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Fire regimes in Amazonia: The relative roles of policy and precipitation

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ABSTRACT

Reducing carbon emissions from deforestation and forest degradation is now a vital component in climate change mitigation strategies. Global initiatives such as REDD+ are receiving growing investments, and in-country policy makers are under pressure to protect intact forests. In 2008, Brazil met these pressures by making deforestation reduction a central piece of its climate change policy. Although previous research found that this policy led to reduced deforestation, decreases in fire–another significant factor in carbon emissions–were not observed. Here we revisit Amazonia, the target location of Brazil's anti-deforestation policies, to determine how precipitation may be affecting forest fires in the area while controlling for other potential biophysical, economic, and institutional correlates. Using data on precipitation and deforestation alongside MODIS active fire and burned area data, this article examines the general spatial-temporal trends of fire in the region between 2001 and 2013. We then implements statistical models to measure the relative impact of precipitation and anti-deforestation policies on both fire events and burned area over the time period. The analysis shows that while deforestation decreased under policy treatment, forest fires were less responsive to policies. Furthermore, the analysis provides strong evidence for the existence of a precipitation effect on both fire events and burned area. Results indicate that a one standard deviation decrease in precipitation from its normal could increase fire events by 11–15% and burned area by 18–27%. The article concludes by addressing the challenges in controlling fire in Amazonia under drier climatic conditions in the presence of abundant fuel and ignition sources.

1. Introduction

The mastery of fire was a turning point in our species' biological and technological evolution and is intricately linked to the onset of the Anthropocene (Steffen et al., 2007; Glikson, 2013). Natural and anthropogenic fires have long played a pivotal role in terrestrial and atmospheric system processes (Bowman et al., 2009) but encroachment of modern agriculture into tropical forests has increased the quantity and frequency of fire in these ecosystems (Neves et al., 2004; Bush et al., 2008). Now, with global initiatives set to reduce carbon emissions from land change (Kollmuss et al., 2008), policymakers are under increased pressure to not only curb deforestation and forest degradation, but also combat fire.

Brazil is notable in this regard because its Amazonian forests hold close to 35% of the world's tropical forest carbon and produces some of the largest emissions from forest loss (Saatchi et al., 2011; Baccini et al., 2012). The Brazilian Amazon has also been hailed as a success story in the reduction of deforestation rates in the last decade, attributed in large part to the successful implementation of public policies (Soares-Filho et al., 2010; Arima et al., 2014; Cisneros et al., 2015). Given the strong relationship between deforestation and anthropogenic fires, the same steep reductions in fire were expected. Instead, fire numbers fluctuated greatly from year to year, possibly influenced by intervening abiotic factors.

The objective of this article is to tackle this issue and examine the main factors that drive the current fire regime in Brazil's Amazonia. Specifically, we examine the relative roles of abiotic factors and anti-deforestation policies in determining the amount of forest fires, while controlling for other potential biophysical, economic, and institutional correlates.[1] To pursue this objective, we first discuss the relationship between deforestation, agricultural expansion, and fire in the basin, while acknowledging the role

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[1] Research has found that indigenous reserves and conservation areas experience much lower levels of fire than their non-protected counterparts, even when controlling for the fact that those protected areas are typically located in remote areas far from agricultural activities (Arima et al., 2007; Nelson and Chomitz, 2011; Barber et al., 2014).

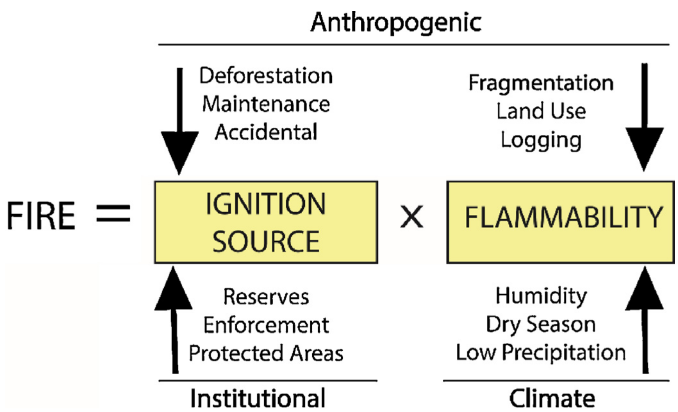

Fig. 1. Conceptual framework for the drivers of fire.

of climatic factors and policy initiatives to date. Next, we show evidence that fire and deforestation rates decoupled from each other after 2007, a main motivation for our analyses. We then present statistical analyses that reveal the extent to which two factors—(1) recent policy measures and (2) deviations in regional precipitation—have affected fire in the Amazon, both in terms of total number of fire events and burned area. Finally, we translate these results into practical significance for policymakers, whose engagement in mitigation strategies may be offset by the precipitation and climate trends of the future.

