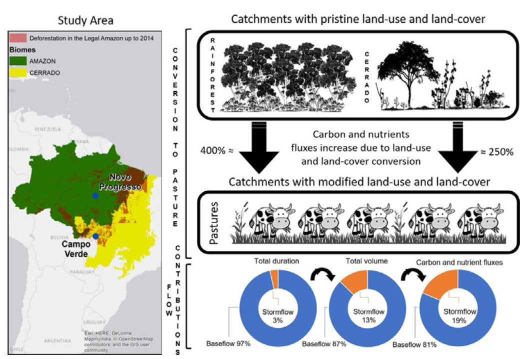
HIGHLIGHTS

- Deforestation negatively impacts stream hydrochemistry in the Amazon and Cerrado.
- High-temporal monitoring approaches reveal unaccounted environmental impacts.
- Concentrations were higher in streams where the forest was replaced by pastures.
- Stormflow is a substantial hydrological pathway for carbon and nutrient losses.

GRAPHICAL ABSTRACT



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ABSTRACT

Studies on the impacts of land-use and land-cover change on stream hydrochemistry in active deforestation zones of the Amazon agricultural frontier are limited and have often used low-temporal-resolution datasets. Moreover, these impacts are not concurrently assessed in well-established agricultural areas and new deforestations hotspots. We aimed to identify these impacts using an experimental setup to collect high-temporal-resolution hydrological and hydrochemical data in two pairs of low-order streams in catchments under contrasting land use and land cover (native vegetation vs. pasture) in the Amazon and Cerrado biomes. Our results indicate that the conversion of natural landscapes to pastures increases carbon and nutrient fluxes via streamflow in both biomes. These changes were the greatest in total inorganic carbon in the Amazon and in potassium in the Cerrado, representing a 5.0- and 5.5-fold increase in the fluxes of each biome, respectively. We found that stormflow, which is often neglected in studies on stream hydrochemistry in the tropics, plays a substantial role in the carbon and nutrient fluxes, especially in the Amazon biome, as its contributions to hydrochemical fluxes are mostly greater than the volumetric contribution to the total streamflow. These findings demonstrate that assessments of the impacts of deforestation in the Amazon and Cerrado biomes should also take into account rapid hydrological pathways; however, this can only be achieved through collection of high-temporal-resolution data.

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1. Introduction

It has been widely acknowledged that surface conditions of terrestrial ecosystems have strong synergies with hydrological processes (Cuo et al., 2013; Neill et al., 2008; Recha et al., 2012; Rodriguez et al., 2010). These processes are often influenced by land-use practices, which, in turn, can change catchment responses, such as stream hydrochemistry (Crossman et al., 2014; El-Khoury et al., 2015; Oni et al., 2014; Öztürk et al., 2013; Salemi et al., 2013; Vogt et al., 2015). Because of large-scale environmental impacts resulting from the conversion of native habitats into agricultural frontiers (Schiesari et al., 2013), it is fundamental to comprehend how land-use and land-cover (LULC) change influences hydrochemical processes in pristine catchments undergoing anthropogenic changes (Jordan et al., 1997; Neill et al., 2013). Therefore, studies have often focused on regions under intensive forest degradation due to agricultural expansion, such as the Brazilian Amazon, to assess the impacts of LULC change on stream hydrochemistry (Dias et al., 2015; Figueiredo et al., 2010b; Germer et al., 2009; Neill et al., 2011; Recha et al., 2013; Williams and Melack, 1997).

The Amazonian agricultural frontier (AAF), also known as the arc of deforestation, extends from the eastern to the southwestern edge of the Brazilian Amazon, comprising a wide area along the Amazon–Cerrado ecotone (Do Vale et al., 2015; Durieux, 2003; Silva et al., 2013). Deforestation in this region has taken place due to agricultural expansion during recent decades, and represents most of the deforestation of the AAF (Brannstrom et al., 2008; Fearnside, 2001; Riskin et al., 2013; Tollefson, 2015). This ongoing change threatens the services provided by native ecosystems, such as the water quantity and quality that sustain aquatic biodiversity and mitigate eutrophication of water bodies (Coe et al., 2013; Davidson et al., 2012; Neary, 2016; Penaluna et al., 2017). However, despite the important contribution of several research initiatives (e.g., Andreae et al., 2015; Lahsen and Nobre, 2007; Satinsky et al., 2014), an understanding of the influence of LULC change on water resources in the Brazilian Amazon region remains limited. Furthermore, the Cerrado biome, where most of the AAF deforestation has occurred (Klink and Machado, 2005), is often not integrated in studies regarding Amazon deforestation; consequently, it is one of the lesser-studied regions in terms of the environmental effects of LULC change resulting from agricultural expansion (Hunke et al., 2015a; Jepson et al., 2010; Oliveira et al., 2015) despite being a biodiversity hotspot for conservation comprised of dry forests, woodland savannas and grasslands (Spera et al., 2016; Strassburg et al., 2017). The conversion of native vegetation to crops and pastures has removed ca. 50% of the original 2 million km^2 in the Cerrado, which is greater than the forest loss in the Amazon biome (Klink and Machado, 2005; Lambin et al., 2013).

