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Climate, landowner residency, and land cover predict local scale fire activity in the Western Amazon

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ABSTRACT

The incidence of escaped agricultural fire has recently been increasing in the Western Amazon, driven by climate variability, land use change, and changes in patterns of residency and land occupation. Preventing and mitigating the negative impacts of fire in the Amazon require a comprehensive understanding not only of what the drivers of fire activity are, but also how these drivers interact and vary across scales. Here, we combine multi-scalar data on land use, climate, and landowner residency to disentangle the drivers of fire activity over 10 years (2001–2010) on individual landholdings in a fire-prone region of the Peruvian Amazon. We examined the relative importance of and interactions between climate variability (drought intensity), land occupation (in particular, landowner absenteeism), and land cover variables (cover of fallow and pasture) for predicting both fire occurrence (whether or not fire was detected on a farm in a given year) and fire size. Drought intensity was the most important predictor of fire occurrence, but land-cover type and degree of landowner absenteeism increased fire probability when conditions were dry enough. On the other hand, drought intensity did not stand out relative to other significant predictors in the fire size model, where degree of landowner absenteeism in a village and percent cover of fallow in a village were also strongly associated with fire size. We also investigated to what extent these variables measured at the individual landholding versus the village scale influenced fire activity. While the predictors measured at the landholding and village scales were approximately of equal importance for modeling fire occurrence, only village scale predictors were important in the model of fire size. These results demonstrate that the relative importance of various drivers of fire activity can vary depending on the scale at which they are measured and the scale of analysis. Additionally, we highlight how a full understanding of the drivers of fire activity should go beyond fire occurrence to consider other metrics of fire activity such as fire size, as implications for fire prevention and mitigation can be different depending on the model considered. Drought early warning systems may be most effective for preventing fire in dry years, but management to address the impacts of landowner absenteeism, such as bolstering community fire control efforts in high-risk areas, could help minimize the size of fires when they do occur. Thus, interventions should focus on minimizing fire size as well as preventing fires altogether, especially because fire is an inexpensive and effective management tool that has been in use for millennia.

1. Introduction

Although humans have long influenced fire regimes on earth, recent anthropogenic drivers are causing major shifts in fire activity in some parts of the world and are expected to further alter global fire regimes in the near future (Bowman et al., 2011; Krawchuk et al., 2009; Turner, 2010). These changes will have consequences for biodiversity, conservation, and ecosystem processes, along with human health, economics, and wellbeing (Bowman et al., 2009; Lohman et al., 2007). Adapting to and mitigating the effects of changing fire regimes requires an understanding of the drivers of both broad scale and local heterogeneity in fire activity, and of the links, interactions, and interdependencies of the multiple drivers of these changes.

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An ideal region in which to examine such questions is the western Amazon. Although humans have used fire to clear land for agriculture and improve hunting grounds in the Amazon for thousands of years (Bowman et al., 2008; Bush et al., 2008), the incidence of escaped agricultural fires has been increasing in recent decades (Alencar et al., 2011; Aragão et al., 2007; Aragão and Shimabukuro, 2010; Armenteras and Retana, 2012; Asner and Alencar, 2010). Because there are few natural ignitions, fires are associated with human activities (Cochrane and Laurance, 2008; Nepstad et al., 2001). Fire is still a common tool used to prepare land for agriculture or grazing, but today, these fires are prone to escaping into adjacent forest or non-forested land, particularly in dry years (Alencar et al., 2004; Nepstad et al., 1999). Amazonian fires can be major sources of greenhouse gas emissions (DeFries et al., 2002, 2008), degrade forests, affect biodiversity and ecosystem services (Cochrane and Schulze, 1999; Gerwing, 2002), and cause property loss and respiratory disease (de Mendonça et al., 2004). Although fire is most prevalent in the southern and eastern parts of the Amazon basin, its incidence is growing in the western Amazon as well (Brown et al., 2011). For example, in the 2005 drought, 22,000 ha burned in the Ucayali region of Peru (Gobierno Regional de Ucayali, 2006).

