Participatory mapping reveals socioeconomic drivers of forest fires in protected areas of the post-conflict Colombian Amazon

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Abstract

1. Wildfires have increased in protected areas (PAs) of the Colombian Amazon following the 2016 peace agreement between the Government and the Revolutionary Armed Forced of Colombia (FARC—Spanish acronym). Recent study efforts to understand this issue suffer from data scarcity and limited consultation of local stakeholder perspectives on factors affecting wildfires.

2. This study uses a social–ecological systems framework to investigate local perceptions of factors driving and/or preventing wildfires in the Los Picachos, La Macarena and Tinigua PAs, which are shared by two Amazonian departments experiencing wildfire increase. Four stakeholder categories were selected to represent varied and possibly conflicting interests: cattle ranchers, the national park service, local authorities and cross-sectional stakeholders. We combined a participative mapping approach with interviews to illustrate stakeholder perceptions of interactions between key variables in graphical causal models. Network analyses were used to determine areas of agreement on key variables, and to compare local priorities with those of key informants at the national level.

3. Local stakeholders and key informants widely agreed on the roles of extensive cattle ranching and land grabbing as key drivers of wildfires. The analysis identified areas for further research into wildfire occurrence within PAs. These include lack of governance and untitled land, as well as the effects of poor access to basic public services on unsustainable ranching methods.

4. This study revealed contested opinions between ranchers and other stakeholders over interactions between ranching, roads and illicit crops, and consequently their effects on wildfire occurrence. This indicates the need for cautious implementation of the National Development Plan, prioritising road maintenance over expansion, integrating arable alternatives to cattle ranching and considering multiple stakeholders in regional decision-making around wildfire reduction. The strengths and limitations of the participative mapping approach employed here...
1 | INTRODUCTION

Wildfires increasingly threaten the Amazon region and the ecosystem services that it provides (Barlow et al. 2019). In addition to their exceptionally high biodiversity (Jenkins et al., 2013), the Amazon’s tropical forests contribute to global climate regulation (Aragão et al., 2014) and function as a valuable carbon sink that is decreasing due to the cumulative effects of fires, drought, deforestation and degradation (Yang et al., 2018). Wildfires not only affect biodiversity by altering species composition (Devischer et al., 2016) but also stimulate regional forest dieback (Malhi et al., 2014). This further weakens the Amazon’s capacity as a carbon sink by releasing carbon at a faster rate than deforestation alone, threatening increased climate instability (Aragão et al., 2018; Silva Junior et al., 2019). The resultant warming has been projected to put local livelihoods at risk by negatively affecting ecosystem services and water availability, as well as economic growth in the tropics (IPCC, 2018).

Current global and regional economic models exacerbate forest degradation by encouraging land clearance through burning (Aragão et al., 2008; Barlow et al., 2019; Betts et al., 2008), and ignition rates greatly exceed the 500–1,000-year natural fire return interval determined from charcoal studies in the Brazilian Amazon (Cochrane, 2009). Brazil’s recent conflagrations bring into stark relief the need for further research into sustainable alternatives to forest clearance, as well as greater attention to escalating deforestation in countries such as Colombia (Nobre, 2019), which contains 7% of the Amazon basin (Armenteras & Retana, 2012).

Colombian Amazonia has experienced a proliferation of wildfires in the highly biodiverse Tinigua–Picachos–Macarena protected areas (PAs) and surrounding regions, following the 2016 peace agreement between the group formerly known as the Revolutionary Armed Forces of Colombia (FARC—Spanish acronym) and the Government (Armenteras et al., 2019). These anthropogenic wildfires clear the PAs’ primary forest and largely correspond to the ‘deforestation’ fires recently defined for the Amazon (Barlow et al., 2019) although they can also become uncontrolled in the dry season (ANLA, 2017; Caracol, 2019; Minambiente, 2018). As well as being exacerbated by climate change, regional fire occurrence has been attributed to the effects of roads, pasture conversion, fragmentation and deforestation (Aragão et al., 2008; Armenteras et al., 2017; Carmenta et al., 2016; Simmons et al., 2016). However, the acquisition of local data on factors driving wildfire increase has been limited in recent years by the armed groups that continue to occupy parts of the region (Armenteras, Negret, et al., 2019; Morales, 2017; Vélez, 2019).

Social considerations such as the local realities facing stakeholders are central, yet often overlooked aspects of natural resource management that provide crucial insights into conservation challenges and solutions (Biggs et al., 2011; Carmenta et al., 2011, 2019). Although departments including Guaviare still grapple with dissident guerrilla fronts, the demobilisation process offers a critical opportunity to widen the scale of investigation and incorporate local perceptions of wildfire dynamics in and around Amazonian PAs as they unfold (The Guardian, 2019).

