Smallholders' Perceptions of Fire in the Brazilian Amazon: Exploring Implications for Governance Arrangements

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Abstract

Fires have been on the rise in the Brazilian Amazon for a decade, causing biodiversity loss, carbon emission, and damage to local people's assets and health. Often blamed as being responsible for starting most of the fires, local farmers are also the main actors involved in fire prevention and firefighting. We explore small-scale farmers' perceptions of fire and governance arrangements through Q methodology and semi-structured interviews. We find that fire prevention and firefighting are both perceived as collective issues. Lack of engagement in these activities is largely related to fire risk perceptions and its controllability, which depends on local collective action, landscape flammability, and the size of the area of fire contagion. To counter large fires, government action is essential. Policies that are supportive of fire control norms and enabling of firefighting seem more likely to achieve positive results than fire bans.

Keywords Brazilian Amazon · Fires · Smallholder farmers · Fire policies · Q methodology

Introduction

The rate of deforestation in the Brazilian Amazon decreased by more than 80% between 2004 and 2014, although it has been increasing again since 2015 (INPE 2018). Nonetheless, since 2002, wildfires are on the rise (Aragao and Shimabukuro 2010), with record fires in 2015 when the rate of deforestation was almost at its lowest. Natural wildfires are not inherent to tropical wet forests, yet fire plays a key role in the Amazon region, used both by large landholders and smallholders. Each time fire is used for swidden agriculture or pasture maintenance, it inevitably represents a potential ignition source for a larger-scale accidental fire event (Diaz *et al.* 2002; Sorrensen 2004). Cano-Crespo *et al.* (2015) find that 74% of forest fires originate from agricultural land. Accidental fires in the Brazilian Amazon produce up to 5% of global carbon emissions (Anderson *et al.* 2015) and might reverse carbon cycles, turning tropical forests into net carbon sources (Baccini *et al.* 2017). Tropical forest fires harm natural ecosystems by reducing habitat size, doubling biodiversity losses from deforestation (Barlow *et al.* 2016), jeopardizing the environmental services these systems provide, and damaging natural resources used by local communities (Ferreira *et al.* 2012). Fires are also an important social issue, as they destroy farming systems and infrastructure and lead to serious economic losses for local populations (Diaz *et al.* 2002; Nepstad *et al.* 1999).

Fire policies have failed to meet the challenges and needs of swidden farming by criminalizing a widespread practice without providing a viable alternative (Carmenta *et al.* 2018). Studying perceptions of fire use and control among smallholders is paramount. Although to date there are no studies attributing the setting of fires to specific actors, smallholders are unlikely to stop using fire in the short term, have less capacity to control it, and suffer the most damage from it. Large landholders have been intensifying production and use fire mainly for land clearing (Godar *et al.* 2014). Policies to

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curb deforestation should limit fire use in large landholdings. Smallholders, on the other hand, use fire for a variety of tasks – clearing, fertilization, and pest control – on a rotation basis. If they lack alternatives to fire for any of these key functions, they are unlikely to stop using it (Morello *et al.* 2018). They also have fewer means to control fires (Nepstad *et al.* 2001), and are the main actors to suffer damage when fires escape (Carmenta *et al.* 2018). In the past, lack of understanding and misalignments with smallholders' perceptions led to ineffective policies (Carmenta *et al.* 2018). Understanding smallholders' perceptions of fire use and control practices is key for conserving the Amazon rainforest and for its sustainable development.

In this study, we explore smallholders' perceptions of fire use, fire control, and firefighting in a post-frontier region of the eastern Amazon, and how these relate to fire risk perceptions and governance preferences. Specifically, we address three main questions: whether fire-free techniques are perceived as suitable alternatives; how small-scale farmers perceive fire control and fire-fighting; and how perceptions of fire risk affect preferences for community or public governance. We posit that not only the perception of the magnitude of fire risk, but also participation in the formation of fire risk – the (perceived) competence and ability to do something about the risk (Gruev-Vintila and Rouquette 2007) – affects preferences for governance (government vs. private-collective) and the type of intervention (risk mitigation vs. fire-fighting). We chose to carry out this study in Paragominas, a municipality of Pará State, long known as a champion of deforestation, and which, after having been blacklisted by the Federal government in 2008, has promoted a Green Municipality initiative to counter deforestation. Even though this initiative prohibits the use of fire, the municipality is still confronted by wide-scale accidental fire episodes. We combined semi-structured interviews with Q methodology as a tool to discern and aggregate common narratives by clustering individual narratives based on their commonalities. Finally, we correlated these narratives to individual and landscape features that affect flammability and the ability to mitigate risk. Our goal is not to achieve a representative poll of the farmers' opinions, but to identify the diversity of the farmers' positions on fires, the reasons behind them, and contribute with insight on policy action.

Fire Risk Mitigation and Governance in the Brazilian Amazon

Faced with fire risk, farmers are confronted with three choices: 1. whether to use fire or to invest in fire-free alternatives; 2. if they use fire, how much effort to allocate to preventive fire control; and 3. whether to rely on firefighting as a substitute for fire prevention. A successful fire risk mitigation outcome depends very importantly on the neighbors' corresponding choices. Fire use and (lack of) control increase fire risk for the neighbors (Bowman *et al.* 2008; Nepstad *et al.* 2001), producing a problem of coordination in which a farmer alone has little incentive to mitigate fire risk – by controlling or stopping the use of fire – unless his neighbors do the same (Cammelli and Angelsen forthcoming). This problem is complicated by the exogenous increase in landscape flammability and fire propagation due to uncertain dry episodes and forest degradation, which reduce incentives to adopt fire control and fire-free agricultural technologies (Nepstad *et al.* 2001). While in the first case the farmer is (collectively) involved in the formation of fire risk, in the second case he is a "risk taker" with no opportunity to engage in any prevention activity. Firefighting appears as a typical social dilemma, requiring all farmers to contribute in engaging in a risky activity, while the private optimum is achieved by free-riding on the others' actions. Fire prevention is only a partial substitute for firefighting. They differ in that prevention is an upfront sunk cost for the farmer (regardless of his neighbors' corresponding action, which determine its success), while firefighting might be less effective and more expensive, but only takes place when a fire event occurs. Governance of public goods (firefighting) or of practices characterized by coordination benefits (fire use and control) can be addressed with direct regulation or by relying on farmers' collective action, which in turn can be incentivized (e.g., with community-based training or payments for environmental services).

