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Wildfires in Amazonia: A pilot study examining the role of farming systems, social capital, and fire contagion

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Abstract

Environmental destruction caused by fires threatens to forever change the ecological composition of tropical rainforests. Researchers have addressed the role of drought and logging on fire propagation and the ecological consequences of fires. Nevertheless, little is known about its human dimensions. This lack of information is of concern because it represents a real and important gap in our own understanding about a major global change factor. This paper attempts to partly redress this shortcoming by presenting a pilot study that considers the importance of farming systems and social capital to the mitigation or exacerbation of fire in Amazonia. The paper explores the theoretical connection between social capital and fire contagion, and presents results from a pilot study examining such links. This study combines satellite data analysis and data on community organization derived from household surveys in the municipio of Uruará in the State of Pará, Brazil.

Keywords: *Fire contagion, Amazonia, Community Cohesion*

Resumen

La destrucción ambiental causada por incendios en los bosques tropicales amenaza su composición ecológica. Los investigadores han estudiado el papel de las sequías y la tala de árboles en la propagación del fuego, y sus consecuencias ecológicas. Sin embargo, poco se conoce acerca de sus dimensiones humanas. Esta falta de información es una preocupación porque representa un real e importante vacío en nuestro entendimiento sobre un factor de cambio global mayor. Este ensayo pretende en parte reparar este defecto examinando la importancia del sistema de cultivo y el capital social en la mitigación o exacerbación de incendios en la Amazonia. El estudio explora la conexión entre el capital social y la propagación causada por los incendios, y presenta resultados de un estudio piloto examinando dicho vínculo. Este estudio combina análisis de información

de satélite e información sobre la importancia de la organización comunitaria derivada de encuestas sobre el hogar en el municipio de Uruará en el estado de Pará, Brasil.

Palabras claves: *propagación de incendios, Amazonia, cohesión comunal*

Introduction

Environmental degradation in the developing world is a serious global problem. Loss of tropical rainforest is of particular importance given its impact on biodiversity, the global carbon cycle, and development sustainability. In this regard, international attention recently has focused on destruction caused by fires, which now threaten to forever change the ecological composition of tropical rainforests. Wildfires that blazed during the El Niño Southern Oscillation (ENSO) episode of 1997-1998 severely damaged 8,000 km² of forest in Indonesia, 600 km² in Mexico, and 10,000 km² of primary forest in Roraima, a State in the Brazilian Amazon. Fires are a natural component of many ecosystems and serve to regulate fuel accumulation, nutrient cycling, and seed germination. This is not the case in the humid tropics because lush vegetation is relatively inflammable given moisture conditions (Denevan, 1992). Be that as it may, anthropogenic fires are now causing devastating impacts on tropical forests worldwide (Wetzel and Omi, 1991).

Researchers have addressed the role of drought on fire propagation (Mueller-Dombois, 1981; Setzer and Pereira, 1991), the impact of logging on fuel build up and flammability (Uhl and Buschbacher, 1985; Woods, 1989), and the ecological consequences of repeated burnings (Cochrane, 1999; Nepstad et al., 1999; Uhl and Kauffman, 1990). They have examined the historic and archeological record to show that so-called undisturbed tropical forest has historically been exposed to both natural and anthropogenic fire (Sanford et al., 1985; Whitmore, 1985; Wetzel and Omi, 1991; Kay, 1998); indeed, some "natural" ecosystems are actually artifacts of aboriginal burning (Sauer, 1958; Pyne, 1995; Denevan 2001; Bowman, 1998).

Despite the extensive research base on the general subject of fire, little is known about the social circumstances under which fire is used and escapes from human control to cause damage as *wildfire*. Wildfires are accidental fires that in the language of economics represent an *externality*, not to be confused with so-called rational fire use. Fires used by small farmers in slash and burn activities represent the second largest contribution to trace gas emissions worldwide (Hao et al., 1990). Consequently, this lack of information represents a substantial gap in our knowledge base on global change factors. This paper attempts to partly redress this shortcoming through an examination of accidental fires in the Brazilian Amazon, subsequently referred to as fire contagion, and an assessment of the potential role farming systems and social capital play in mitigating or exacerbating these destructive fires.

