

Community owned solutions for fire management in tropical ecosystems: case studies from Indigenous communities of South America

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Abstract

Fire plays an increasingly significant role in tropical forest and savanna ecosystems, contributing to greenhouse gas emissions and impacting on biodiversity. Emerging research shows the potential role of Indigenous land use practices for controlling deforestation and reducing CO₂ emissions. Analysis of satellite imagery suggests that Indigenous lands have the lowest incidence of wildfires, significantly contributing to maintaining carbon stocks and enhancing biodiversity. Yet, acknowledgement of Indigenous peoples' role in fire management and control is limited, and in many cases dismissed, especially in policy-making circles. In this paper, we review existing data on Indigenous fire management and impact, focusing on examples from tropical forest and savanna ecosystems in Venezuela, Brazil and Guyana. We highlight how the complexities of community owned solutions for fire management are being lost as well as undermined by continued efforts on fire suppression and firefighting, and emerging approaches to incorporate Indigenous fire management into market, incentive-based for climate change mitigation. Our aim is to build a case for supporting Indigenous fire practices within all scales of decision-making by strengthening Indigenous knowledge systems to ensure more effective and sustainable fire management.

Keywords: Indigenous fire management, community owned solutions, policy-making, Venezuela, Brazil, Guyana

Introduction

Environmental management and governance across the developing world is facing an unpredictable and dynamic future, with challenges from entrenched poverty and inequality, slow progress and unintended consequences of national and international development policy, and rapid changes in the natural environment itself. At the same time, there is growing evidence for the fundamental role of Indigenous land use practices in controlling deforestation, reducing CO₂ emissions and enhancing biodiversity. The United Nations [1] recognises that there are over 370 million Indigenous people in at least 90 countries, still undertaking unique practices distinct from those of surrounding dominant societies. Emerging research shows the fundamental role of Indigenous land use practices for controlling deforestation and reducing CO₂ emissions – analysis of satellite imagery suggests that Indigenous lands have reduced rates of deforestation and habitat conversion, and lower greenhouse gas (GHG) emissions, compared to surrounding areas [2-5]. Stevens et al. [6], for example, found that in Bolivia, from 2000 to 2010, only 0.5 % of Indigenous lands were deforested, compared with 3.2 % overall in the Bolivian Amazon. Rates of deforestation were thus six times lower in Indigenous lands compared to other forests. In another study in the Brazilian Amazon, Petersen and Stevens [7] found that from 2000 to 2012, forest loss was only 0.6 % inside Indigenous lands compared with 7.0 % outside. Thus more than 10 times lower. Carranza et al. [8] show that in the Brazilian *cerrado*, Indigenous lands experienced lower habitat conversion during 2002 to 2009 than did matched unprotected sites. Similarly, Flantua et al. [9] observed that in the western Indigenous Pemón inhabited sector of Canaima National Park, Venezuela, deforestation rates between 1986-2006 were considerably low at -0.037% (associated with traditional farming), compared to the 10 km unprotected buffer zone (-0.17%) and average national rates (-0.63%).

The growing empirical data providing evidence for the sustainability of Indigenous peoples' practices in environmental management has prompted much work on power-sharing arrangements, decentralised resource governance, and community-based natural resource management [10], as well as calls to recognise divergent values, participation in political decision-making and equitable distribution of benefits [11]. Yet, although there is increased presence of Indigenous peoples and other marginalised local communities in policy mechanisms [12], Indigenous practice and knowledge is still marginalised in research, development and policy-making circles, primarily as a result of ontological differences i.e. a mismatch in cultural understandings between Indigenous and non-Indigenous perspectives [13].

For example, analysis of information sharing in the current REDD+ process in Indonesia found a disconnect between governmental, transnational, and domestic civil society organisations [14]. This suggests that multiple perspectives are unlikely to be fully integrated, and that groups may regard one another as information sources lacking in credibility and legitimacy. In other studies, scale-related challenges of ignorance (e.g. national policies adversely constrain local policies), mismatch (e.g. differences in institutions governing resources and the biogeophysical scale of the resource), and plurality (e.g. failure to recognise differences in perceptions and values) have been identified as barriers to information

exchange [15]. The way discourses derived from ontologies are formulated into practical interventions is also particularly important for Indigenous peoples, whose knowledges, values and practices in natural resource management are currently undergoing significant change across the world.