Contemporary fire policies in the Brazilian Amazon outside conservation units have encompassed a series of distinct approaches: prohibition of fire, agricultural innovation, and promotion of rules for "best practices" fire management (Carmenta *et al.* 2018). However, prohibitive approaches have generally prevailed. Federal laws in Brazil forbid uncontrolled fire use (Chap. IX of the Brazilian Forest Code, law 12651/2012), while some municipal and state laws (e.g., Paragominas and Acre) forbid all fire use. Other policies, e.g., PROARCO and "Good Fire Management," are based on collective action, and favor agreement on fire control rules within communities and readiness for fire-fighting (Carmenta *et al.* 2011; Sorrensen 2009). These latter policies produced only limited results, with fire accidents returning after the programs ended, calling the autonomous capacity and interest of communities into question (Costa 2006). Prohibitive approaches also fail because of a mismatch between legal requirements and practice, and misalignment with farmers' expectations (Carmenta *et al.* 2011, 2018). Indeed, little is known about the farmers' own perception of fire-free technologies, fire-control practices, and the governance arrangements that might encourage fire prevention. Such understanding is essential to design effective policies (Carmenta *et al.* 2018).

Study Area

Initially, we planned to carry out our study in the municipality of Paragominas, located in the post-frontier region of Pará State (Fig. 1), where the issue of fire has become a major threat and fire use has been entirely banned by law. During interviews, we were informed about community-based fire policies implemented in the neighboring municipality of Ipixuna do Pará, and we decided to enrich our initial sample with interviews in this neighboring municipality.

Paragominas, a municipality of 91,000 inhabitants, was known for a long time as a champion of deforestation, for cattle production (1980s) and timber extraction (1990s) (Viana *et al.* 2016). In 2008, Paragominas was strongly impacted by the federal "Arco de Fogo" operation, in which the 36 municipalities that were contributing the most to deforestation in the Amazon were blacklisted and targeted through credit tightening, lower government transfers, market-access restrictions, and law enforcement (Viana *et al.* 2016). In 2009 a Green Municipality Pact was signed by Paragominas's municipal stakeholders to achieve zero-deforestation and sustainable production. Consequently, in 2010, the municipality exited the federal list and became a success story, although

the transition was limited to a slowdown in deforestation (Piketty *et al.* 2015). Led by large landowners, the municipal environmental policy chose to prohibit all use of fire (Municipal Law 765/2011), while making no provisions for the more than 5000 smallholder fire-using households. A PrevFogo brigade of six agents was tasked with preventing fire accidents in the federal land settlements during burning season (Paragonorte and Luis Inacio), providing training on fire prevention but rarely participating in firefighting.

Ipixuna do Pará is a smaller municipality, with a population half that of Paragominas (IBGE 2010). Ipixuna has always been more compliant with environmental laws (Guimarães *et al.* 2011) and its name did not appear on the deforestation blacklist. Land ownership is less concentrated (Guimarães *et al.* 2011) and local fire policies specifically target smallholders, who represent 76% of the population (IBGE 2010). Ipixuna's Environmental Office is proactively involved in fire control through coordination among the government organizations that were part of the Biannual Forest Fire Prevention and Fighting Program (2011–2012). Major activities have included community training on fire use and firefighting, arbitration among disputing neighbors, occasional fines (only two were applied in 2011, with purpose of deterrence) and
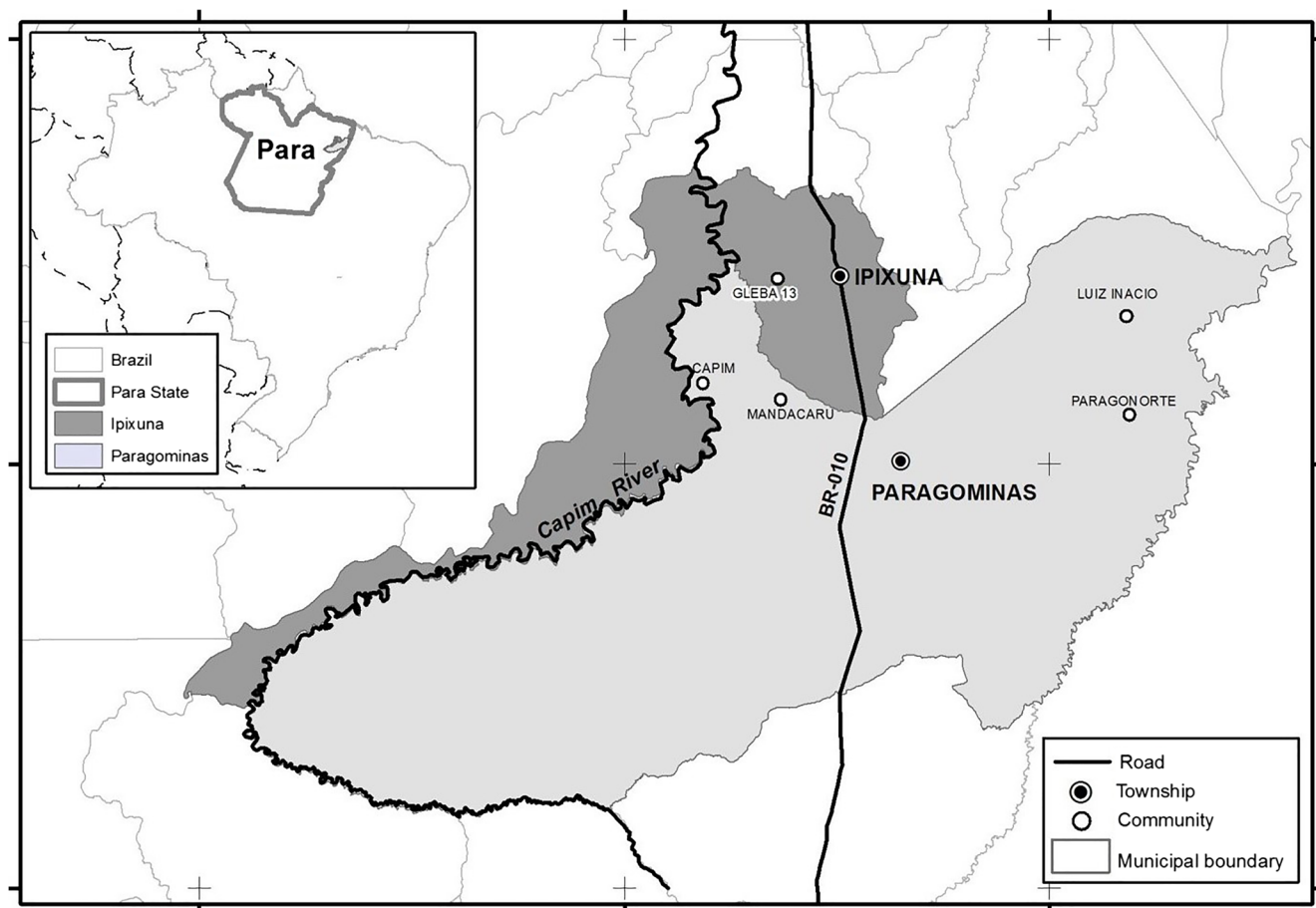

Fig. 1 Location of the communities visited for the study

improved access to the fire licensing system (required by the national Forest Code, but not implemented by Pará State). Ipixuna do Pará displays a sligthly higher amount of fires per km^2 than Paragominas (except during the program years), and both are substantially higher than the average of Pará, especially during drought years (Fig. 2).