A social-ecological systems framework can effectively utilise social science methodology to include multiple regional perspectives (Alves, 2008; Berkes et al., 1998; Devischer et al., 2016). Many of the Amazonian fire studies that incorporate social field research often focus on individual actors such as Indigenous groups (Mistry et al., 2016) or specific countries such as Brazil (Carmenta et al., 2013, 2019; Eloy et al., 2019; Viana et al., 2016). However, the urgent need for multi-stakeholder participation in PA policy formulation for the Colombian Amazon is clear from the civil unrest surrounding evictions from PAs such as La Macarena, and the military efforts to halt deforestation through ‘Operation Artemisa’ (El Tiempo, 2018b; Paz Cardona, 2019). Such exclusionary approaches to PA conservation in the tropics have historically exacerbated social conflict and even biodiversity loss through marginalisation of the rural poor (Brockington & Igoe, 2006; Lele et al., 2010; Martin et al., 2014).

Plural valuation of multiple stakeholder perspectives has been advocated as a more equitable and sustainable approach to natural resource governance (Jacobs et al., 2020). Participatory mental mapping approaches offer intuitive methods for identifying common ground and disagreement between local and marginalised social actors, whose perspectives are key to the successful evaluation of conservation and resource management initiatives (Bennett, 2018; Biggs et al., 2011). Research into targeted solutions to wildfire occurrence in Colombian PAs should therefore contest power imbalances by enabling and strengthening participatory dialogue between diverse regional actors (Jacobs et al., 2020; Schreckenberg et al., 2017).

1.1 | Participatory cognitive mapping as a boundary object

Participatory cognitive mapping offers a multi-stakeholder methodology that is ‘especially appropriate for data poor situations’ (Özesmi & Özesmi, 2004, p. 62) such as post-conflict Colombia. The technique has been employed across a range of social-ecological systems (Hobbs et al., 2002), including fire dynamics in Bolivia (Devischer, Malhi, et al., 2016) in order to facilitate participative dialogue between actors who may not ordinarily interact. This lack
of interaction can exacerbate urban–rural power imbalances and the policy-practice gap, undermining local faith in fire management initiatives (Carmenta et al., 2019). Participative mapping can help to address this by coordinating multiple stakeholder perspectives in order to better understand interactions within a complex system (Reddy et al., 2019).

This study adapts participatory maps for use as ‘boundary objects’ (Star & Griesemer, 1989) to overcome logistical and disciplinary barriers to dialogue among disparate stakeholders. As a conceptually simple and transferable graphical method (Mendoza & Prabhu, 2003), maps can be combined with focus groups, in which individuals’ concepts are abstracted into variables by the collective, allowing for the higher levels of confidentiality recommended for research in post-conflict scenarios (Ford et al., 2017). This is especially important in Colombia, where public defenders of the environment are particularly at risk of criminalisation and acts of violence (Forst, 2018). By integrating disparate forms of knowledge through collective, grounded inquiry (Christen et al., 2015) participative mapping has the potential to democratise environmental decision-making in post-conflict regions of the Global South.

The perspectives of four stakeholder groups were aggregated to address two key questions: (a) What do stakeholders perceive as the most important key variables influencing wildfire in PAs?; (b) How can these variables be effectively addressed by policies based on their interactions within the system?

2 | METHODS

This study uses a mixed methods approach that combines participative mapping with semi-structured key informant interviews to provide an explorative, baseline understanding of stakeholder perceptions around the social–ecological system driving wildfire in PAs of the post-conflict Colombian Amazon.

2.1 | Study area

The study focused on the Macarena Special Management Area (AMEM—Spanish acronym), which is shared by the Caquetá, Guaviare and Meta departments. It comprises a complex of Integrated Management Areas (IUCN Category VI) and three national protected areas (IUCN Category II): (a) Cordillera de Los Picachos, (b) Sierra de la Macarena and (c) Tinigua, which cover ~1,040,620 ha of humid tropical forest.

The AMEM was designated in 1989 to protect this Andean biodiversity corridor from development pressures including timber harvesting and forest clearance for cattle ranching and illicit cocoa cultivation (Autoridad Nacional de Licencias Ambientales – ANLA, 2017). Beginning with the 19th century rubber boom, the territorial ‘colonisation’ process was continued by colonos/campesinos: rural landholders displaced by violence and economic pressure in the 20th century (SINCHI, 1999, 2000).