Fire in Amazonia

Ecological and human interactions

Until recently, many thought rainforests were resistant to fire because of high humidity and precipitation (Wetzel and Omi, 1991; Kay, 1998), however geological evidence demonstrates that fire was a historical occurrence in the Amazon (Sanford et al., 1985), although not of the magnitude and frequency to cause ecosystem changes to fire resistant species (Uhl and Buschbacher, 1985). The rapid pace of human encroachment in expanding frontiers, coupled with drought conditions, possibly associated with global

warming, has made fire an alarming concern in the Amazon basin. Under normal climatic conditions, undisturbed forest canopy reaches a cover of 95 percent, enabling the forest to maintain its moisture and fire resistance. Prolonged dry periods such as those associated with ENSO events, cause leaf shedding to intensify, and the forest floor to dry, leaving even undisturbed forests vulnerable. After fire, the forest canopy diminishes to nearly 60 percent, and sunlight desiccates the forest floor thereby increasing the quantity of fuel and risk of fire (Cochrane and Schulze, 1999).

Although fire is most intense during ENSO episodes, the threat of fire remains during non-drought periods due to human encroachment (Cochrane, 1999; Nepstad et al., 1999; Uhl et al., 1989; Uhl and Kauffman, 1990). Selective logging exacerbates the problem by damaging remaining trees, increasing debris on the forest floor, opening the forest canopy, and altering the forest micro-climate (Nepstad et al., 1995; Uhl and Kauffman, 1990; Cochrane, 1999). Further complicating the threat of wildfires in Amazonia is the complexity of poverty and social conditions that provide little technological alternative to poor forest-dwellers. Thus individuals with few financial resources rely on fire as their primary agricultural technology. Clearly, the use of fire augments the possibility that on occasion fires escape control and do unintentional damage, both economic and ecological.

Several studies in Amazonia have elaborated fire categories, useful for any discussion of the subject (Sorenson, 1998; Nepstad et al., 1999). Nepstad et al. (1999) identify three fire types. The first is *deforestation fire* intended to clear primary forest for either agriculture or pasture. The second, *fire on deforested land*, includes fire used to kill weeds and fertilize both pasture and agricultural plots. The third type encompasses accidental fires or fire contagion, and is called *forest surface fires*. These are commonly referred to as wildfires, which is any fire that spreads from intentional burn sites. In the language of economics these are externalities and not to be confused with so-called rational fire use. Sorenson (1998) provides similar categories, but separates pasture fire from agricultural fire because fuel loads, and thus fire efficiency, are different.

Cochrane and Schulze (1999) examine the effect of *forest surface fires* on selectively logged forests in Eastern Amazonia. After an initial burn, average stem mortality is 41 percent, canopy cover is reduced by 40 percent, and virtually all of the understory vegetation is destroyed. The critical factor regarding the potential for forest recovery is the fire-return interval. If fire disturbance is a one-time event then forest recovery is highly likely. However, with fire-return intervals between 5 to 20 years the forest quickly erodes to secondary growth. Ultimately, if the fire-return interval is frequent enough (0 to 5 years) and the fire intensity is great, the result can be the complete replacement of forest with scrub-savanna vegetation.

What recent research in Amazonian suggests is the possibility of *positive feedback* between deforestation, drought, and fire, whereby deforestation leads to diminished rainfall, increased vulnerability to fire, and consequently more deforestation (Laurance and Williamson, 2001; Hoffman, Schroeder and Jackson, 2003). This cycle of autocatalytic destruction could bring about vegetative shifts to savanna woodlands (Serrao, Nepstad, and Walker, 1996), not unknown to the historic record (Boserup, 1965).

Farming system and fire use

Clearly, the use of fire bears some relationship to the farming system in question. Nepstad et al. (1999) suggest that wealthier farmers will experience fewer fire-related problems, given the desire to protect investments in housing and farm-related infrastructure. Walker (2000) argues that farming system and fire use practices are closely corre-

lated. Subsistence farmers and ranchers are dependent on fire, while individuals with perennial plantations, like wealthy farmers, have investments that need to be protected from fire. In particular, in areas where fire vulnerability is high, land managers will be hesitant to plant perennials and may instead opt for pasture-based farming to minimize risk. Compounding matters, pasture-based farming, which is a fire dependent technology, may actually intensify fire ignitions and, thus, increase vulnerability to fire.

The focus of this paper is on small-farmer communities because, as with deforestation, such farmers are often viewed as one of the primary agents of fire in Amazonia. In fact, burning by small farmers represents the second largest contribution to trace gas emissions worldwide (Hao et al., 1990). Slash-and-burn is a commonly applied low-capital technology used around the world. Under a slash-and-burn regime, land is first cleared to the extent possible using the tools available, and fire is set to remove remaining weeds and trees, and to release nutrients to the soil, thereby increasing fertility. Although, according to Brazilian law, the provoking of fire in woods or forests is illegal and may be punishable by two to four years imprisonment and a fine, of six months to one year if set without malice, nevertheless, poor farmers typically rely on fire as their primary agricultural technology, despite government efforts to outlaw its use.