Data were collected between March and May 2013 in a sample of smallholder communities chosen to represent the diversity of situations encountered in Paragominas: four older riverside communities and 12 communities in more recent land-reform settlements.

The older communities were founded in the early 1950s by "*ribeirinhos*" (riverside populations) and were structured around the establishment of Catholic Church units in the region. Livelihoods are mainly based on extractive activities, including swidden crops (*roça*) and forest resources. The landscape is still dominated by forest cover although increasing cattle ranching has led to land clearing. These communities are relatively small, with populations ranging between 10 and 50 households.

The land-reform settlements we visited were created by INCRA (National Institute of Colonization and Land Reform) in the late 1990s on large properties (*fazendas*) that were abandoned after the decline of large-scale cattle and timber activities. Two of them had more than 1000 households each, organized in communities of usually more than 200 families. Their livelihoods depend mainly on annual crops and cattle ranching. Fire events are frequent and large because of the higher flammability of the landscape, which is dominated by pastures (loaded with fuel). We observed higher fire risk and related conflicts between neighbors, which made farmers less comfortable talking about fire issues.

Methods

Collecting reliable data on fire use and control is challenging because uncontrolled fires are forbidden by law and because of the conflicts linked to fire damage. To overcome this challenge, we chose to apply Q methodology, with an interactive board game and set of cards, followed by semi-structured interviews, to gather specific information on the farming system and individual descriptions of risk perceptions and governance preferences (guidelines, analysis, and summary statistics are included in the supplementary material - SI). By asking for the respondents' opinions on a set of pre-compiled statements and a constrained score distribution, we were able to start a conversation about uncomfortable topics (e.g., fire losses and related conflicts), and initiate extensive semi-structured interviews. Results of the latter enriched and informed interpretation of Q results.

We chose sampled participants by asking community leaders and local organizations to help us identify individuals with diverse profiles, such as innovator or entrepreneurial farmers, producers who had suffered serious fire damage, or who used original strategies to control fires, and with different degrees of involvement in agriculture.

Q Methodology, Design and Analysis

Q methodology entails designing statements representing the area of interest and asking interviewees to rank statements in a constrained score distribution, and to comment on the resulting patch (Brown 1980). This enables the respondent

Fig. 2 Fire count per 100.000 km2 in the study area
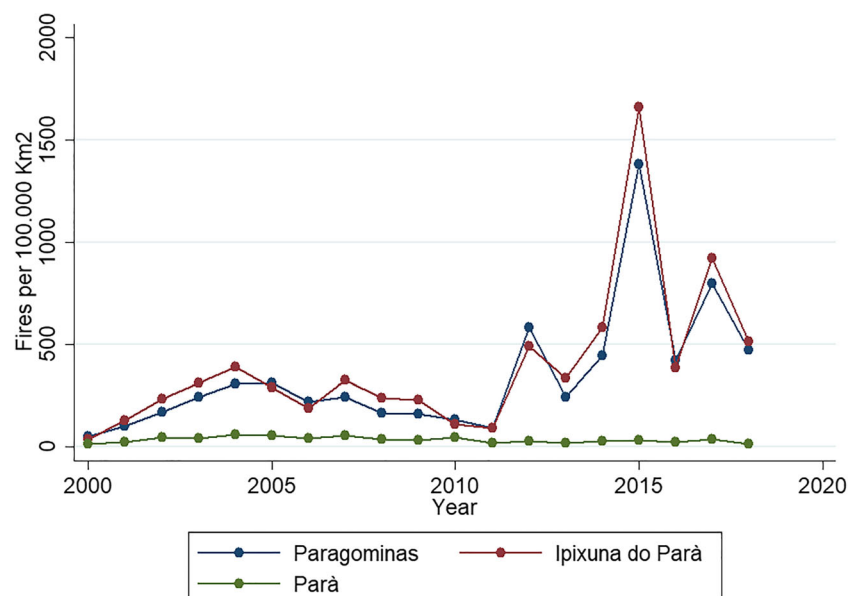
to take a position even on issues that may be uncomfortable to him or her, by taking advantage of the constrained distribution of the scores to be allocated among statements.

The 55 participants were asked to rank 17 statements on a 5-step scale (from 2 "strong agreement" to −2 "strong disagreement"). The authors selected the statements based on their understanding of fires, formulated through existing literature and previous interviews as well as on group work and piloting we had carried out during rural appraisals in Paragominas communities. Together, these statements were aimed at representing the respondents' views on fire use, fire control, firefighting, the risk of fire accidents, and preferences for fire governance (Table 1).

Statements concerning fire use were aimed at capturing views about the role of fire in current livelihoods: whether the use of fire is a right, whether its use by the farmer and his neighbors should be reduced, and whether alternatives to fire use are perceived as available. Statements on fire control were aimed at revealing related social norms, and whether this activity is considered collective or individual. Statements concerning fire-fighting were aimed at capturing two perceptions: of personal and group readiness, and of the others' contributions, which is key for successful reciprocity in contribution to the maintenance of public goods (Fischbacher *et al.* 2001). Statements on fire risk perceptions were aimed at capturing perceived magnitude of risk of the exposure of the farmer's property to wildfires. Finally, statements for governance preferences were aimed at contrasting self-governance at the community level against enforced government regulations.

The Q set was refined in four pilot interviews. Due to the generally low levels of literacy of the respondents, despite the use of the board and cards, the test was often administered verbally, needing on average half an hour per interviewee. In four cases, the interviewees were not able to complete the test and were excluded from the sample.

Data from Q methodology was aggregated into four factors with a principal component analysis following the statistical procedure described in Brown (1980), and detailed in the SI. Successively, we reconstructed narratives by interpreting factors in light of results from the semi-structured interviews.

