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Land use intensity trajectories on Amazonian pastures derived from Landsat time series

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ABSTRACT

Monitoring changes in land use intensity of grazing systems in the Amazon is an important prerequisite to study the complex political and socio-economic forces driving Amazonian deforestation. Remote sensing offers the potential to map pasture vegetation over large areas, but mapping pasture conditions consistently through time is not a trivial task because of seasonal changes associated with phenology and data gaps from clouds and cloud shadows. In this study, we tested spectral-temporal metrics derived from intra-annual Landsat time series to distinguish between grass-dominated and woody pastures. The abundance of woody vegetation on pastures is an indicator for management intensity, since the duration and intensity of land use steer secondary succession rates, apart from climate and soil conditions. We used the developed Landsat-based metrics to analyze pasture intensity trajectories between 1985 and 2012 in Novo Progresso, Brazil, finding that woody vegetation cover generally decreased after four to ten years of grazing activity. Pastures established in the 80s and early 90s showed a higher fraction of woody vegetation during their initial land use history than pastures established in the early 2000s. Historic intensity trajectories suggested a trend towards more intensive land use in the last decade, which aligns well with regional environmental policies and market dynamics. This study demonstrates the potential of dense Landsat time series to monitor land-use intensification on Amazonian pastures.

1. Introduction

Conversion of tropical primary forests into managed grasslands is the dominant land use change process in the Brazilian Amazon region (Bowman et al., 2012). Historically, cattle pastures have been operated on low productivity, with stocking densities frequently below one animal per hectare (Valentim and Andrade, 2009). Nevertheless, the Amazon cattle herd has undergone swift expansion. A doubling of the number of animals was registered in the federal state of Pará between 1999 and 2005, thereby exceeding 18 million animals (IBGE, 2006). This rapid growth of cattle herds coupled with inefficient management practices suggests that there has been a substantial expansion of pastoral land, potentially accompanied by increased grazing intensity.

Encroachment of woody vegetation indicates decreased agronomical productivity on pastures (Asner et al., 2004a), due to diminished accessibility of forage grass patches and competition between indigestive woody vegetation and forage species for light and plant-available nutrients (Feldpausch et al., 2004). The speed and amount of secondary succession on Amazonian pastures is generally high (Moran et al., 2000) and greatly influenced by the duration and intensity of land use (Alves et al., 2003; Uhl et al., 1988).

Land use intensity on pastures is driven by a variety of factors such as stocking rates, herbicide and fertilizer inputs, liming, burning and clearing of shrubs and trees (Fearnside, 2001; Landers, 2007; Nepstad et al., 1996). The Amazon production system is dominated by traditional management practices, such as frequent pasture burning and labor-intensive manual removal of woody vegetation (Asner et al., 2004b; Mertens et al., 2002); whereas, capital-intensive practices to restore high levels of forage grass productivity remain an exception (Fearnside, 1997; Landers, 2007). Pasture intensification is hence achieved through increasing stocking rates and the frequency of pasture burning, thereby diminishing the abundance of woody vegetation (Asner et al., 2004b). Historically changing frameworks in politics and markets create or diminish incentives for land use intensification, thus potentially leading to variations in regional management schemes (Bowman

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et al., 2012). Monitoring the dynamics of woody vegetation fractions on managed grasslands can consequently help to understand spatial and temporal trends in pasture intensity.

Remote sensing is ideally suited for monitoring the extensive Amazon pasture systems. Previous approaches to characterize vegetation dynamics on managed grasslands using remote sensing widely confirmed findings of field based studies and indicated a great potential for increasing the understanding of regional vegetation dynamics. Asner et al. (2004b) and Numata et al. (2007) identified pasture degradation processes by combining field measurements with remotely sensed data. They derived pixel-wise fractions of photosynthetically active vegetation (PV), non-photosynthetically active vegetation (NPV) and soil (S) using spectral mixture analysis of Landsat imagery. Decreasing PV fractions revealed land use age as the most relevant factor determining long-term pasture productivity declines, followed by indicators of management intensity, climate and soils. However, despite its particular relevance in the Amazon biome (Dias-Filho, 2011; Landers, 2007), the process of woody vegetation encroachment has not been considered in these studies. Davidson et al. (2008) identified a potential positive bias of PV fractions caused by woody vegetation and underlined the importance of distinguishing between the spectral responses of shrubs and trees from pasture grasses when using remote sensing to monitor pasture biophysical properties in the Amazon.