After declaring Guaviare and most of Caquetá as Forest Reserves (areas promoting low-impact forest use but without strict protection) in 1959, the State gradually rescinded this status in some areas and incentivised settlement from the 1950s (SINCHI, 2011, 2016). The majority of land titles in Caquetá and Guaviare belong to smallholder (≤50 ha) campesinos (SINCHI, 2011, 2016), and land inequality remains high (Gini coefficients of 0.70 and 0.81 respectively, UPRA, 2015). The combined effects of these territorial restructurings and inequalities have contributed to uncertainty and conflict surrounding land use and ownership (Acuña & Rincón, 2007). These range from protests over the forced eviction of ranchers from national PAs by the army (La Nación, 2018a) to the expulsion of forest rangers by FARC dissidents that continue to operate in the area (El Espectador, 2020).

Regional studies indicate that local fires are related to anthropogenic activities such as agricultural clearing for pasture and crops, as well as logging (Armenteras et al., 2013; Dávalos et al., 2016; Tasker & Arima, 2016; Xaud et al., 2013). Open fires are prohibited in Colombia’s rural areas, except for strictly controlled burns for soil preparation, harvesting and stubble or frost removal, as well as small open pit mining (Meza et al., 2019). These must take place more than 100 metres from conservation areas, natural forest and protected reserves, such as the Picachos–Tinigua–Macarena network (Ministerio de Ambiente, 2005), and can be suspended at any time by the Environmental Ministry (CDA, 2018).

However, NASA’s Fire Information for Resource Management System (FIRMS) detected an increase in 1 km² pixels containing active fires within the AMEM since the 2016 peace agreement (Figure 1). Although the majority of these were in integrated management areas (IMAs), the Picachos–Tinigua–Macarena PAs exhibited increased pixel counts in 2018–2020 from the 5 years before the peace agreement. The decline in 2019 fire occurrence may be explained by higher amounts of rainfall in December 2019, delaying Colombia’s dry season to 2020 (Amador-Jiménez et al., 2020), when higher active fire pixel counts were again detected.

2.2 | Participatory mapping

We adapted a participatory mapping method from fuzzy cognitive mapping (FCM), following Devisscher, Malhi, et al. (2016). This approach allows experts on a social–ecological system to illustrate complex causal connections between its component variables in a graphical causal model (Figure 2), which can be repeated across different individuals and aggregated by the researcher (Kosko, 1988). After defining a single reference point in time (Özesmi & Özesmi, 2004), in this case, the present day, individuals enumerate and discuss variables they perceive as important or influential within a social–ecological system (e.g., wildfires in PAs).

Following variable selection, participants wrote these in a circle guided by a facilitator (Devisscher, Malhi, et al., 2016), adding directed...
connections (edges) with positive/negative weights using real numbers between \([-1, 1]\). A positive edge from variable A to variable B states a direct positive effect of A on B; a negative edge states a direct negative effect of A on B. Trial mapping exercises in Caquetá informed the use of strong, medium and low edge weightings (0.2 for weak edges, 0.5 for medium and 0.8 for strong edges, and \(-0.2\), \(-0.5\) and \(-0.8\) for negative connections). Although this crisp weighing system may not capture all of the nuance, uncertainty and vagueness implicit in social–ecological problems, it has been employed in rural contexts where participants lack the time and experience to effectively engage with finer weighting scales (Nyaki et al., 2014). Participants could add, remove or edit variables and edges throughout the mapping exercise.

2.3 Focus groups and selection of participants

In June 2019, we produced four participatory maps through focus groups representing key regional stakeholders, namely: (1) Local authorities; (2) national park service; and (3) cattle ranchers in Guaviare. (4) Cross-sectional stakeholders included participants representing all of the three previous stakeholder groups, but in Caquetá (Figure 3). These groups were selected on the basis of their widely perceived roles in controlling (groups 1 and 2) and/or stimulating (group 3) wildfire (Minambiente, 2018a). The cattle rancher groups included individuals who had been working in the region for \(\geq 8\) years with property sizes ranging from 10 to 140 ha (mean

![Figure 1](image-url)
People and Nature

The cross-sectional stakeholder group included representatives of Caquetá’s local government, national park service and cattle ranchers with property sizes ranging from 90 to 120 ha (mean property size = 105 ha).