Although a number of studies have examined fire practices of indigenous peoples (Lewis, 1989; Russell-Smith et al., 1997; Bowman, 1998), relatively little has been done on colonist farmers. An exception is Sorrenson (1998) who documents several techniques used by small farmers to contain the spread of fires, including seasonal timing to ensure adequate moisture, the construction of fire-breaks to prevent fire spread into adjacent crops and forest, and leaving behind un-slashed fallow around the burn area to act as a buffer. Despite common awareness about these techniques, they are not used consistently, and fires accidentally spread into adjacent fields and forest. The question that this paper examines is why certain communities choose to use fire containment techniques and others do not.

The main problem with traditional fire use is that few people attempt to control their fires because they rely on the nearby moist forest to contain the blaze (Wetzler and Omi, 1991). Many contend that fire use, and hence its accidental spread, is a cultural manifestation (Pyne, 1995; Sorrenson, 1998; Wetzler and Omi, 1991). In the Brazilian context, Pyne (1995) calls fire culture 'queimada para limpeza,' the *cleaning* fire, and suggests that such fire technology is "... a folk art, tempered by trial and error prescription developed over the course of centuries," (Pyne, 1995: 82). The *cleaning* fire in Brazil is used across the country in both rural and urban areas to rid the land of waste and clean the environment.

The role of community and social capital

The use of the term *culture* in this context implies that there are collective, learned behaviors concerning the use and control of fire. Collective behavior in turn is manifested when a group adheres to a community of interest relating to resource management. Although culture typically refers to more aggregate phenomena that cut across individual communities, cultural background may be critical to communities formed in Brazil's development frontiers, which experience immigration from vastly different parts of the country.

Indeed, there is growing recognition of the role community plays in resource management, particularly in so-called developing countries (Berkes, 1989; Kiss, 1990; Ascher, 1995; Gibson and Marks, 1995; Arizpe, 1996; Simmons, 1997; Agrawal and Gibson, 1999).

Ascher (1995) suggests the importance of community involvement in achieving forest sustainability in the developing world. Gibson and Marks (1995) describe community-based wildlife management in Africa, and Arizpe (1996) considers community perceptions of deforestation in Mexico. Although much informative work has been done, no one has addressed the issue of fire in this context, despite the obvious fact that fire externalities can only be contained by unified actions involving the cooperation of individuals, or communities.

The notion of *community* is not an exact one and has long been the subject of debate (Hillery, 1955; Gusfield, 1975; Taylor, 1976; Singleton and Taylor, 1992; Rose, 1997). The concept has both spatial and sociological components (Carter and Squires, 1993). Although space is identified as essential to the creation of a sense of *place* and community cohesion (Massey, 1994), conservation goals require that the community share more than geography. On the sociological side, community is often taken to comprise a group of relatively homogeneous households with equitable distribution of economic resources and rewards, and common characteristics in terms of ethnicity, religion, caste, or language (Agrawal and Gibson, 1999). In such communities, shared norms concerning resource conservation can prohibit destructive actions and promote cooperative decision-making, and often lead to the creation of informal and/or formal institutions (Ostrom et al., 1993; Agrawal and Gibson, 1999).

Social Capital, a term recently coined to describe similar phenomena, is likewise controversial. Both concepts are used to describe the internal coherence (or commitment, empathy) derived from a sense of cultural identification (or belonging, commonality, shared norms), which can be influential in determining the outcome of events, whether positive or negative (See Dasgupta and Stiglitz 1980 for detailed discussion). Social capital may be key in achieving resource conservation and sustainability because it provides necessary incentives for individual members to give up some individuality pursuant to the group objective (Ostrom et al., 1993; Agrawal and Gibson, 1999). With respect to fire, strong social capital and community interest in fire prevention may in fact mitigate the escape of wildfires, in particular.

Defining and measuring social capital is problematic. Few empirical studies have been performed, and much debate stems around whether to measure the source (i.e., social homogeneity), the substance (i.e., degree of internal coherence), or the outcome (i.e., fire contagion). In order to understand social capital in a practical setting, Krishna (2000) suggests that both relational and institutional forms of social capital be considered. Relational social capital involves the values, attitudes, norms, and beliefs, which dispose individuals toward cooperation, while institutional social capital includes structural elements such as roles, rules, procedures, and organizations.