Results

The Q analysis identified four main factors[1] (Table 1). A larger positive factor score corresponds to stronger agreement, a smaller negative factor score corresponds to stronger disagreement. To improve reading, grey scale ranges from white (strong disagreement) to dark grey (strong agreement). We test

for most significant differences and indicate them with stars. The characteristics of the group of farmers' related to each factor are reported in the SI.

There are large differences in perspectives on the legitimacy of fire use and perceived magnitude of fire risk (Table 1; Statement S1 to S5). However, there is little disagreement concerning fire control (S6 to S9). With some relevant exceptions, farmers underline the complementarity between the private-collective and government action, with a slight preference for the latter. First, we present the main results for the statements that are most contentious, or that most aggregate consensus, whether positive or negative, in the light of the post Q-test interviews. We then interpret the four main factors based on the most distinguished statements to reconstruct the different narratives regarding fire.

Values correspond to standardized factor scores. More positive scores are displayed with darker background colors, and asterisks indicate the most prominent statements, i.e., when differences between scores are significant ($*p > 0.1$; $**p > 0.05$; $***p > 0.01$)

Common Perceptions and Main Points of Debate

The farmers acknowledge not only that alternatives to fire use exist, but also that their implementation would require a lower level of fire risk (Statement S 1 consensus, negative; S2, 3, 4, 5 dissension). We observed very few tree plantations and perennial crops and 40% of the survey participants stated that they would plant perennial crops if fire risk was low enough: "[…] if the fire stops coming I would plant açai, mango, bacaba, and more, I would like to. But, why would I clear land, plant trees, and fertilize them knowing that fire will come and destroy everything?" (Seu Cearense,[2] *PA Paragonorte).* Small cattle ranchers are the most wary of accidental fires, afraid of losing expensive fences and fencing wire, and to have to rent pastures for their animals left without fodder.

Perceptions of fire risk are heterogeneous (S15 dissension), and pertain to three distinct sources of fire risk: from their own lack of fire control, *fogo do vizinho* (fire [coming] from the neighbor), and *fogo de longe* (fire [coming] from afar). While the first and the second fire sources identify the person responsible for the accident, the third is a residual category, which indicates how difficult it is to trace back the origins of fires and to identify the individual responsible. In our sample 48% of the respondents had suffered more than two fire accidents in the last 5 years, with fires originating almost equally from neighbors and 'from afar.' In general, we found that the more the origin of the fire is attributed to 'from afar,' the more it is considered uncontrollable.

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[1] 34 sorts (individuals) loaded significantly on four factors, accounting for 55% of total variance.

[2] The names of interviewees have been changed to respect their anonymity.

Table 1 Characterization of the four factors

	Statements (S)	Factor A	Factor B	Factor C	Factor D
Fire use	S1. Slash and burn is the only way to produce, and I think that there are no alternatives.	-1.69	-0.82***	-1.49	-1.66
	S2. Slash and burn is a good way to produce, but it is dangerous; I have to be careful.	0.20***	1.42***	0.79***	-1.53***
	S3. Slash and burn is not a good way to produce; we need to change practices.	1.06***	-0.09	-0.04	-0.19
	S4. Using fire is a farmer's right.	-0.47*	-1.34***	1.41***	0.06***
	S5. I don't think burning is the right way to produce anymore; I think my neighbor should stop using fire.	1.60***	-0.29***	-1.20***	0.82***
Fire control	S6. I think that fire issues are properly discussed in the community.	-0.65***	0.13	0.53	0.52
	S7. Building firebreaks takes a lot of time; I can choose whether to build them or not.	-0.92	-1.20	-1.67***	-1.41
	S8. My neighbors and I burn together in an organized way.	-0.34***	0.29	0,052	0.44
	S9. When my neighbor burns, I stay on my property to check for fire spread.	0.28	0.34	-0.03	-0.69***
Fire-fighting	S10. When an accident occurs I think everybody is ready to help.	-0.54	1.08**	-0.65	0.35***
	S11. I think people should help more during fire accidents.	0.55	0.41	0.042	1.86***
	S12. I always help during fire accidents.	-0.96**	0.19	0.30	-0.40**
Fire risk	S13. Fire will never enter my property, which is well protected.	-1.57	-1.92*	-1.32	-0.50***
	S14. My property is now well protected, but in the past, accidents occurred and caused damage.	0.40	-0.78	-0.50	1.25***
	S15. I am frightened that a fire will come and destroy everything.	0.54***	1.36***	0.01**	-0.51***
Governance preferences	S16. Fires should be better controlled; the community has an important role in producing rules.	1.01	-0.23***	1.08	1.02
	S17. Fires must be controlled; those who do not control them must be punished. Government enforcement is most welcome.	1.51	1.46	1.42	0.57***

	Factor A	Factor B	Factor C	Factor D
Variance	28%	11%	10%	6%
Eigenvalue	15.59	6.04	5.32	3.37
N	14	9	7	4
Factor reliance	93%	93%	93%	93%

Agricultural use of fire is often perceived as the main source of fires. Many alternative hypotheses are, however, also mentioned during the interviews, such as cigarette butts, burning of trash, arson, and even children's games. A frequently mentioned and indirect reason for fire is forest degradation and land abandonment, a common problem in land-reform settlements. Farmers lament the invasion of capim furão (*Panicum aquaticum*) in pastures and forest edges, which increases fuel load. Landowner absence reduces the availability of fire-fighting labor and increases the likelihood that squatters, less likely to be careful about fire, move in and take over the areas concerned.

The farmers do share a norm for fire control (S7 consensus, negative). But the origin and the source of the fire are uncertain and difficult to determine, as is the identification of the culprit responsible for the event. It is also difficult to obtain compensation for the associated damage. Farmers suffering fire losses report that despite having strong suspicions about the identity of the culprit, they will feel awkward ("ficar tolo") in making a direct accusation, and fear that this might lead to retaliations, which in these regions can go as far as to culminate in a gun fight ("estar com medo de um tiro"). The person accused would typically argue that the fire did not ignite on his property and that he was not the one responsible. Indeed, he will instead claim that he is the fire's first victim.

> "I know my neighbor is wrong, but if we complain he will get angry, and then we will have to fight. If someone is damaged by fire, best is to remain silent." (Seu Mario, PA Luis Inacio)

Finally, farmers report that even if the actual culprit were to be identified, fines or compensation will be difficult to obtain given the overall limited financial capacity.

Most farmers believe in a partnership between the community and the government to enforce fire control (S16,17 consensus, positive). Yet, local associations seem to play little pro-active role in organizing collective action. Leaders often perceive their role as brokers between the community and the government: in the words of Dona Luiza, president of the association of Escadinha (Paragonorte): "my role as a president is to seek help from outside [the community]." This hope is for support in the form of subsidized tractors and fertilizers from the municipality or INCRA, or help from PrevFogo and municipal fire brigades. Associations rarely meet the expectations of the participants, leading to a delegitimization of local associations and their leaders, who report a drop in participation and an increase in association turnover.