We used snowball sampling (Atkinson & Flint, 2001) to select relevant participants within the study area (Figure 4): local authorities and national park staff were interviewed in their regional headquarters of San José (Guaviare) and Florencia (Caquetá); Cattle ranchers were interviewed in Calamar (Guaviare within the AMEM), and El Doncello (Caquetá), a ranching hub which has been at the centre of recent protests surrounding evictions from the AMEM (El Tiempo, 2020; Semana Sostenible, 2020). The cross-sectional focus group was interviewed in San Vicente del Caguán (Caquetá), on the edge of the IMA. Participants were asked to respond to what was relevant to their landscape and the nearby PAs.

Stakeholders were asked to identify and discuss the interactions between economic, social, institutional and environmental variables that influenced wildfires directly or indirectly in initial 1–2 hr focus group sessions (Carley & Palmquist, 1992; Özesmi & Özesmi, 2004). Following discussion, individuals wrote the factors they perceived as most important on an erasable whiteboard using coloured markers, discussing, removing or combining overlapping variables. The

FIGURE 2 Sample map of a hypothetical unrelated system presented to participants

FIGURE 3 Flow chart detailing focus group locations and exercises
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6.4 | Key informant interviews

Maps were compared with semi-structured interviews with three key informants, selected on the basis of their organisations’ key roles in post-conflict management of Amazonian PAs according to preliminary literature review (El Tiempo, 2018a; UNDP, 2016; Zárate et al., 2018). In Colombia, a Researcher from the Sinchi Amazonic Institute of Scientific Research (SINCHI) was interviewed in Spanish, and the Director General of Parques Nacionales Naturales (PNN) was interviewed in English. Former Colombian President Juan Manuel Santos, whose administration initiated the peace process and increased Colombia’s PAs by 31 million hectares, was interviewed in the United Kingdom, in English. Each informant was asked to discuss interactions between economic, social, institutional and environmental variables that influence wildfire in PAs directly or indirectly.

2.5 | Data analyses

Each map was entered into an adjacency matrix in which the numerically weighted connections (edges) of each variable with the others

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**FIGURE 4** Map of the study area, with five sites in and around the Macarena Special Management Area (AMEM). Interviews took place in (i) Florencia, Caquetá, (ii) El Doncello, Caquetá, and workshops in (1) San Vicente del Caguán, Caquetá, (2) San José del Guaviare and (3) Calamar, Guaviare

less accessible cattle ranchers carried out the variable selection exercise orally. Separating the variable selection exercises from the map building helped to keep the focus groups appropriately small (~3–4 individuals) for emotionally charged topics (Morgan, 1996; Smithson, 2007).

The cross-sectional focus group carried out both activities (variable selection and assigning causal weights) with representatives of each sector during one session in Caquetá, in order to reduce regional travel in compliance with a departmental risk assessment. It is important to acknowledge that these larger group dynamics can affect the extent to which individuals feel comfortable expressing their views (Smithson, 2007). However, the group’s process of taking it in turns to add or remove variables/edges and then discussing and explaining these as a whole helped to involve all participants while building towards a group consensus (Morgan, 1996).

The Sustainable Development Corporation for Northern and Eastern Amazonia, who represented local authorities in Guaviare, were presented with the variables defined by the cross-sectional stakeholder group, as this also included local authorities such as municipal councillors. The final, aggregated map involved 25 individuals.
were recorded in each row, with 0 indicating no edge (Devisscher, Malhi, et al., 2016; Kosko, 1988; Mazlack, 2009). The average values of each edge were then combined into a normalised and aggregated matrix (Devisscher, Malhi, et al., 2016, see aggregated matrix in Appendix S2). Equal weightings were given to all participants, so as not to privilege any single group (Devisscher, Malhi, et al., 2016; Özesmi & Özsesmi, 2004). Those edges that were repeated were reinforced by their appearance in other maps through the average weightings; those that appeared in fewer maps were included in the aggregated map, but were assigned a weight of 0 for maps in which they did not appear. Concepts which overlapped extensively, and whose edges did not conflict were ‘condensed’ into larger units (Harary et al., 1965; Laurila-Pant et al., 2015; Özesmi & Özsesmi, 2004). Edges of negative variables (e.g. ‘loss of biodiversity’) were occasionally inverted (e.g. ‘functional ecosystem services’) for homogenisation in the aggregated map.