The current dominance of market based instruments (MBIs), such as Payments for Ecosystem Services (PES) including REDD+, means that Indigenous peoples and other marginalised communities are at the forefront as 'implementers' of these environmental (and associated climate change mitigation) policies [12]. In the context of PES and REDD+, this is not only through receiving funds to maintain sellable and tradable 'ecosystem services', but also to monitor, report and verify the status of the environment to fulfil state obligations to international funding organisations. Yet, although MBIs espouse a range of creative and innovative solutions to environmental management, critically, their ideological foundations within a neoliberal agenda which promotes "selling nature to save it", is in stark contradiction with Indigenous ontologies based on human-nonhuman-spiritual relationships¹³. Recent studies indicate that in practice, MBIs not only escalate inequalities through privileging elites and intermediary organisations, but also fall short in 'permanence' as a result of lack of land tenure, corruption and the failure to defend community land rights from competing interests [16]. In addition, financial incentives through MBIs have the potential to actually 'crowd out' pre-existing intrinsic environmental motivations and ethics, changing Indigenous value systems [16-17]. This all reveals an intention to assimilate Indigenous culture into the dominant and Western economic model, rather than supporting self-affirmation of Indigenous identity and autonomy [18].

Within this wider context of environmental governance and Indigenous practices, the use and management of fire continues to be a much debated and controversial topic. In the last decade, devastating wildfires have wreaked havoc on many tropical forest and savanna ecosystems, including those in the Amazon Basin. Carbon cycle studies of the Brazilian Amazon show that its current net carbon sink (net biome productivity, NBP) of +0.16 (ranging from +0.11 to +0.21) PgCyear⁻¹, equivalent to 13.3% of global carbon emissions from land-use change for 2008, can be negated or reversed during drought years (NBP = -0.06 (-0.31 to +0.01) PgCyear⁻¹), with forest fires likely to be the dominant flux (48.3% relative contribution) of carbon during extreme droughts [19]. South America had the most important contribution to carbon emissions (37% between 1997-2009), particularly associated with post-clearing land use for pasture or soy plantations in the Brazilian Amazon, which represents a higher combustion completeness not compensated by regrowth on decadal time scales [20]. Thus, climate change, deforestation and the expansion of agriculture are the major drivers for the increasing scale and frequency of wildfires in the region, and although national laws attempt to prevent and control the use of fire, the extensive burning of the landscape signifies a mismatch between fire policies and burning practices [21]. With a growing recognition across the world that combatting landscape fires is not only ecologically, but also socially and economically unviable, drawing on traditional Indigenous fire management could be a useful lens through which to find practical fire management solutions, but also lessons on how environmental governance could be structured and implemented more widely.

In this paper, we review existing data on Indigenous fire management, focusing on examples from tropical forest and savanna ecosystems in Venezuela, Brazil and Guyana (Figure 1), countries in which we, as authors, have considerable fieldwork experience. We highlight the key attributes of fire management techniques stemming from Indigenous communities themselves i.e. community owned solutions for fire management, and some of the challenges. We then go on to review institutional responses to fire management, and current approaches linked to climate change and MBIs. The aim of this paper is to reflect on the current situation of Indigenous fire management, and present possible ways forward.

INSERT FIGURE 1

State of play on Indigenous fire management

Fire is used by Indigenous peoples for a variety of purposes that have interconnected ecological, social and spiritual importance (Table 1). These have been well documented by studies across the world and include agricultural and pastoral use, hunting, gathering, fishing, stimulating vegetation growth and abundance, clearing vegetation, habitat protection, domestic use, and medicinal/healing and spiritual use [22-24]. Huffman [25], assessing traditional fire knowledge documented in 35 studies, including accounts from 27 countries on 6 continents, proposes a typology of traditional fire use and associated knowledge based on the economic system of burning, or the agro-ecological type. These are: swidden - rotational farming through clearing and burning small forest patches; arborist – fire is used to maintain trees either in groves or individually, sometimes for stimulating fruit production and/or maintaining sacred sites; tame pasture - fires are used to maintain forage for domestic livestock in delineated pastures, and; open native vegetation - fire is used in unconfined areas of expansive native vegetation for hunting, gathering, nomadic pastoralism, clearing travel routes, maintaining village sites, communication, etc.