When asked about what would be needed to increase other farmers' effort for mitigating fire risk, many farmers welcome the intervention of authorities: *"We need somebody powerful and influential to come here and speak to everybody"* (Seu Gilberto, Gleba 13).

Firefighting is frequently mentioned in interviews, and the associated statements rank high in the Q test (S11, consensus, positive). However, only a few farmers reported success in containing fire. Observation during follow-up visits during the 2015 fire season confirmed that, as the result of poor capacity, little action was undertaken to contain fires. The farmers who engaged in fire-fighting often reported traumas, such as a fear of flames and respiratory difficulties that persisted weeks after the event. Firefighting is believed to be a substitute for preventive control of fire to a limited degree. With limited capacity, the goal of firefighting is generally reported to be the diversion of fires away from sensitive areas (houses, pastures) towards the forest where it can be more easily controlled. The fact that farmers emphasize control rather than prevention might be the consequence of an emotional response or of a preference for immediate action rather than preventive activities. The latter require substantial upfront effort with uncertain benefits, which also depend to a very large extent on the complementary action of other farmers, climatic hazards, and the occurrence of 'fires from afar.' Even then, some farmers reported strong incentives for neighbors to cooperate in firefighting because extinguishing a fire in one property prevents it from spreading to adjacent ones.

Interpretation: Reconstructing the Four Narratives

Below we reconstruct the four narratives based on interpretation of the most distinguished statements of each factor (indicated in parentheses) and the features of the farmers belonging to each factor (reported in Table 1 in the SI).

Narrative A: Moderately High Fire Risk, Technological Positivists

Narrative A expresses the point of view of farmers willing to engage in a transition away from the use of fire (S3, S2). Its use is not perceived as a farmer's right (S4), and its use by neighbors is called into question (S5).[3] Perceived fire risk is moderately high (S13, S14) and fire control is seen as a moral obligation (S7). In the opinion of these farmers, both the community and public institutions ought to mitigate fire risk, with the role of government being more prominent than that of the community (S4, S5). They consider that there is little communication and coordination for fire control with the neighbors (S8) as well as little involvement by them in fire-fighting (S12).

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[3] Table 1 indicates for factor A, sentence 4 a score of -0.47^*, which means that the farmers moderately disagree, with a slight significant difference compared to other factors ($p > 0.1$). For sentence 5, the score is 1.60^{***}, which means that the farmers strongly agree, with a strong significant difference ($p > 0.01$).

This is the most popular narrative, as 14 farmers load on factor A, the majority of whom are presidents of local associations and thus more likely to be in contact with technical institutions (see SI for farmer groups description). Most farmers from older riverside communities fit with this narrative. Despite their traditional livelihoods, they show a high degree of willingness to engage in an agricultural transition. New technologies are quite attractive to these farmers, as they learn about tractors and other alternative techniques from television, radio and through technical assistance, but in practice, have little access to them. These farmers do participate in fire risk formation: they have suffered damage from accidental fires originating mainly from neighbors, on which they perceive a higher control – through collective action – as compared to 'fires from afar.' This is a common situation in older communities given the low probability of contagion from afar in the still relatively well-preserved forests.

Narrative B: High Perceived Fire Risk, Public Intervention for Fire Control

The farmers fitting with this narrative have the highest risk perception (S13, S15), and are oriented towards the use of controlled fire (S2). For these farmers, fire is not a farmer's right (S4). They believe that other techniques are available (S1) but this belief is at a lower level than for the other groups. These farmers do not think that fire control should be the responsibility of the community (S16); to them, public intervention is the only solution (S17).

As many as 83% of the farmers fitting with narrative B have experienced accidents caused by fire originating 'from afar.' The settlements in which most of these farmers live are characterized by degraded pastures and are therefore prone to fire. Open pastures are highly flammable and can carry fire over several tens of kilometers. Fire is thus seen as an exogenous risk to be coped with, and against which little can be done. These farmers are in favor of and, in some sense, dependent on external help, with government intervention being viewed as the only solution to fires. They all state that if there were no fire risk, they would plant profitable perennial crops, but in the current situation, they prefer to continue farming annual crops. This narrative shows little participation in risk formation because farmers do not feel responsible for its mitigation as it 'comes from afar.'

Narrative C: Moderately Low Perceived Risk, Controlled Fire Is the Preferred Option

For the farmers in this group, slash-and-burn agriculture is not the only available production technique (S1), yet fire use is a farmer's right (S4). There is no legitimate reason to ask the

neighbors to stop using fire (S5), yet controlling fire is an imperative (S7). Fire risk is perceived as moderately low (S13-S14) and, like those fitting with narrative A, these farmers prefer governance arrangements that involve both the community and public institutions, with the latter having a more prominent role.

Of the seven farmers fitting with this narrative, six have been trained in fire control and all have already discussed fire during community meetings. Three of the seven respondents are from the municipality of Ipixuna do Pará, where the local government is actively involved in fire management, and two are from the recent land-reform settlement Luiz Inacio, where technical assistance from Paragominas municipality has been concentrated in recent years. Interestingly, these farmers are those with most experience with tractors (five out of seven farmers having tried tractors at least once), and yet this group has the most favorable view of fire use. It seems as if they have found the use of tractors to be disappointing.

Narrative D: Less Involved in Risk Formation, Fire-Fighting Is the Solution

For the farmers fitting with this narrative, fire is not the right way to produce (S2, S5), but they are indifferent towards other agricultural techniques (S3). Compared to the other groups, Narrative D displays the lowest perception of risk (S13, S14, S15). At first view, this might seem surprising, as all farmers fitting with this narrative have suffered serious damage due to fire in the past. The explanation lies in their currently low reliance on agriculture: three of them receive a retirement pension, and the fourth has opened a small shop, which might reduce their perceived fire risk exposure.

Narrative D considers that the community has an important role to play (S16). The need for cooperation in fighting fire is the highest ranked statement (S11), but there is no real confidence that others will help (S10). Indeed, the respondents acknowledge that they themselves do not cooperate in fighting fire (S14). This narrative distinguishes itself from the others because the demand for government intervention is significantly lower (S17).