2.6 | Network structure analysis

Network analyses were applied to map adjacency matrices in RStudio v3.5.2 (Newman, 2010). We used local indices of the edges immediately connected to each node to calculate degree centrality and classify them as (a) transmitters; (b) receivers; and (c) ordinary variables (Table 1; Özesmi & Özsesmi, 2004; Solana-Gutiérrez et al., 2017; Väidianu, 2013). Transmitters’ high ratio of outgoing to incoming edges suggests higher capacities to act as drivers that influence other variables (Devisscher, Malhi, et al., 2016). Receivers’ high ratio of incoming to outgoing edges suggests they are susceptible to the effects of drivers that connect to them. Ordinary variables are those with neither a disproportionately high number of incoming nor outgoing edges.

Degree centrality is limited to measuring the effects of immediate neighbours upon a variable (Sharkey, 2017). However, Katz centrality allows variables to accumulate influence from across the network, with more distantly connected variables contributing less than immediate neighbours (Lavin et al., 2018). We therefore ranked variables according to their Katz centrality to determine their importance in the network, using the default attenuation factor \( \alpha = 0.1 \) in Python’s Network X library (Hagberg et al., 2008). Maps were visualised using the igraph package in RStudio 3.5.2 (Csardi & Nepusz, 2006).

| TABLE 1 | Response variables of the aggregated map |
|---|---|
| **Metric** | **Description** |
| Degree centrality | |
| (i) In-degree (ID) | Sum of absolute values of a variable’s incoming connections or edges (column sum in adjacency matrix) |
| (ii) Out-degree (OD) | Sum of absolute values of a variable’s outgoing connections or edges (row sum in adjacency matrix) |
| Transmitter variables | ‘True’ transmitters had ID value of zero; ‘Ordinary’ transmitters were within the upper quartile of OD/ID ratio, functioning as system ‘drivers’ (Devisscher, Malhi, et al., 2016) |
| Receiver variables | Variables within the upper quartile of ID/OD ratio, functioning as system ‘outcomes’ (Devisscher, Malhi, et al., 2016) |
| Central (Katz) variables | Variables with highest Katz centrality, which accounts for the cumulative influence of connections with other influential variables (Lavin et al., 2018) |
| Density | Measure of connectivity between variables, calculated by dividing the number of edges \( (E) \) by the maximum possible number of edges between \( (N) \) variables (Devisscher, Malhi, et al., 2016; Özesmi & Özsesmi, 2004). \( D = \frac{E}{N(N-1)} \) |

2.7 | Ethics

Informed consent was obtained and recorded from all participants at the beginning of focus groups and interviews in compliance with the University of Oxford’s Central University Research Ethics Committee (#SOGE 1A 19-27). Written consent was obtained where possible, with verbal consent being recorded where necessary due to literacy constraints.

3 | RESULTS

3.1 | Network structure analysis

The aggregated network (see Figure 5 for a simplified diagram and Appendix S3 for the entire network) contained 36 variables affecting wildfire with 112 edges (density = 0.09). Although stakeholders tended to agree on the positivity/negativity of shared edges, the connection between roads and ranching evinced disagreement. The national park service (Appendix S4.3) and cross-sectional stakeholders (Appendix S4.2) attributed a positive relationship (roads drive ranching), and ranchers (Appendix S4.1) attributed a negative one (roads reduce ranching). The resulting ‘weak’ positive relationship (+0.2) represents the mean of two strong positive connections (+0.8), one strong negative connection (−0.8) and one non-existent connection (0).

3.2 | Transmitter variables

There were 13 ‘True’ transmitters (36%—Table 2).

3.3 | Receiver variables

The aggregated map contained no ‘True’ receiver variables (zero out-degree centrality); Ordinary receivers are listed in Table 3. These include five of the upper percentile of central variables (Table 4),
suggesting that some of the most important variables may be driven by underlying processes that influence them in the map.

### 3.4 Central (Katz) variables

As expected, forest fires possessed highest Katz centrality, followed by deforestation and climatic phenomena (Table 4). These were followed by extensive cattle ranching, land grabbing, lack of basic public services, lack of governance, unsustainable ranching methods and untitled land.

### 3.5 Key informant interviews

All of the nine central variables were also mentioned by every key informant (see Appendix S5 for a table detailing commonality between the maps and key informants). The former President and PNN Director listed cattle ranching as the most important direct forest fire driver, and the SINCHI Researcher selected land grabbing, both central variables. This indicated broad agreement on variables across interviewees and data collection methods.