INSERT TABLE 1

Various studies show how fire use takes place at different times during the seasonal calendar in relation to particular livelihoods and resource management activities, and that this relates to finely-tuned Indigenous understandings of different environmental and climatic indicators. For example, many Indigenous groups throughout lowland South America traditionally have timed their agricultural cycles to the appearance of the Pleiades stars in the early evening and their movement across the sky [27]. The timings of fire are also aligned to phases of the moon. Importantly, the numerous uses of fire mean that burning is a relatively constant activity, particularly during the dry season, generally at low-levels, thereby helping to prevent the build-up of flammable fuel and the incidents of large-scale uncontrollable wildfires [23]. Experimental studies of fire behaviour suggest that this patch mosaic burning not only reduces the occurrence of dangerous fires, but also increases spatial and temporal vegetation heterogeneity and biodiversity [28-29].

Indigenous fire management is effective in that it is an emergent property of a linked social-ecological system where Indigenous knowledge and culture, and associated livelihoods, are intimately interconnected with landscape management practices. For example, the Mebêngokrê (Kayapó) of the Capoto-Jarina in Mato Grosso, Brazil, use fire to hunt for land tortoises which form part of an extended yearly traditional festival with implications for social processes including courtship, community cohesion, youth initiation and inter-generational knowledge transfer (Mistry and Berardi, personal observation). For the Pemón, the practice of Mayú - a system of mutual cooperation in the elaboration of large-scale tasks in traditional farming e.g. cutting trees and burning the felled biomass - is not only essential for the survival of individuals, but also a social interaction facilitating the formation and establishment of social bonding and inter-generational knowledge transfer (Bilbao, personal observation). Therefore, savanna and forest ecosystems are being protected within Indigenous lands not because they are being 'managed' in a direct and active way, but as the indirect outcomes of a healthy social-ecological system i.e. the outcome of practices that maintain social and ecological integrity, or what can be termed "community owned solutions" [30] (p.10).

Challenges for Indigenous fire management

As stated above, Indigenous fire management, as with other Indigenous practices, is strongly tied to Indigenous knowledge and culture, as well as local governance structures and processes, which in turn are based on leadership and collective actions. For example, Mistry et al. [23] explain how the social structures within the Krahô of Brazil determine the leaders or 'knowledge-bearers' for fire, the Wakmejê, who decide on the different aspects of the fire burning regime during the dry season. Every morning at sunrise, the Wakmejê men meet at the centre of the village (the 'ka') to discuss the day's activities, and depending on the time of the season, the group decides on the course of action. Welch [31] describes how, within the Xavante of Brazil, young mentors and elders help to encourage active learning and entrust younger people to assume responsibility for their own acquisition and production of knowledge pertaining to the ecology of fire use, the burning calendar, and associated group hunting strategies and ceremonies.

However, the current status of traditional fire management within Indigenous communities can be associated with inter-related issues of a general loss of knowledge, a breakdown of social cohesion within communities, and conflicts (particularly ideological) between Indigenous and non-Indigenous stakeholders.

Amongst the Krahô, Brazil, for example, most burning occurred in groups and with the consensus of fire knowledge bearing individuals. However, many younger Krahô men that had been influenced by outsiders, namely farmers of European descent, openly criticised burning during communal meetings, resulting in many early season protective and resource enhancing fire practices not being implemented [23]. At the same time, because the fire practices of individuals were not under the scrutiny of the group, these continued to be used, mostly in the late dry season resulting in increasingly damaging fires that reinforced antagonisms against fire use. This was being exacerbated by the incidents of poachers coming into their land and using fire in the late dry season.

Evidence from the savannas of the South Rupununi, Guyana, suggests that landscapes may be subject to too many later dry season fires and not enough savanna patch burning and forest-edge burning in the late wet season and early dry season as was traditionally done [26]. The causes of this increase in dry season fires were multiple and included changes in farming and hunting practices, an increase in the number of privately owned cattle, a lack of agreement amongst the different villages and with cattle ranchers over the use of fire for cattle grazing, and a general loss of fire knowledge by young people. For example, it was suggested that the increased burning by *vaqueros* (cowboys) in relation to pastoral and rodeo activities during the dry season was a result of young *vaqueros* no longer having the knowledge on how to use fire sustainably. At the same time, young Wapishana and Makushi and some community leaders were more critical about the use of fire as they had more regular contact with state natural resource management officials and environmental organisations that promoted anti-fire discourses [26]. As with the Krahô, changing Indigenous values to focus on fire prevention and suppression could have the effect of making the problem worse.