Discussion

Fire Use and Fire-Free Alternatives

We compared the farmers' views on fire use and fire control. Although there is substantial acknowledgement that alternative techniques are available and that fires should be controlled, there is substantial disagreement on whether burning is a farmer right. Currently, federal regulations do allow burning but only after obtaining a license to do so (Chap. IX of the

Brazilian Forest Code, law 12651/2012). The government does not however offer a livelihood substitute to farmers in case fire is not licensed or allowed only under unrealistic timelines or conditions (e.g., when the permit is granted too late, or allowing burning when the rainy season has already started) (Carmenta *et al.* 2011). And even so, regulation is poorly applied. The licensing system is de facto absent in Pará (unless municipalities stand in for the state, such as in Ipixuna), and some municipalities, such as Paragominas have simply banned all fires. Even though fire licensing (and its prohibition) may be difficult to implement, it also faces considerable resistance by those farmers who rely on fire for their livelihoods, believing that they have the right to use fire. Fire control regulations, on the other hand, seem to be better aligned with farmers' expectation, as we discuss below.

The farmers supporting the adoption of mechanized land-preparation techniques are the ones who have little experience of tractor use (Narrative A), while those who are most in favor of continuing to use fire are those who have more experience with tractors (Narrative C). This paradox can be explained – in the light of the interviews – by the fact that machines are ill-suited to the local context and cannot fully substitute fire in all its tasks, such as fertilization and pest control. Furthermore, the machines available are usually limited to light tractors with plows which are often unusable on former swidden fields strewn with unburnt log debris. In such cases, unsubsidized rental of heavy tractors is deemed too expensive by farmers, while local institutions are reluctant to make them available, fearing their use for land clearing. The potential of policies encouraging mechanization therefore depends on the substitution of fire in all its functions – land clearing, fertilization and pest control (Morello *et al.* 2018) – in the given market and environmental context.

Fire Control and Firefighting: Individual or Collective Issues?

Fire use, fire control, and firefighting decisions are inevitably collective choices, in the sense that the farmers' choices depend on their neighbors' complementary actions (Cammelli and Angelsen forthcoming). Although our results show that farmers are largely conscious of this interdependency and collective dimension of the fire issue, they also point to the current limited collective organization.

Fighting fire is to some extent a substitute of preventive fire control. The decision to rely on one or the other depends on the farmers' willingness to bear the upfront costs of fire control and on whether the source of fire risk is internal or external to the farm, which in turn is related to the land-use decisions of each farmer and those of his neighbors.

Fire control investments prevent the fire that the farmer ignites to prepare land from burning other crops, forests, and buildings and other facilities on the property (Bowman *et al.*

2008), but it can cost up to 80% of a small farmer's profits (Nepstad *et al.* 1999). While prevention costs are sunk and upfront – e.g., building firebreaks around the area to be burnt – its benefits are uncertain, as fires from neighboring fields or 'from afar' might enter the property anyway, and damage or destroy valuable assets. Unless all farmers control their fires, there is no individual incentive to undertake costly fire prevention (Cammelli and Angelsen forthcoming). The benefit of a farmer's fire control are threatened by uncertain (neighbor) coordination and by exogenous 'fires from afar,' which can even take the form of drought-induced mega-fires (Alencar *et al.* 2015).

In the same region, Cammelli and Angelsen (forthcoming) found that 43% of farmers in the Paragominas area were affected by fires at least once in the previous 5 years, with 6% of the fires originating from their own plots, 41% from neighbors, and 53% 'from afar.' The fact that farmers across factors agree that fire control is a moral imperative (S7) supports the view that it is indeed a collective issue. However, there is little agreement on whether fire control should be carried out collectively or individually (S6, 8, 9), and, in case of accidents, whether compensations should be paid by the farmer who let the fire escape to the ones who suffered losses. This uncertainty leads to lax enforcement of fire control norms and few or no compensation claims after fire accidents (Cammelli and Angelsen forthcoming), which in turn discourage investments such as fertilizers, perennial crops or improved pasture varieties that are fire-free and profitable but exposed to fire risk (Nepstad *et al.* 2001). In our sample, tree plantations and perennials are perceived as profitable but risky crops. Of the interviewed farmers, 40% would only plant perennials if the fire risk was low enough. Hoch *et al.* (2009) report a 15% to 60% fire risk affecting tree plantation in the Amazon region. Faced with increasing fire risk, farmers have an incentive to switch back to fire use to mitigate losses, and no incentives to control it. Unless successful coordination for fire risk mitigation is achieved, individuals have little motivation for adopting fire control and fire-free technologies. Firefighting by smallholders does not require significant sunk costs but has little chance of success. However, if many farmers combine their firefighting efforts, there may be an improvement in outcomes. The fact that farmers in our sample expect others to help in case of a fire suggests that firefighting is considered a collective obligation. Surprisingly, beliefs that others should be ready to help (S10) are not linked to the own contribution to firefighting (S12), which, for narrative D, might be due to the older ages of the respondents.

While PrevFogo successfully trains and mobilizes fire brigades in conservation units (Ramos *et al.* 2016), there is no systematic policy to involve smallholders in fire-fighting or to offer a reward for their stewardship. Future research could assess the potential of replication of fire brigades mobilization in smallholder communities.

Table 2 Relationships between participation in risk formation, perception of fire risk and governance preference

Participation in risk formation ► Perception of risk magnitude ▼	Low	High
Low	D exit from agriculture	C complementary solutions (fire control)
High	B external governance	A complementary solutions (fire-free transition)

Participation in risk formation is discussed in "Q Methodology, Design and Analysis" Section, perception of risk magnitude is based on S13, S14, S15, and governance preference is based on S16, S17

Participation in Risk Formation and Governance Preferences

The perceived fire risk is highly heterogeneous, and there seems to be a pattern connecting perceptions of risk magnitude, their formation, the perceived responsibility and ability to mitigate risk, and governance preferences (Table 2). A higher fire risk may engender higher coordination, because of the wish to counteract the effects of a likely unfavorable event. Yet economic reasoning suggests that a higher risk of large and uncontrollable fires undermines the benefits of achieving local coordination for fire control, because losses will occur anyway (Cammelli and Angelsen forthcoming). When the origin of fire risk is perceived as uncontrollable (e.g., 'fires from afar' or pasture fires), actors become less involved in risk and are less likely to take individual or collective action against it. Analogous patterns were found among homeowners exposed to fire risk in France and the US (Pégard 2010; Winter and Fried 2000).

We find that high and uncontrollable fire risk is indeed associated with preference for more government intervention (Narrative B), while the opposite is associated with a preference for less government intervention (Narrative D). Consistent with narrative B, Carmenta et al. (2013) found that in the Tapajos National Forest, local populations perceive fires as natural occurrences, and consequently had no system to enforce fire control norms. Actors more involved in risk formation prefer complementary collective and public action, yet they stress different proposed solutions: fire control (Narrative C) and fire-free technologies (Narrative A).