Variables which were mentioned by ≥2 key informants, but which did not appear in the maps included the forest fire driver of mining, and the following forest fire preventatives, responses and mitigators: military operations, early warning systems, conservation credits and Indigenous practices. Indigenous groups in particular were stressed as ‘the best guardians of the environment’ who ‘take care of the forests, the fauna and all the ecosystem’ despite not appearing in the locally constructed map. Conservation credits, which were mentioned by two key informants, and oil palm, which was only mentioned by the PNN Director, also appeared in the rancher map. However, these were described as foreseeable (not current) and therefore removed in

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1 Former President.
2 PNN Director.
3 SINCHI Researcher.
4 | DISCUSSION

Participative mapping and supplementary interviews identified nine central variables that influence forest fires in PAs, according to local stakeholders and key informants. Aside from the three ecological receiver (response) variables of forest fires, deforestation and climatic phenomena, these were (a) extensive cattle ranching; (b) land grabbing; (c) lack of basic public services; (d) lack of governance; (e) unsustainable ranching methods; and (f) unitled land. Each of these will be discussed in turn, in relation to their functioning within the social–ecological system driving wildfire.

4.1 | Extensive cattle ranching

As a central receiver variable, extensive cattle ranching was the strongest direct forest fire driver (excluding the ecological receiver variables of climate change and deforestation). It not only drives these variables, but also shares a positive feedback with the latter, while its direct (+0.6) effect on forest fires ranks far above the aggregated map’s absolute average edge weight (0.27). This corroborates reports that ranching drives up to 80% of deforestation in Brazil’s Northern region (Nepstad et al., 2008). One rancher described how cattle ranching employs burning to clear land for pasture:

Here the rancher and the farmer, in order to cultivate effectively, according to them, needs to crop and leave the trees and cuttings to dry, to burn and afterwards to plant. If you did not burn, there will supposedly be no crops.

Ranchers attributed this practice especially to large-scale landowners (>500 ha), 28 of whom own approximately 91% of Guaviare’s unrestricted territory (outside forest reserves), with the remaining 9% held in smaller parcels across 5,456 owners (SINCHI, 2016).

At the smaller scale (<150 ha), ranchers explained cattle ranching as the only option available to those attempting to transition from illicit coca to other forms of agriculture:

There was no alternative [to coca], so that the choice was cattle ranching [...] because there are no roads,
because there is no marketing and distribution, and people invested in agriculture and they lost their money.

The pastural expansion which accompanies frontier development, often replacing coca, is an important deforestation driver in the Colombian Amazon, which must be stabilised through improved infrastructure and basic services, as well as conservation governance (Dávalos et al., 2016). With coca plantations covering 41,382 ha in Putumayo-Caquetá, and 10,500 ha in Meta-Guaviare (UNODC, 2018), unsupported land use transitions could add another 50,000 ha of pasture, at least 8,000 ha of which is located in PAs.5

4.2 | Land grabbing

As a direct driver of deforestation (0.2) and forest fires (0.4), the central receiver variable of land grabbing represents a key area for intervention. According to the aggregated map, this could involve addressing untitled land, land titling expectations, agricultural expansion and illegal armed groups. Roads, weak institutions and lack of governance were also important land grabbing drivers, in conjunction with colonisation culture (the customs surrounding land clearance brought to the territory by 20th century colonists). This suggests that territorial consolidation by the government can be usefully supported by addressing both infrastructural and cultural factors as well.

The Director of Parques Nacionales Naturales described Governmental investigations into the ‘mafias’ to which every key informant attributed the issue of land grabbing. Importantly, the SINCHI Researcher distinguished the small-scale clearance of 1–5 hectares per year by campesino families from mafias, which clear 100 ha in 3–4 weeks. While there is a need to address this prominent land grabbing technique (Lizcano, 2018), the lack of focus on ‘mafias’ in the maps could illustrate variation between the ways in which national policymakers and local stakeholders can perceive the same issues (Kingdon, 1984). Critical evaluation of other land grabbing forms mentioned in the local focus groups, for instance on behalf of multinational companies, is therefore also important to avoid policy misfits that fail to address reported stressors (Bunce et al., 2010).

For example, the rancher group discussed and eventually removed the oil industry variable from their map, explaining:

Thank God, they have not arrived here yet. We hope they never will.

The sentiment is clear, as is that of the Siona group protesting oil exploration on their reserve in neighbouring Putumayo. With every key informant listing Indigenous practices, reserves and their traditional ecological knowledge as key to forest fire mitigation, violation of Indigenous land rights must be treated as seriously as other forms of land grabbing. Any other approach risks extending Colombian land reform’s unresolved bias towards local elites to multinational corporations (Bucheli, 2006; Grajales, 2011).