In Roraima, Brazil, traditional practices in the use of fire for agriculture by Indigenous communities (Ingaricó, Macuxi, Patamona, Taurepang, Wapichana and others) have been strongly criticised by governmental institutions, who have developed several initiatives to replace clearing and burning with the use of tractors under the slogan "technology is white, not Indian" [32]. Amongst Pemón communities of the Canaima National Park, Venezuela, many young people have been critical of traditional fire use, largely due to a loss of traditional knowledge coupled with environmental education programs focusing on fire control run by state resource managers from the National Parks Institute (INPARQUES) and the Caroni Electricity Company (formerly EDELCA, now CORPOELEC) [33]. These intergenerational divides between young Pemón and elders has led to a decline in prescribed burning, which in turn has led to a build-up of flammable biomass and an increase in large-scale wildfires in the late dry season in some areas of the Gran Sabana [34-35].

According to Huffman [25], the status of traditional fire knowledge can be defined as: robust – fire systems that have persisted and continue to evolve over time, allowing for some changes in continuity but remaining essentially intact until today; declining – where traditional fire knowledge still exists within members of a given culture, but in which demographic, economic, political, land use, or other changes threaten its continued viability; rejuvenating – where active efforts are underway to both recover or to share traditional fire knowledge in landscapes in which traditional fire management was once the norm; or, historical – where active fire management is no longer practiced and most traditional fire knowledge is largely historical, preserved in written, graphical, or anecdotal accounts. Although we know that Indigenous groups from different localities have in-depth contextual knowledge on fire management, we also know that traditional fire knowledge is declining. Lehman [36], in the case of reviving burning practices of the Palawa of Tasmania, indicates that although there was enthusiasm for re-establishing early dry season patch burning, these went out of control. Rejuvenating traditional fire practices in the short term is not easy or straightforward when settled and westernised Indigenous communities may have lost

the depth of understanding developed over a thousand generations of living with the land.

There are concerns on how and to what extent existing knowledge is being or can be adapted to meet needs as local social-ecological systems change. For example, there are Indigenous observations of changing fire regimes in response to changing rainfall patterns - appearance of the Pleiades star has become or is becoming an unreliable indicator of the onset of the rainy season - with forests becoming drier and burning more easily and to a greater extent [24]. In addition to larger forest and savanna fires during droughts, evidence from the South Rupununi, Guyana, indicates that changes in weather patterns could also be affecting the extent to which prescribed fire practices are carried out at the end of the rainy season in order to be prepared to manage fires in the dry season [26]. Nevertheless, Bliege Bird et al. [37] show that there are dynamic interactions between people and climate at the landscape level, with Aboriginal hunters buffering the impacts of climate variability with dramatically smaller but more numerous fires in dry cool conditions.

Another important but little discussed area is the impact of invasive species on fire regimes within Indigenous territories. Bardsley and Wiseman [38] point to the growing evidence that the invasive plant species, buffel grass (*Cenchrus ciliaris*), has already reduced biodiversity in areas where it is well established, and is beginning to alter fire management practices in Anangu territory in South Australia. In Brazil, we have seen the growing presence and spread of introduced pasture and invasive species such as *Brachiaria decumbens* within Indigenous territories, and subsequent higher intensity fire events leading to forest degradation (Mistry and Berardi, personal observations). Climate change will only exacerbate these fire and invasive species interactions by, for example, increasing dry biomass loads of these fast growing non-native species, especially during La Nina years of high rainfall, especially in areas where seed of pasture grass is already abundant [39].