Participation in risk formation is related to the perception of uncertain sources of ignition and factors of propagation. Climatic hazards may lead to incautious behavior because information and learning about drought-induced fire risk is limited (Brondizio and Moran 2008). Factors affecting landscape flammability not only concern degradation and invasive grass species, but are also socially determined (Sorrensen 2004): in interviews, farmers complained about abandoned lots in land-reform settlements, which are overgrown by flammable vegetation and exposed to fires without the protection and fighting effort of resident landowners. Schwartz et al. (2015) find that landowner absenteeism is an indicator of fires in the Pucallapa region in Colombia, suggesting that this phenomenon might have a

regional scope. The age structure of populations may also explain landscape flammability. In areas of consolidated deforestation, high fuel load usually coexists with an elderly population (Sorrensen 2004), which may result in a lack of sufficient labor for fire control and fire-fighting.

Community fire control on the basis of local associations and unions alone might be insufficient to mitigate fire risk when the fire contagion basin encompasses large areas, affecting a large number of communities together. When fires expand from the neighborhood to the landscape, higher-level institutions need to be involved and government action is essential. In the Ipixuna municipality, a combination of fire prevention training, improved access to the licensing system, arbitration between neighbors, and a few sanctioning actions at the municipal scale have made it possible to reduce the expected risk of fire spreading from other neighborhoods and to increase participation in risk formation. The example of Ipixuna (mainly represented by Narrative C) suggests how policies can mitigate perceived fire risk and promote better conditions for participation in risk formation, for instance legitimizing local sanctioning measures and increasing collective action for firefighting and fire control.

In contrast, drastic policies such as the Paragominas fire ban might reduce participation in risk formation if not coupled with technological alternatives to fire use and if not aligned with farmers' motivation (Carmenta et al. 2018). Instead, supporting regulations such as an easily accessible fire licensing system (coupled with clauses enabling fire-free agriculture when the permit is denied) makes farmers responsible for controlling fire. By investing in fire officers authorized to issue fire licenses and mediate disputes originating from fire accidents, local governments can increase the farmers' participation in risk formation and reduce their perceived risk magnitude, improving the likelihood of coordinated fire control.

Conclusions

In a changing climate, reducing fires in the Amazon basin and preserving the fire-dependent livelihoods of local people is an increasing challenge. The Amazon is too big for public institutions to intervene in a timely and effective manner for all fire events (cf. Morello et al. 2017). Local people play a

fundamental role not only in fire ignition, but also in fire control and firefighting (Nepstad *et al.* 1999). Although banning fire may appear as a tempting solution for policy makers (Carmenta *et al.* 2018), we show that incentivizing fire control makes more sense for the farmers' reality. This however does not mean leaving control only up to the farmers communities, the farmers themselves ask for more public intervention.

Understanding the farmers' perceptions and their diversity is essential to interpret the local reality of fire and to devise effective policies that are complementary to the farmers' actions (Brondizio and Moran 2008). Depending on local climate and vegetation structures, fires follow different patterns of ignition and propagation and represent different levels of danger. The farmers' experiences and narratives thus differ accordingly and should be reflected in fire policies.

Even though our study is exploratory in nature, it provides some key insights. Fire use, fire control and firefighting decisions are collective choices, in the sense that the farmers' choices depend on their neighbors' complementary actions. These actions in turn depend on the farmers' perceptions of risk and their participation in risk formation, which is determined by the scale of fire contagion, and the adequacy of the institutions involved in fire control and firefighting. Community-level institutions are inadequate to promote fire control and firefighting when fire propagates beyond community boundaries, because benefits of within-community collective action are threatened by collective action failure in other communities. Coordination across communities is jeopardized by the large number of agents involved and long distances, which reduce communication. Most farmers demand a partnership with public authorities, whether for fire control or firefighting, depending on their participation in fire risk formation. Fire bans are hard to apply without providing alternative means of livelihood. Policies aligned with local fire control norms (easing licensing and/or fines) and enabling local people to fight fires are likely to encourage local collective action by mitigating perceived fire risk and increasing participation in risk formation. Mitigating fire risk appears as a necessary step for a transition out of fire use, yet substituting fire in all its tasks (land clearing, fertilization, and pest control) remains a challenge.

Compliance with Ethical Standards

Conflict of Interest   The authors declare they have no conflict of interest.

References

Alencar, A. A., Brando, P. M., Asner, G. P., and Putz, F. E. (2015). Landscape fragmentation, severe drought, and the new Amazon forest fire regime. Ecological Applications 25: 1493–1505.

Anderson, L. O., Aragão, L. E., Gloor, M., Arai, E., Adami, M., Saatchi, S. S., Malhi, Y., Shimabukuro, Y. E., Barlow, J., and Berenguer, E. (2015). Disentangling the contribution of multiple land covers to fire-mediated carbon emissions in Amazonia during the 2010 drought. Global Biogeochemical Cycles 29: 1739–1753.

Aragao, L. E., and Shimabukuro, Y. E. (2010). The incidence of fire in Amazonian forests with implications for REDD. Science 328: 1275–1278.

Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., and Houghton, R. (2017). Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science 358: 230–234.

Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Nally, R. M., Thomson, J. R., Ferraz, S. F.d.B., Louzada, J., Oliveira, V. H. F., Parry, L., Ribeiro de Castro Solar, R., Vieira, I. C. G., Aragão, L. E. O. C., Begotti, R. A., Braga, R. F., Cardoso, T. M. Jr., R.C.D.O., S., C. M. Jr., Moura, N. G., Nunes, S. S., Siqueira, J. V., Pardini, R., Silveira, J. M., Vaz-de-Mello, F. Z., Veiga, R. C. S., Venturieri, A., and Gardner, T. A. (2016). Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature 535(7610): 144.

Bowman, M. S., Amacher, G. S., and Merry, F. D. (2008). Fire use and prevention by traditional households in the Brazilian Amazon. Ecological Economics 67: 117–130.

Brondizio, E. S., and Moran, E. F. (2008). Human dimensions of climate change: The vulnerability of small farmers in the Amazon. Philos Trans R Soc Lond B Biol Sci 363: 1803–1809.

Brown, S. R. (1980). Political subjectivity: Applications of Q methodology in political science, Yale University Press New Haven, CT.