Social capital and fire contagion: a case study

The hypothesis of this preliminary research is that in a community with strong 'identity,' stemming from shared kernels of commonality (source), the social capital (source) generated will provide incentive for members to *internalize* the externality of fire, and, as a result, fire contagion (outcome) would be limited. In other words, members of a community that has shared identity, interests, and norms will be less inclined to allow fire to accidentally spread beyond intended burn areas, and may, in fact, have formal or informal institutions that dictate the use and control of fire.

In order to assess these possible relationships a pilot study was done using data available for Uruará, Brazil (Figure 1), to estimate whether shared commonality (source) led to expected outcomes, in this case lessened fire contagion.

Figure 1. Study region: Uruará, Pará, Brazil

The study involved first, the construction of a GIS using data derived from remote sensed image analysis and household and community level surveys. Analysis and classification of satellite images provide a dependent variable, namely the extent of fire contagion at the property level, and household surveys, conducted by Walker and Wood in 1996, provide information reflecting social capital characteristics and farming system attributes. The survey sample includes 261 small producers, possessing 345 property lots of 100 hectares along the Transamazon Highway in the proposed study region of Uruará.

GIS database

A GIS was created to examine the spatial patterns and connections between social capital and fire contagion. Essential layers in the GIS include property lot boundaries for the study region and fire scar analysis. First, the property lot boundaries were digitized from maps from the National Institute of Colonization and Agrarian Reform (INCRA), and then were set to real world coordinates. Next, identification numbers were used to link the data derived from household interviews to the appropriate lots in the GIS. The variables available at the property level include indicators of (1) social capital, such as political organization, wealth endowment, birthplace, and place of previous residence, and (2) farming system, consisting of time and investments in annuals, livestock, and perennials production.

Next, fire scar detection was completed for the satellite image covering the study region.¹ Though often hard to detect in satellite imagery, sub-canopy fire scars up to two years old can be seen using linear mixture modeling (Cochrane and Souza, 1998). This technique decomposes the six optical TM bands into three fractional images corresponding to green vegetation, canopy shade, and non-photosynthetic vegetation (NPV). The fraction of NPV is normally very low (2%), but increases significantly after even low intensity fires due to the mortality of both canopy and sub-canopy trees, which allows more NPV to be 'seen' by the satellite (e. g. dead branches, dead leaves, forest floor).

Fire scar magnitudes represent areas impacted by accidental fire, which unlike intentional deforestation for the purpose of agriculture and/or pasture formation shows an irregular shape often removed from the forest-edge (Cochrane, 1999). Figure 2 shows the spatial pattern of fire contagion within the study region. The areas shown in gray are lands affected by forest surface fire and the black rectangular lines represent the property boundaries. The GIS allows for the overlay of the fire contagion coverage with numerous farming system and social capital variables, such as strength of political organization used in the statistical analysis to follow. The spatial relationship between fire contagion and strength of political organization are shown in Figure 3.

Figure 2. Fire contagion with property boundaries

Figure 3. Fire contagion and political organization

Statistical analysis

A logistic regression using the 1996 survey data and fire measure derived from the satellite data analysis was employed to estimate the possible links between social capital and fire contagion. The dependent variable used in the regression was a categorical indicator of whether the farm had experienced fire contagion (yes-1 or no-0) based on fire detected on the satellite image. The only social capital measure available as an independent variable was the presence of political organization. This indicator was derived from a key informant interview that assessed the strength of political organization based on location. All the households located on politically organized roads were categorized as organized (1), and all others were labeled not organized (0). Several farming systems variables, including primary activity in annuals, livestock, and perennials, were included as independent variables. These variables reflect the proportion of time spent on each activity. It is expected that fire will be more likely on properties engaged in livestock and annuals production, and less likely where perennials are predominant. Finally, land title (yes or no), property value, time on the farm, and distance from road were entered as control variables. The expectation is that fire contagion will be less likely on properties with title and of higher values because the owners have investments to protect. On the other hand, fire contagion is more likely on long established farms, and on properties near roads that serve as conduits of fire.

The results from the regression provide limited insight (Table 1). The time on the farm and distance from roads are the only variables that were statistically significant. Nevertheless, the results reveal suggestive relationships between the importance of pasture and perennials to the occurrence of fire, with significance levels less than .10. The greater importance placed on pasture, the more likely one is to experience fire contagion, as suggested. Involvement in perennials also appears to be positively linked to fire, albeit counter-intuitively. The expectation is that those with investments in perennials would be more likely to guard against accidental fire, and, therefore, not be as vulnerable to such contagion.