Institutional approaches to fire management

Until recently, the paradigm of 'zero fire' was the norm in many areas of the world including Venezuela, Brazil and Guyana. All fires were seen as a threat to biodiversity conservation and natural resources management, and the institutional response was to suppress the intentional lighting of fires, and when these did occur, to 'fight' or 'combat' fire through policies supporting fire suppression/protection and fire-fighting [28, 40]. Colonial explorers, missionaries, and naturalists were the first to advocate a negative narrative of traditional fire use as degrading and harmful to the environment, exacerbated in recent years by scientists, the media, politicians, and tourists [41]. In the Gran Sabana, Canaima National Park, Venezuela, for example, the derogatory phrase 'Pemón Los Quemones' (crudely translated as 'Pemón the Pyromaniacs') has generated considerable conflict over fire management between state resource management actors and Indigenous peoples, reflecting wider Indigenous struggles over territorial land claims and self-determination [33]. Similarly, the conservation discourse in Brazil which has historically believed that all anthropogenic burning, including Indigenous, is destructive, has also been widely adopted by powerful interest groups such as the 'Ruralistas' (bloc of large pro-

agrobusiness landowners) as part of the political narrative contesting Indigenous rights to land [5]. This is in the context of international climate change mitigation strategies such as REDD+ in which fire's association with deforestation, whether small-scale through Indigenous shifting cultivation, or large-scale through logging and agricultural expansion, is under scrutiny for compromising carbon permanence and undermining the potential of sustainable forest management [42].

Venezuelan policy environment

Venezuela has one of the most progressive Indigenous rights regime in South America. It is the only state in South America that officially recognises, within its constitution, Indigenous peoples' rights to maintain their own production practices, protects collective intellectual property of knowledge, technologies and innovations [43]. Specific legislation focusing on Indigenous communities, such as the 'Ley Orgánica de Pueblos y Comunidades Indígenas' [44] has also strengthened Indigenous rights to genetic resources and ancestral knowledge. Despite the progressive constitution and regulations, and the relative protection of Indigenous rights in national parks, the use of fire is still heavily restricted and combated (Art 65, Ley Penal del Ambiente) [45]. National parks have priority measures of protection and the National Institute of Parks (INPARQUES) is the highest administrative authority in charge of their management and conservation. INPARQUES, created in 1978, is an autonomous body ascribed to the Ministry of Eco-Socialism and Waters (MINEA, formerly Ministry for the Environment and Renewable Natural Resources). Thus the environmental authorities are in charge of the prevention and control of fires.

In 1978, a Program for Prevention and Protection Against Forests was created to impart knowledge, experience and skills for training forest rangers, but it was only in 2001 during the Presidency of Hugo Chavez, that the Law of Fire-Fighters and Civil Emergency Management (Ley Cuerpos de Bomberos y Bomberas y Administración de Emergencias de Carácter Civil) [46], was enacted, promoting, some years later, the graduation of the first professional forest fire-fighters in the country. This law also gave rise to the Unified National Command against Forest Fires, to coordinate the different entities - MINEA, INPARQUES, the Bolivarian National Guard and Civil Protection, regional and local bodies – during the dry season to prevent and mitigate fires in the country.

One of the firefighting programs in Venezuela with the longest trajectory and better endowed in terms of equipment and infrastructure (helicopters, airplanes, landing strips, guardhouses, etc.), is the Control of Wildfire Program (PCIV), implemented by the 'Initial Attack Brigade Carlos Todd' of CORPOELEC (the regional hydro-electrical company). The PCIV was created in 1981 to prevent, detect, and fight wildfires in order to protect the headwaters of the Caroní River which supplies the Guri Reservoir and the 'Central Hidroeléctrica Simón Bolívar', where 70% of the country's hydroelectric power is generated. 21,000 km² of this highly protected area is located in the Gran Sabana and includes the eastern sector of Canaima National Park [47]. Although members of the PCIV brigade are Indigenous Pemón, Indigenous knowledge has not been used in firefighting practices, and fire exclusion has been the official fire policy adopted in the Park. In spite of carrying out expensive and enormous fire suppression efforts, on average only 13% of total fires are combated due to the high number of fires over a large area [48]. Moreover, the Pemón use fire

in their daily activities, constituting an essential part of their cultural identity and contributing to their livelihood needs [49]. Thus, the conservation policies undertaken in the past few decades in the Canaima National Park (reflecting the national context) have not only been based on the exclusion of fire, but have also largely ignore the perceptions, expectations, and knowledge of its inhabitants, which has led to serious conflict between the Pemón people and government agencies.