Cammelli, F., Angelsen, A. (*forthcoming*) Amazonian farmers' response to fire policies and climate change. Ecological Economics

Cano-Crespo, A., Oliveira, P. J., Boit, A., Cardoso, M., and Thonicke, K. (2015). Forest edge burning in the Brazilian Amazon promoted by escaping fires from managed pastures. Journal of Geophysical Research: Biogeosciences 120: 2095–2107.

Carmenta, R., Parry, L., Blackburn, A., Vermeylen, S., and Barlow, J. (2011). Understanding human-fire interactions in tropical forest regions: A case for interdisciplinary research across the natural and social sciences. Ecology and Society 16(1): 53.

Carmenta, R., Vermeylen, S., Parry, L., and Barlow, J. (2013). Shifting cultivation and fire policy: Insights from the Brazilian Amazon. Human Ecology 41: 603–614.

Carmenta, R., Coudel, E., and Steward, A. M. (2018). Forbidden fire: Does criminalising fire hinder conservation efforts in swidden landscapes of the Brazilian Amazon? The Geographical Journal 185(1): 23–37.

Costa (2006). Comunicação & Meio ambiente: A análise das campanhas de prevenção a incendios florestais na Amazonia. . Serie Teses do Núcleo de Altos Estudos Amazonicos. In Belem, Editora da Universidade Federal do Pará, Brazil.

Diaz, M.d.C.V., Nepstad, D., Mendonça, M.J.C., da Motta, R.S., Alencar, A., Gomes, J.C., Ortiz, R.A. (2002) O preço oculto do fogo na Amazônia: Os custos econômicos associados as queimadas e incêndios florestais. Relatório Instituto de Pesquisa Ambiental da Amazônia (IPAM)/Instituto de Pesquisa Econômica Aplicada (IPEA)/Centro de Pesquisa Woods Hole.

Ferreira, J. N., Guariguata, M., Koh, L. P., Mansourian, S., Parrotta, J., Sasaki, N., and Schmitt, C. B. (2012). Impacts of forest and land management on biodiversity and carbon, in Parrotta, Wildburger, Mansourian. (org.).Understanding Relationships between Biodiversity, Carbon, Forests and People: The Key to Achieving REDD+Objectives. Vienna: IUFRO World Series 31: 53–80.

Fischbacher, U., Gächter, S., and Fehr, E. (2001). Are people condition-ally cooperative? Evidence from a public goods experiment. Economics Letters 71: 397–404.

Godar, J., Gardner, T. A., Tizado, E. J., and Pacheco, P. (2014). Actor-specific contributions to the deforestation slowdown in the Brazilian Amazon. Proceedings of the National Academy of Sciences 111: 15591–15596.

Gruev-Vintila, A., and Rouquette, M. (2007). Social thinking about Collective Risk: How Do Risk-related Practice and Personal Involvement Impact Its Social Representations? Journal of Risk Research 10(4): 555–581.

Guimarães, J., Veríssimo, A., Amaral, P., and Demachki, A. (2011). Municípios Verdes: caminhos para a sustentabilidade, Imazon, Belem, PA.

Hoch, L., Pokorny, B., and De Jong, W. (2009). How successful is tree growing for smallholders in the Amazon? International Forestry Review 11: 299–310.

IBGE, (2010) IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Censo Demográfico 2010. Rio de Janeiro: IBGE, 2010. https://ww2.ibge.gov.br/home/estatistica/populacao/censo2010/default.shtm.

INPE (2018). PRODES (Projeto de Estimativa de Desflorestamento da Amazônia), INPE (Instituto Nacional de Pesquisa Espacial), São José dos Campos-SP, p. 2018 http://www.dpi.inpe.br/prodesdigital/prodes.php.

Morello, T., Ramos, R., Steil, L., Parry, L., Barlow, J., Markusson, N., and Ferreira, A. (2017). Fires in Brazilian Amazon: Why does policy have a limited impact? Ambiente & Sociedade 20: 19–38.

Morello, T. F., Piketty, M.-G., Gardner, T., Parry, L., Barlow, J., Ferreira, J., and Tancredi, N. S. (2018). Fertilizer Adoption by Smallholders in the Brazilian Amazon: Farm-level Evidence. Ecological Economics 144: 278–291.

Nepstad, D.C., Moreira, A.G., Alencar, A.A. (1999) A floresta em chamas: origens, impactos e prevenção de fogo na Amazônia. Programa Piloto para a Proteção das Florestas Tropicais do Brasil, Brasília, Banco Mundial.

Nepstad, D., Carvalho, G., Cristina Barros, A., Alencar, A., Paulo Capobianco, J., Bishop, J., Moutinho, P., Lefebvre, P., Lopes

Silva, U., and Prins, E. (2001). Road paving, fire regime feedbacks, and the future of Amazon forests. Forest Ecology and Management 154: 395–407.

Pégard, B. (2010). Fire risk and fire management in the context of global climate change: An anlysis of the Provence region or the South-East France and the blue mountains region of Australia. In Institute of environmental studies, faculty of art and social sciences, University of New South Wales, p. 444.

Piketty, M.-G., Poccard-Chapuis, R., Drigo, I., Coudel, E., Plassin, S., Laurent, F., and Thâles, M. (2015). Multi-level governance of land use changes in the Brazilian Amazon: Lessons from Paragominas, State of Pará. Forests 6: 1516–1536.

Ramos, R. M., Fonseca, R. L., and Morello, T. F. (2016). Unidades de conservação e proteção contra incêndios florestais: relação entre focos de calor e ações articuladas pelas brigadas contratadas. Biodiversidade Brasileira 6: 135–148.

Schwartz, N. B., Uriarte, M., Gutiérrez-Vélez, V. H., Baethgen, W., DeFries, R., Fernandes, K., and Pinedo-Vasquez, M. A. (2015). Climate, landowner residency, and land cover predict local scale fire activity in the Western Amazon. Global Environmental Change 31: 144–153.

Sorrensen, C. (2004). Contributions of fire use study to land use/cover change frameworks: Understanding landscape change in agricultural frontiers. Human Ecology 32: 395–420.

Sorrensen, C. (2009). Potential hazards of land policy: Conservation, rural development and fire use in the Brazilian Amazon. Land Use Policy 26: 782–791.

Viana, C., Coudel, E., Barlow, J., Ferreira, J., Gardner, T., and Parry, L. (2016). How does hybrid governance emerge? Role of the elite in building a Green Municipality in the Eastern Brazilian Amazon. Environmental Policy and Governance 26: 337–350.

Winter, G., and Fried, J. (2000). Homeowner Perspectives on Fire Hazard, Responsibility, and Management Strategies at the Wildland-Urban Interface. Society & Natural Resources 13: 33–49.