Variable	Odds Ratio Estimate	P> ChiSq
Organized	0.722	0.3113
Titled	0.761	0.4081
Time	1.104	<.0001
Distance	0.976	0.0512
Value	1.000	0.332
Pasture	1.015	0.0737
Perennials	1.000	0.0864

Table. 1 Logistic Regression Results

Future work

Although the spatial patterns generated by the GIS and the statistical analysis are of interest, more work is necessary to improve the data, and better specify a model linking fire contagion with social capital and farming systems. In particular, the exact land area within each property boundary affected by fire contagion can be calculated using the GIS, and subsequently entered as a dependent variable in a regression analysis with independent variables from the 1996 household survey. The fire scar magnitude might be given as

Y_i , subscripted in i to indicate some arbitrary holding. For estimation purposes, this may be written as,

$$Y_i = f(X_{ic}, X_{if}, X_{id}) + \epsilon_i,$$

where f is a linear function, X_{ic} is a vector of social capital variables associated with farm i , X_{if} is a vector of farm system variables, and ϵ_i is a random error term.

To complete such an analysis, the variables need to be refined. First, the fire contagion measure derived from the satellite image analysis should be examined to ensure that the modeling approach is in fact detecting forest surface fire. Such an assessment will require ground-truthing, which has not been done in the study site. Next, the independent variables representing social capital (i.e., wealth endowment, birthplace, religion) require modification. These variables are presently at the household level and do not reveal whether homogeneity exists at the community level, which is of key interest to this study. For instance, wealth endowment does not necessarily contribute to fire contagion, but inequality among members within a community may. We hypothesize that in an area with equitable wealth distribution, individuals will be less inclined to allow fire to spread to a neighbor's property. On the other hand, if small farmers share boundaries with a wealthy absentee landlord, they may take less care to ensure fire containment. The incidence of wildfires in this setting could, in fact, reflect conflict stemming from dysfunctional social relations or lack of social capital (Pipes, 1990; Walker and Wood, 1998).

To modify these measures, the GIS could be used to reveal the spatial distribution of a given variable (i. e., wealth), and an additional indicator could be included at the property level that indicates the degree of equality within the area. Once the variables have been modified, regression analysis can be performed with each property representing an observation. Because fire contagion is by its nature a spatial phenomenon, statistical analysis may be impacted by problems associated with spatial autocorrelation. Consequently, spatial regression would be expected to improve results.

Conclusions

Although many scholars have written about the importance of community and social capital for resource management, few studies have actually tried to operationalize their influential character in an empirical study. In addition, little is known about fire in this regard, which is perhaps surprising given its widespread use as an agricultural technology and its destructive potential. Clearly, fire externalities can only be contained by unified action involving the cooperation of individuals acting in concert, as communities of interest.

This paper attempts a preliminary assessment of these unknown dimensions, suggesting a potential connection between the farming system, community characteristics, social capital, and accidental fires. The paper outlines a methodology combining household surveys and remotely sensed data in an assessment of fire contagion at the property level in the Brazilian Amazon. The results from the logistic regressions suggest an autonomous effect of time, an access component, and farming system impact on fire contagion. The statistically significant results for duration on farm points to the simple fact that the longer a property is at risk for experiencing fire, the more likely it is that this will occur. The significant results for the distance from road variable suggests that fire contagion is more likely near the road, possibly as the result of greater density of settlement where individual land managers use fire, thus increasing exposure to accidental fire spread

from neighboring properties. Furthermore, the results suggest a potential relationship between accidental fire and cattle ranching, which is not surprising given the extensive use of fire in preparing and cleaning pasture. This finding may also provide limited support for the hypothesis raised by Walker (2000), that increased fire risk may influence land-managers' decision to opt for pasture-based farming instead of more vulnerable production systems, such as perennials.¹ Although we have theorized an effect for community and social capital, our findings do not provide any support for this relationship. However, it may be premature to rule out a community effect given that this preliminary research only used one variable, political organization, based on a key informant interview. Clearly, refinement of the data variables and the collection of more precise measures of community and social capital are needed.

In conclusion, this paper introduces a fundamental connection between the social dimensions of fire use and misuse, and fire contagion, and outlines a practical methodology for testing these relationships. Wildfires in Amazonia, as in other parts of the world, pose a serious global environmental threat. In order to curb the destruction of the Amazon rainforest, policy must be informed of the actions and motivations behind those individuals that rely on fire. Findings from research like that proposed here, could potentially make important contributions to understanding the social context of wildfires, providing insights to policy initiatives intended to ameliorate this problem.

Note

¹The regression results show a perverse but insignificant effect for perennials with greater likelihood of fire on lots with perennials. We believe this result may be due to the fire scar algorithm, which may be confusing fire contagion with gaps in the canopy of perennial groves, such as cacao. To rectify this will require ground-truthing, which we propose in future work.

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