Brazilian policy environment

In Brazil, the Forest Code (first issued in 1934, and most recently revised in 2012) was the first piece of legislation to make burning without specified precautions illegal (Art. 22) [50]. In 1989, decree No 97.635 regulated article 27 of the Forest Code, and created the National System of Prevention and Control of Forest Fires (PREVFOGO). The aim of PREVFOGO was to support the monitoring, prevention and combat of forest fires, and to develop and disseminate technical training and education in fire control. However, although fire was mentioned in various environmental governance laws, it did not appear in specific regulations until 1998, following the large forest fires in Roraima induced by the 1997-1998 El Niño Southern Oscillation. The national and international outcry from these fires prompted the federal government to create decree No.2661 redefining the role of PREVFOGO and for the first time, establishing detailed procedures on the use of prescribed fires. In addition, a series of new fire policies and management initiatives were introduced, including the Program for Prevention and Control of Fires in the Brazilian Amazon Forest (PROARCO) with the main goal of controlling and preventing large-scale wildfires in the Brazilian Amazon.

Since then, fire management has been mostly subsumed within the climate change agenda, through the 2009 National Climate Change Policy and its programs which include the Program for Combating Deforestation in the Amazon (PPCDAm), the Program for Combating Deforestation and Forest Fires in the Cerrado (PPCerrado), state level plans and the Low-Carbon Agriculture Plan (ABC) [51]. For example, under PPCerrado, the 'Projeto Cerrado/Jalapão' aims to improve the prevention and control of irregular burning and forest fires in the Jalapão region, thus contributing to the maintenance of the Cerrado as a globally relevant carbon sink [52]. Activities include training, awareness raising and environmental education, implementation of demonstrations of alternatives to the use of fire, and the strengthening of state committees for preventing and fighting fires. In addition, the project has been testing an integrated fire management ('*Manejo Integrado do Fogo*', MIF) approach based on prescribed early dry season burning to create patchy landscapes and reduce the probability of large late dry-season fires. MIF was applied in 2014 within three conservation areas - the Jalapão State Park (Tocantins), the Ecological Station of Serra Geral do Tocantins (Tocantins) and the Chapada das Mesas National Park (Maranhão). The main objective was to inform controlled burning activities by observations from satellite sensors indicating the degree of biomass desiccation across the landscape, accompanied by simultaneous biomass and fire measurements in the field. The approach, in this case, was to identify, in real-time, emerging small patches of drying vegetation appropriate for burning, which would

not spread easily into the surrounding more humid vegetation. Repeated use of this technique throughout the dry season would result in a mosaic of small burn scars, which would result in a reduction of all combustible biomass, while presenting larger and destructive wildfires from occurring. In 2015, the MIF was applied in the Xerente Indigenous Territory (Tocantins) following a study of traditional fire knowledge with elders of the community to develop a fire calendar and prescribed burn planning using remotely sensed imagery combined with geoprocessing tools such as SAM (Spectral Angle Mapping) [53].

The results of MIF are still forthcoming, but they do show a change in approach within Brazilian institutions. Not only is there a move away from categorising all fire as 'bad', there is also a recognition that Indigenous fire knowledge is a valid form of knowledge that could inform policy-making. Nevertheless, efforts to actively involve Indigenous people in fire management has to date mostly been in the form of fire brigades. There are currently 34 Indigenous Brigades employed during the dry season period to help combat fires [54].

Guyanese policy environment

In Guyana, fire has been inextricably linked with forest management and timber extractive activities. As a driver of deforestation, fire has been implicated in the recent REDD+ activities through which Guyana aims to implement its Low Carbon Development Strategy (LCDS); a national plan to reorient Guyana's economy on to a low-carbon path [55]. The latest Readiness Preparation Proposal for REDD+ [56] outlines national level activities to be conducted to achieve readiness for the implementation of a forest carbon financing mechanism, and includes the formation of a national forest fire management strategy (p.62). Rodríguez et al. [26] report on the launch by the Guyana Forestry Commission of a pilot dry season fire monitoring programme in various communities of the South Rupununi in November 2010, and a recent aerial fire assessment took place in the same locations by the Ministry of Natural Resources and the Environment [57]. However, there has been little evidence that any fire management policy has been developed to date, and there seems to be no recognition within policy-making of traditional fire use in savannas by Indigenous groups.

