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Forest fragmentation and edge influence on fire occurrence and intensity under different management types in Amazon forests

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ABSTRACT

The ecological characteristics of forest edges have been intensively studied in the Amazon region, but the occurrence and intensity of fires as large-scale edge effects are less well known, as is the role of different types of management in modifying this relationship. We used remote sensing techniques to examine the relationship between forest fragmentation, fire and management across NW Amazonia. Our study was based on forest data for 2005 and on active fire data from the MODerate-resolution imaging Spectro-radiometer (MODIS), with information on the occurrence and strength of fires based on fire radiative power (FRP) data. We analyzed the fragmentation and fire occurrence and intensity in a 50×50 km grid. We also calculated the distance at which edge-related fires occur in the forest interior and outside the forest edge. Forest fragmentation had a significant impact on fire occurrence and fire intensity, supporting the hypothesis that the more fragmented a forest is, the higher the degree of biomass combustion. These results are in agreement with the occurrence of an edge effect on both the occurrence and the intensity of fire. The different types of management in the region influence the occurrence and intensity of fire, whereas fire as a large-scale edge effect occurs independent of the management type. Finally, we suggest that a high connectivity in protected areas and indigenous reserves and also in outside areas should be encouraged to minimize edge-driven fire processes.

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1. Introduction

Fire in the tropics is closely linked to deforestation, either through slash-and-burn agriculture or through the land clearing and management involved in cattle ranching, making fire usage one of the major threats to neotropical forests (Metzger, 2002; Wassenaar et al., 2007; Morton et al., 2008; Silvestrini et al., 2011). Favored by the increasing demands for agricultural land and timber products the development of forested areas has promoted management practices that increase the risk of forest fires. Fire in the Brazilian Amazon tends to occur more frequently in fragmented forests and is associated primarily with forest edges (Cochrane, 2001; Cochrane and Laurance, 2002). Most edge-related fires move into forests from deforested areas, and further deforestation fragments the remaining forest. The alteration of the fire regime becomes further influenced by the proximity to the deforested forest edges (Cochrane, 2003) and produces amongst others increased desiccation and fuel loads in the edge areas (Laurance, 2000; Nascimento and Laurance, 2002; Briant et al., 2010). The combination of forest deforestation and fragmentation makes the Amazonian forest more vulnerable to fires (Cochrane, 2003), and this phenomenon is exacerbated by climate change (Cochrane and Laurance, 2008; Cochrane and Barber, 2009).

Land-use and land-cover changes and the increasing expansion of agricultural frontiers into tropical forests have increased the focus on the best approaches for the conservation and management of the territory and, in particular, on the role of reserves (either protected areas or indigenous reserves) in protecting biodiversity (Nepstad et al., 2006; Oliveira et al., 2007). In the Amazon, these areas are central for biodiversity conservation strategies but are also key elements for safeguarding the remaining habitats and species from deforestation fires (Nepstad et al., 2006; Adeney et al., 2009). In theory, different types of management allow different land uses in a region. Either because of these restrictions or because of the low accessibility of protected areas and reserves, these land designations usually furnish effective protection against deforestation fires (Adeney et al., 2009). However, isolated nature reserves have also been shown to be vulnerable to edge-related fires (Cochrane and Laurance, 2002). The extent to which protected areas and indigenous reserves are effective at preventing the increased frequency and intensity of forest edge-related fires is generally unknown for the entire Amazon region.

Remote sensing techniques have been used to map the patterns, sizes and even emissions of fires (Dwyer et al., 2000; van der Werf et al., 2004; Giglio et al., 2006; Chuvieco et al., 2008; Chang and

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Song, 2009). Recently, measures of fire strength have been tested using several sensors (MODerate resolution imaging Spectro-radiometer [MODIS] and Spinning Enhanced Visible and Infrared Imager [SEVIRI]) to provide immediate information on the fire radiative power (FRP) in megawatts (MW) (Wooster et al., 2005; Ichoku et al., 2008). Although the FRP is only an instantaneous measure, it is linearly related to the total amount of fuel biomass consumed by fires (Wooster et al., 2005). Thus, it can be used as a measure of fire intensity over extensive areas affected by fire events (Ichoku et al., 2008).

Northwestern Amazonia is one of the wettest tropical rainforest regions of the Amazon Basin. Although the human population density of the region is still low, the area is a very active colonization front (Armenteras et al., 2006; Armenteras-Pascual et al., 2011). In this region, several types of reserves are present (protected areas, indigenous reserves and integrated-management districts), allowing different types of land use. Different land-use types can have different effects on the pattern, occurrence and intensity of fires. The objective of this study is to analyze the roles of forest fragmentation and the edge effect on forest fire occurrence and intensity in areas of the region with different management types. We address three questions: (a) Does forest fragmentation influence fire occurrence and intensity in NW Amazonia? (b) Is there an edge effect on fire occurrence and intensity? (c) Do the different types of management in the region influence fire occurrence and intensity by modifying forest fragmentation and the edge effect?

2. Methods

2.1. Study site

The Amazon Basin has a total area of 6.3 million km^2, with 5 million km^2 in Brazil and the remaining area divided among Bolivia, Colombia, Ecuador, Peru and Venezuela. The study area (Fig. 1) corresponds to the northwestern part of the Amazon, in particular, the Colombian Amazon region. This region includes 7% of the entire Amazon Basin, and 40% of it is south of the Equator. The region is highly diverse and still retains a high percentage of forest (87.8%). It has a low population density, but there is a very active colonization front that originated in the Andes toward the east (Armenteras-Pascual et al., 2011; Armenteras and Retana, 2012). The total area studied covers a surface of 45,779,502 ha, of which 6,307,173 ha are included in 8 national protected areas (PAs) and 2 national natural reservations (Nukak and Puinawai, hereafter referred to as PAs), 21,737,367 ha in 147 indigenous reserves (IRs) and 1,476,162 ha in six integrated-management districts (IMDs, areas delimited under sustainable development criteria). Forest size range of the fragments vary from 1 ha to 750,000 ha approximately in PAs, to 1,500,000 ha in IRs and to 26,500 ha in IMDs. Private lands or untitled areas (16,258,801 ha) occur outside these designated areas with the smallest forest fragment of 1 ha and the biggest of 500,000 ha approximately.

2.2. Data sources and analyses

The forest data for 2005 were obtained from the official project "Scientific and institutional capacity building to support Reducing Emissions from Deforestation and Degradation (REDD) projects in Colombia" (Instituto de Hidrología Meteorología y Estudios Ambientales - IDEAM, 2011). We used the fire-hotspots series product MODIS, which is included in the Collection 5.1 temporal thermal analysis active-fire dataset (Davies et al., 2009). We downloaded the daily dataset from January 2001 to December 2011; this dataset is available at FIRMS (Fire Information for Resource Management System: Archiving and Distributing MODIS Active Fire Data, Collection 5.1). For each fire hotspot between 2005 and

Fig. 1. Study area.

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