4.3 | Lack of investment in basic public services

Lack of investment in basic public services appeared as a central ordinary variable, reflecting similar priorities identified by smallholders in Brazil (Carmenta et al., 2013). It directly drove lack of governance, illegal armed groups and extensive cattle ranching, while contributing to poor road conditions and unsustainable ranching methods. Ranchers described how the lack of investment in road maintenance drove farmers to choose livestock over arable agriculture, which requires better transportation infrastructure:

If you need to sell an animal, you can take it by foot; you don’t need the road, [...], but if we are going to plant, for example, cassava and plantain here, we end up getting stuck with them.

Smallholders have explained the proliferation of cattle ranching in the Brazilian Amazon with similar reasoning (Pereira et al., 2016). In Guaviare, ranchers particularly stressed the damage suffered by roads as climate change intensifies flooding, indicating that the map’s feedback between climatic phenomena and road deterioration could stimulate further extensive ranching, if road maintenance is not improved. However, all such conclusions should take into account the uncertainty implicit in the map’s contested opinions over the connection between roads and ranching.

Although the projected expansion of Caquetá’s road network (Foro Regional, 2018–2022) could facilitate alternative livelihoods reliant on connectivity, new roads expose forests to destructive exploitation (Laurance et al., 2009), and should be supplementary to rural reform and distributional improvements. Otherwise, the aggregated map indicates that road development should be exercised with extreme caution, prioritising maintenance over expansion to avoid ‘uncontrolled colonisation’ (Clerici et al., 2019).

4.4 | Lack of governance

The central ordinary variable of lack of governance was driven by weak institutions and the lack of basic public services. The former President also made this connection when describing ‘the lack of judicial action against forest fires, (...) which has to do with lack of territorial control and lack of adequate institutions’. By contrast, a rancher described how guerrilla groups limited forest burning and clearance before the peace agreement:

They had control of the area, [...] there was no government or military presence [...], and if you did not comply with the rules as they gave them, it was immediate banishment, or death.

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Interview with Julia Miranda Londono, Director of PNN.
While there is no doubt these human rights violations outweigh any potential conservation gains, the power vacuum left by the FARC has allowed habitat destruction to continue largely unchecked (Clerici et al., 2019). Some ex-combatants have even returned to arms from dissatisfaction with the promised amnesty (La Nación, 2018b), and such key conditions of the peace agreement must clearly be fulfilled to prevent dissenion and further social and environmental harm (El País, 2019; UN News, 2019). Conflict rekindling could exacerbate the lack of governance, as well as illicit crops, another wildfire driver in the map (Davalos, 2003).

The PNN Director also highlighted the new National Land Agency as ‘a very important institution; very weak, but very important’, which is currently unable to resolve Colombia’s land rights issues due to the lack of governance. However, the map’s ‘local organisations’ and ‘NGO’ variables indicate that such institutional vacuums can be partially alleviated by non-governmental organisations including Centro de Pensamiento Anticorrupción (CEPAC) and the United States Agency for International Development. Nonetheless, these alternatives will not remove the need to strengthen institutions and territorial governance; Parques Nacionales Naturales’ ratio of 50,000 ha to each ranger remains well below international standards (Washington Post, 2018).

### 4.5 Unsustainable ranching methods

This ordinary central variable referred to the lack of technical education in more sustainable livestock management practices, such as that offered by an agroecological training partnership between the Centro de Pensamiento Anticorrupción, ETH Zurich and two Colombian universities. While these initiatives were praised by ranchers who had access to them, their reliance on international partners combines with the prohibitive expense of techniques such as pasture rotation and trail verge management to limit their current scale.

Although the National Development Plan promises renewed investment in rural sustainability (Mintransporte, 2019), local authorities’ use of the conditional tense (e.g. ‘more social investments [...] would permit the implementation of silvopastoral and agroforestry methods’) to describe this implies it is not yet felt. On the contrary, ranchers explained how perverse investments in ranching disincentivised 84 campesinos with voluntary conservation agreements:

> There are no credits for these campesinos. Why? Because they have forests, which mean nothing for entities like the bank which lends these. [The bank] says: “no, you don’t have anything because you have forest”, but if a person were to have livestock: “Ah, yes, of course!”

This institutional encouragement towards land clearance for unsustainable ranching is indicative of the rigidity traps that arise from prioritising homogenous production systems over the maintenance of heterogeneous landscapes (Carpenter & Brock, 2008). The cattle ranchers even went so far as to designate their profession ‘a necessary evil’. Improved credit access could incentivise landowners to preserve, rather than clear forests, and finance sustainable ranching techniques currently described as prohibitively expensive.