Fire can only occur when conditions are favorable; it requires fuels, an ignition source, and sufficiently dry weather conditions to ignite and spread. Fire regimes, the spatial and temporal patterns of fire observed in an ecosystem, are the result of vegetation, climate, and ignition controls acting simultaneously (Moritz et al., 2005). Human activities can affect fire regimes by interfering with any of these controls. For example, land use and management activities can change fuel amounts, composition, and configuration and affect the number and spatiotemporal patterns of ignitions (Nepstad et al., 1999), while roads can act as fire breaks, but also can be a source of anthropogenic ignitions (Archibald et al., 2009; Bowman et al., 2011; Cardille et al., 2001; Hawbaker and Radeloff, 2013). Promoting grazing, introducing exotic plants, engaging in fire suppression, and other activities can similarly affect patterns of fire (Bowman et al., 2011).

The degree to which various controls on fire activity limit fire depends on the study location (Bowman et al., 2009; Krawchuk et al., 2009; Krawchuk and Moritz, 2011; Parisien and Moritz, 2009). For example, in places with wet climates where productivity, and thus fuel availability, is high, fire is limited by fuel moisture. In very dry climates where fuels are almost always dry enough to burn, fuel quantity can be limiting instead (Krawchuk and Moritz, 2011). Where natural ignitions are very rare, the availability of anthropogenic ignitions changes the degree to which ignitions limit fire (Cochrane and Laurance, 2008; Nepstad et al., 2001).

The spatial scale of analysis also affects which drivers best explain patterns of fire activity (Parisien and Moritz, 2009; Parks et al., 2012). Climate exerts control across broad areas, while topography and vegetation are important in driving finer scale heterogeneity. Within broad fire-prone regions there can be considerable spatial and temporal heterogeneity in frequency, intensity, and severity of fires, and local patterns of fire activity are the result of climate, fuel, and ignition controls acting simultaneously and to different degrees, and reflect the ways humans influence each of these controls. Thorough understanding of a fire regime requires examining patterns of fire at a number of different spatial scales: focusing on broad scales might blur out the drivers of local scale heterogeneity, while focusing only on very local scales may miss informative and important regional patterns in fire activity. For example, a focus on climate may overlook the role of topography in driving local variation in fire regimes, while a focus on the way topography influences patterns of fire might not detect the role of interannual climate variability in driving regional synchrony and year-to-year variability in fire activity.

Similarly, the most important biophysical factors predicting fire occurrence (defined as whether a particular place burns or not) may be different from those predicting other metrics of fire activity such as fire intensity or fire size. In ecosystems where natural ignitions are rare, availability of ignitions could be the most important driver of fire occurrence, but once a fire starts, fuel quantity could be the strongest predictor of fire intensity and the spatial configuration or connectivity of fuels could be most important for fire size. In ecosystems where ignitions are frequent but conditions are rarely dry enough for fires to start, fuel moisture might be the most important factor limiting fire occurrence, intensity, and size.

Here, we combine multi-scalar data on land use, climate, and landowner residence from remote sensing, meteorological stations and socio-economic surveys to further disentangle the drivers of two different metrics of fire activity – fire occurrence and fire size – over 10 years on individual landholdings in a fire prone region of the Peruvian Amazon. We focused on the following questions:

1) What is the relative importance of climate, landowner place of residence, and land cover for predicting fire activity in the Ucayali region of the Peruvian Amazon and how do these drivers interact?

We expected that climate would exert the strongest control on fire, but in dry years, variables related to human activities would play an important role in determining finer scale patterns of fire activity.

2) To what extent do characteristics of a particular landholding, as opposed to characteristics of the village or region around it, predict fire activity on that landholding?

Because most landholdings are relatively small and thus potentially highly susceptible to fire spread from adjacent properties, we expected that characteristics of the village around a landholding would be a stronger predictor of fire activity than conditions on a landholding itself.

3) Are the drivers of fire occurrence different from those of fire size?

We expected that the predictors of fire occurrence would be different from those of fire size: fire occurrence would be more closely associated with spatial and temporal patterns of ignition sources (related to patterns of human activity) while fire size would be associated with variables that affect fuel quantity and moisture, in particular land cover and drought intensity, and that reflect social control, in particular the number of landowners present in the village.

2. Material and methods

2.1. Study area

This study focused on an area within the Ucayali region of Peru, near the urban areas of Pucallpa and Campo Verde (Fig. 1). Elevation ranges from 150 to 250 m, and annual mean precipitation averages 1500–2500 mm/year with an annual dry season from July to September (Gutiérrez-Vélez and DeFries, 2013). The study region has been connected to Lima and other urban centers in the coast and mountains of Peru by a highway and networks of roads for more than six decades. It has attracted many migrants from elsewhere in Peru in recent years (Uriarte et al., 2012) and has undergone extensive land-use change and deforestation including