Detailed monitoring of woody vegetation encroachment requires an appropriate observation frequency (Campbell et al., 2012), especially in the fast-growing Amazon biome. Recent studies focusing on monitoring pasture vegetation dynamics at Landsat-like spatial resolution used either chronosequences to model succession by sampling sites of varying age within single date imagery (e.g., Asner et al., 2004b; Numata, 2003), or trajectories derived from multi-date imagery with partly irregular observation intervals spanning two years or more (e.g., Numata et al., 2007). Multi-year intervals limit the level of detail in which vegetation trajectories can be captured, thereby highlighting the need for novel approaches to consistently monitor pastures over long time periods in appropriate time intervals. The Landsat image archive of the United States Geological Survey (USGS) facilitates the analysis of dense image time series at 30 m spatial resolution (Wulder et al., 2012). In this context, spectral variability metrics capturing the temporal variation of surface reflectance have the potential to distinguish spectrally similar land use classes in heterogeneous ecosystems (e.g., Griffiths et al., 2013; Müller et al., 2015). The analysis of spectral variability metrics may also help to distinguish grass-dominated pastures from those with increased levels of woody vegetation.

The aim of this study was to explore the potential of dense Landsat time series to characterize historic changes in land use intensity on grazing lands in tropical forest landscapes of South America. Specifically, the main objectives were to: (1) identify suitable spectral-temporal metrics associated to woody vegetation cover to serve as proxy for land use intensity, and (2) to use these metrics for characterizing historic changes in land use intensity at an annual interval.

2. Data and methods

2.1. Study area

Post-deforestation land use in Novo Progresso (Southern Pará in Brazil, see Fig. 1) is dominated by pastoral activities (87%; IBGE, 2006), rendering this region highly suitable for pasture-related research. The climatic conditions in Southern Pará favor fast vegetation growth and rapid re-establishment of shrub and tree species after forest clearing (Moran et al., 2000). The region's climate is characterized by strong seasonality in precipitation. The average annual precipitation sums up to 2225 mm of which 97% fall between September and May (TRMM, 2013). The dry season lasts from end of May to end of August, with annual variations of up to a few weeks. The region is characterized by nutrient-poor soils and a rolling topography with rock outcrops.

Economic development was triggered by the National Integration Plan in the 1960s and the subsequent construction of the BR-163 highway, which provided incentives for land-seeking farmers to settle in the remote areas of the Amazon (Mertens et al., 2002). Deforestation rates rose sharply until they peaked in 2004. In 2012, roughly 20% of our study area were cleared (INPE, 2013). The dynamic land change history of this frontier region can be regarded

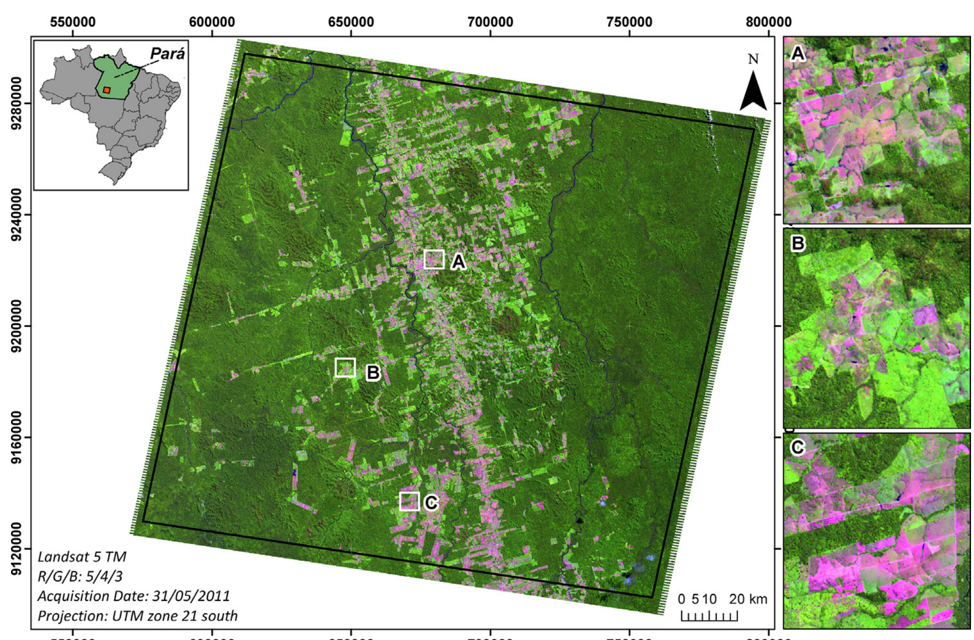

Fig. 1. Location of the study area in Brazil (top left) and false-color Landsat TM image. Image chips (right) show pastures with low vegetation cover (magenta), high levels of secondary vegetation (bright green), and primary forests (dark green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)