2. Background

2.1. Anthropogenic fires in Amazonia

Although natural wildfires are relatively rare in the Brazilian Amazon, anthropogenic fires remain a regular threat (Uhl et al., 1989; Uhl and Kauffman, 1990; Cochrane et al., 1999; Nepstad et al., 1999; Sorrensen, 2009; Aragão and Shimabukuro, 2010; Alencar et al., 2011; Brando et al., 2013; Shlisky et al., 2009). These fires are tightly linked to the encroachment of the agricultural and logging frontiers into primary forest. Numerous studies have found a strong statistical relationship between fire incidence and agricultural activity, typically proxied by distance to roads, farmgate prices, and distance to deforested areas (Nepstad et al., 2001; Alencar et al., 2004; Arima et al., 2007; Barber et al., 2014). In addition, logging and forest fragmentation increase fuel loadings (i.e litter material) and decrease understory humidity (Uhl and Kauffman, 1990; Cochrane and Schulze, 1999; Nepstad et al., 2001), while millions of farmers and ranchers provide the ignition sources as they use fire to burn forest biomass during the deforestation process. Burns are often followed by the encroachment of grass species, increasing fine fuel loads and fire intensity (Veldman et al., 2009; Silvério et al., 2013; Brando et al., 2014). Once planted pastures are established, ranchers often use fires to control invasive shrubs and trees (i.e. maintenance fires) that compete with the desired grasses (Uhl and Buschbacher, 1985; Nepstad et al., 1999, 2001; Laurance et al., 2001; Sorrensen, 2009; Arima et al., 2007; Schroeder et al., 2009; Walker et al., 2009). The end result is that even accidental fires in the Amazon are anthropogenic in origin; the result of deforestation or maintenance fires that escape control and advance into logged or primary forests (Holdsworth and Uhl, 1997; Nepstad et al., 1999, 2001).

2.2. The role of abiotic conditions

Ignition sources from human activities are necessary but wildfires can only ignite and spread if abiotic conditions are adequate to transform vegetation into flammable material. Climatic parameters, including precipitation, humidity, wind speed (Aragão et al., 2008; Marengo et al., 2008; Alencar et al., 2015), and events such as the El Niño Southern Oscillation (ENSO) or extreme droughts are all important factors (Nepstad et al., 1995; Barbosa and Fearnside, 2000; Nepstad et al., 2001; Galindo et al., 2003; Marlon et al., 2008; Alencar et al., 2011; Brando et al., 2013; Brando et al., 2014). For instance, recurrent fires occur more often during ENSO years (Alencar et al., 2004, 2011, 2015), and recent work has also shown a strong linkage between the Atlantic Multidecadal Southern Oscillation Index and patterns of precipitation and fire in the southern and southwestern Amazon (Chen et al., 2011). If burned more than once, these forests experience a dramatic increase in the risk of understory fire (Alencar et al., 2004; Morton et al., 2013) and up to a 28% increase in their chances of being burned a subsequent time (Alencar et al., 2011). Subsequent burns may lead to altered regeneration patterns (Balch et al., 2013), increased susceptibility and burn intensity (Cochrane and Schulze, 1998; Cochrane et al., 1999) and increases in global atmospheric CO_2 (a figure that reached 395.31 ± 0.10 ppm in 2013 according to the Quéré et al. (2015)). In some parts of the Brazilian Amazon, the return interval for fires is already 5–11 times more frequent than estimates for natural fire regimes (Alencar et al., 2011).

2.3. Environmental policies and the link between deforestation, fire & precipitation

In this section, we review the recent anti-deforestation policies implemented in Brazil and show how, despite an early correlation, fire and deforestation rates decouple from each other after 2007; perhaps because fire regimes respond not only to policies but also to abiotic conditions.

Following the 27,772 km^2 of deforestation observed in 2004, Brazil enacted the first Action Plan to Prevent and Control Deforestation in Amazonia (PPCDAm-I). Implemented between 2004 and 2007, this plan restructured Brazil's environmental agency's mission (IBAMA) to focus exclusively on enforcement and regulation. IBAMA began using INPE's 'real-time' deforestation detection (DETER) to target its enforcement efforts in the field (Abdala, 2008), and the country's protected areas were expanded dramatically. Between 2004 and 2008, 25 million hectares of federal conservation units, 10 million hectares of indigenous lands, and 25 million hectares of state conservation units were added to the protected areas system in Amazonia (Abdala, 2008). These efforts were followed by the second phase of PPCDAm (2008–2011), focused on monitoring and enforcement of environmental legislation. As part of this new phase, 36 municipalities were placed on a list for special enforcement efforts due to historically high deforestation rates. This list was later expanded to 43 (2009) and 48 municipalities (2011). As of 2012, 46 municipalities remain on the list (52 municipalities were blacklisted in total) (Fig. 2).

Once on the list, landholders in those municipalities were subjected to greater monitoring scrutiny (i.e. more fines and citations for non-compliance with environmental laws) (Barreto and Silva, 2010; Arima et al., 2014). To this day, removal from the list is contingent upon sustained reduction of deforestation rates, creation of georeferenced cadastral maps of private properties, and plans for restoring areas deforested illegally in each property (MMA, 2013). In addition, in 2009, federal prosecutors initiated civil actions against meat packing plants purchasing cattle from non-compliant farms. As part of the initiative, prosecutors offered to suspend the actions if companies agreed to purchase cattle only from ranches that followed the directives established by PPCDAm. Together, these actions have been hailed as a success story in