The negative impacts on water quality due to LULC change are reported to be a result of interrelated processes (i.e., changes in vegetation, soil and hydrology) that negatively disturbs its land capability, which is the ability of the land to sustain its use (Valle et al., 2014; Valle Junior et al., 2015). On the AAF, soil and hydrological changes have been linked to forest clearing and conversion to pastures (Neill et al., 2008; Zimmermann et al., 2006). Indeed, LULC change on the AAF has been primarily driven by the expansion of pastures (Armenteras et al., 2013; Schierhorn et al., 2016). After some years, these pastures are often either replaced by cash crop systems (Barona et al., 2010; Cohn et al., 2016) or abandoned due to decreased grass productivity, ultimately reaching advanced stages of degradation (Davidson et al., 2012). Variations in nutrient input into rivers caused by LULC change on the AAF deserve particular attention because of their potential impact on both biogeochemistry and aquatic ecosystem functioning (Neill et al., 2011). Even though rain and dry forests account for ca. 60% of the net primary production of global terrestrial ecosystems (Grace et al., 2006; Potter et al., 2012), the effects of the impacts of LULC change in these systems are not well studied as they are for other regions of the world (Luke et al., 2017).

The initial effects of LULC change on the hydrochemistry of rivers have often been observed in low-order streams (Hope et al., 2004; Neill et al., 2001; Richey et al., 1997), which connect the terrestrial environment to large rivers and integrate environmental processes, especially landscapes undergoing change (Alexander et al., 2000; Moreira-Turcq et al., 2003). These characteristics qualify small streams as sensitive indicators of changes in ecosystems due to human activities and allow their use as important references in carbon exportation studies and as early warning systems for ecological change (Christophersen et al., 1994). Although many studies have evaluated the dynamics of carbon and nutrients in streams in several regions of the world (e.g. Southeastern USA (Marchman et al., 2015), subtropical China (Yan et al., 2015), Germany (Strohmeier et al., 2013) and Canada (Jollymore et al., 2012)), studies of carbon export dynamics in low-order tropical catchments are still scarce (de Paula et al., 2016). There is increasing research interest in high-temporal-resolution data collection in low-order fluvial systems that should also be taken into account in hydrochemistry studies (Hughes et al., 2005; Richey et al., 2011; Wohl et al., 2012) due to their importance to the global carbon dynamics (Bass et al., 2014).

The dynamics of stream hydrochemistry that have remained largely invisible due to the monitoring schemes that only consider weekly or monthly sampling (Kirchner and Neal, 2013), have been gradually unveiled due to approaches that use subdaily sampling intervals (Tang et al., 2008). However, the high-frequency water sampling approach that has been shown to be useful for these studies in temperate regions (Clark et al., 2007) has been discredited in tropical regions (Chaussê et al., 2016). Moreover, findings in Amazonian headwater streams that have used subhourly sampling routines have found that the conversion of forests to fertilized agricultural lands changed neither the stream water chemistry nor nutrient output per unit of catchment area (Neill et al., 2017; Riskin et al., 2017).

Our study aims to identify the differences in stream carbon and nutrient (CAN) concentrations and output fluxes during prevalent baseflow and stormflow conditions in headwater catchments under contrasting LULC (native vegetation vs. pasture), thereby contributing to the understanding of CAN drivers in low-order streams on the AAF. Our hypothesis is that LULC change is impacting stream hydrochemistry in active deforestation zones of the Amazon and Cerrado biomes, with the stormflow, which is often neglected in studies in these regions, as a substantial contributor to the total CAN fluxes.

2. Study area

Our study follows the space-for-time substitution approach to compare adjacent headwater catchments with different LULC but with similar characteristics, i.e. slope, geology, soils, aspect and climate (Troch et al., 2015). Studies have often used this approach to understand the effects of vegetation and land use on hydrological responses in small catchments (Brown et al., 2005; de Moraes et al., 2006; Germer et al., 2010; Muñoz-Villers and McDonnell, 2013; Ogden et al., 2013; Roa-García et al., 2011). It has also been applied to compare the impacts of LULC change on stream hydrochemistry of contrasting catchments (Sun et al., 2013; Zhao et al., 2010).

We used two pairs of microcatchments on the AAF (Fig. 1) with contrasting LULC. Each pair of catchments consists of a catchment with predominantly native vegetation land cover and a catchment with predominantly pasture land cover used for extensive cattle ranching. One pair of catchments is in the municipality of Novo Progresso (Brazilian state of Pará), which is a hotspot of deforestation in the Amazon biome (Pinheiro et al., 2016; Rufin et al., 2015), and the other pair is in the municipality of Campo Verde (Brazilian state of Mato Grosso), which is a region that has been massively

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