### 4.6 Untitled land

Extensive literature explores the ongoing land rights disputes influencing Colombia’s conflicts, including the unequal distribution of property, the difficulties of formalising land ownership in rural communities and communities’ violent displacement from their territories (Botero, 2016; Latorre, 2015; Valencia Agudelo, 2017). Such insecure land rights negatively affect smallholder productivity and resource conservation (Godfray, 2013).

Stakeholders saw abandoned land resulting from previous armed conflicts as directly perpetuating land grabbing, lack of investment in basic public services, forest fires and colonisation culture (Colombian Constitutional Court, 1995; USAID, 2013). All key informants stressed the issue’s complexity, as the Director of Parques Nacionales Naturales described:

> Knowledge about the property of the land, is very, very small, [...] without knowing where is the land, who owns the land, who is the real owner of the land, you will never be able to give the solution.

The status of this untitled land exacerbates expectations of land titling, which the SINCHI Researcher explained in the context of the reserve sustracción (subtraction) process. This describes the state’s degazettement of certain forestry reserves in Caquetá and Guaviare in the late 20th century. The historic practice continues to incentivise land seizure:

> People who are not from the territory and who see these untitled lands, see that they can invest a million [COP] per hectare to deforest, knowing that supposedly the state is going to come and is going to legalise that as well.

The Director of Parques Nacionales Naturales described state-led efforts to halt this, which can be supported by readdressing the expectations stimulated by previous policies such as the parcellation of public lands and sustracción (Congress of Colombia, 1959; Decreto 2811 del 18 de Diciembre de 1974, 1974).

### 4.7 Strengths and limitations

Participative mapping offers many advantages for social–ecological research, including the ability to integrate knowledge from varied stakeholders (Gray et al., 2014) and even to infer future scenarios (Firmansyah et al., 2019; Gray et al., 2013). Broad agreement on
central variables across stakeholders and data collection methods suggests that the method can synthesise key trends in stakeholder perspectives around resource management in remote post-conflict regions of the Global South. However, the semi-quantitative nature of the map makes it unable to determine quantitatively which variable is ultimately the most influential in the evolution of the system.

Researchers made several assumptions during the condensation of factors into 36 variables, which are documented in supporting information (Appendix S1). Doing so may have limited the number of factors and relationships involved, and therefore additional areas of agreement or disagreement, as well as the centrality of some variables, particularly lower ranking factors and peripheral relationships. Maps were taken as accurate representations of stakeholders’ views, notwithstanding the literacy and time constraints facing some participants. The circular layout of the variables on paper, which was chosen to encourage a less biased and more systematic approach, may also have limited additional factors and complex interconnections to a sparser map than the system actually perceived.

Although the 13 True transmitter variables may indicate perceptions of a rigid ‘top-down’ system (Vasslides & Jensen, 2016), numerous transmitters can also suggest underdeveloped causal relations (Martinez et al., 2018). Additionally, the structures of maps which were split between different individuals for variable selection and map construction are only a true reflection of those involved in the latter phase. Maps should therefore be interpreted as indicative and subjective simplifications of the system in question.

5 | CONCLUSION

Participative mapping of the system driving wildfire occurrence in three PAs of Colombian Amazonia reveals the perceived influence of extensive and unsustainable cattle ranching, land grabbing, untitled land and the lack of governance and basic public services. Both local stakeholders and key informants agreed on the importance of these variables, as well as the interlinked ecological variables of deforestation and increased climatic phenomena.

Although the peace agreements’ aims to strengthen territorial control and promote rural development intersect with the stakeholders’ aggregated perspectives, the map revealed the contested nature of variables such as roads and their changing relationship to forest fire occurrence when implemented in conjunction with other forms of development. With cattle ranching strongly affected by access to basic public services and rural connectivity, this study reveals the importance of holistic development that addresses systemically important variables such as territorial control, rural economic alternatives and the titling and distribution of land (Armenteras, Negret, et al., 2019). Systemic change may involve readressing the legacies of agrarian colonisation that continue to drive Amazonian forest fires.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHORS’ CONTRIBUTIONS

C.A.T., I.O.M. and D.A. conceived the ideas and secured funding; C.A.T., I.O.M., T.D. and D.A. designed the methodology; C.A.T., L.O.-C., G.A.G.G. and M.C.M.E. collected the data; C.A.T. and I.O.M. analysed the data with significant input from Devisscher; C.A.T. and I.O.M. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Interview transcripts are not available due to data privacy agreements made with the participants. Participative maps and all other data are available in Dryad Digital Repository https://doi.org/10.5061/dryad.cz8w9gj3n (Tebbutt et al., 2021).

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