Emerging market based instruments integrating Indigenous fire management

The case of Australia is heralded as a progressive example in which Indigenous fire knowledge is being incorporated into market based instruments for fire management that includes goals for carbon cycling and reducing greenhouse gas emissions [58-59]. Savanna fire management in northern Australia, where early dry season prescribed burns are used to prevent late dry season wildfires, is an approved offset methodology under Australia's Carbon Farming Initiative (CFI) [60]. Australian Carbon Credit Units generated through the CFI can contribute to meeting Australia's commitments under international agreements to reduce greenhouse gas emissions.

For example, the Western Arnhem Land Fire Abatement (WALFA) and the Central Arnhem Land Fire Abatement (CALFA) projects are PES schemes that aim to reduce greenhouse gas emissions in the atmosphere while creating employment opportunities for Indigenous people in remote regions. WALFA is mainly funded by a subsidiary of the multinational ConocoPhillips, which aims to partially offset its emissions of greenhouse gases from a liquefied natural gas plant in Darwin (100,000 tons of CO₂ equivalent annually) against AU \$1 million a year for 17 years. This funding supports several Indigenous ranger groups located in western Arnhem Land, which work in collaboration with traditional owners of the region as well as fire ecologists. The multinational is thus seeking to reduce its carbon footprint and abate its greenhouse gas emissions, not by limiting its own production and release of such gases, but by funding fire management programs that are led by and benefit Indigenous people. The CALFA project is organized along the same lines as WALFA (though initially funded through public subsidies with private funding expected over the longer term), and involves several Indigenous ranger groups working in central and south eastern Arnhem Land.

The perceived success of the Australian experience of savanna fire management, particularly the WALFA case study and model (reducing greenhouse gas emissions by 30%) [61], has led to Australia funding an initiative through its aid budget to promote the international applicability of the fire management methodology and experience (see <http://www.unutki.org/>).

However, Petty et al. [62] show how these new emissions-reducing programs run the risk of further marginalising Indigenous people. Inherent in the nature of institutionalised management programs is to replace the complexity and contingency of Indigenous fire management with standardised goals, while treating Indigenous people as workers executing plans developed by others rather than as genuine partners. They suggest that the funding model for the WALFA project creates an incentive to focus on following a complex emissions-accounting methodology that *"...ties the practice of burning very tightly to the accounting of burning. This forces a close registering and recording of burning, whose metrics are then tied to an external scheme, and represents a dramatic shift in the character of Aboriginal fire management, which is rooted in place based knowledge, dynamic decision making, and attention to unique seasonal changes in vegetation"* [62] (p.157). The approach also creates a sub-group of Indigenous rangers, who are tasked to carry out systematic fire management in the early dry season at the behest of the institutions they represent. However, they are criticised by the community members for not having in-depth knowledge and applying too much fire carelessly, while at the same time are excluded from using the technocratic fire management resources for lacking of training and skills [63-64].

Indeed, in many countries, there is a reliance on technological applications as a solution to fire management, with a clear (and dominant) discourse aligned with geospatial technology where voice and power over decision-making is in the hands of those with the technology (e.g. scientists, governments) rather than those without (e.g. local farmers, Indigenous peoples) [40]. In a review of fire studies in tropical humid forest areas, Carmenta et al. [65] found that remote sensing techniques for detecting fire were favoured by resource/park managers and policymakers because

of their replicability and representation of a seemingly objective reality. Indigenous communities are excluded from this technocratic approach in that the overly simplistic remotely sensed 'reality' does not correspond to the multidimensional (spiritual, social, ecological) experiences as perceived by Indigenous people. Most importantly, the institutionalisation of Indigenous fire management, and its scientific and technocratic discourse strongly privileges one particular aspect of Indigenous fire management: early dry-season burning to protect against late dry-season burning [62]. This fails to recognise that Indigenous fire management is characterised by regular and sometimes opportunistic burning throughout the dry season linked to various social, ecological and spiritual purposes (as shown in Table 1), which can buffer the impacts of climate variability [37] and produce habitat mosaics that support landscape biodiversity [66-67].

A 'case' for supporting Indigenous fire practices within government fire management policy

Our review of the current literature on Indigenous fire management highlights the following:

- Fire is an integral component of savanna and forest landscapes worldwide.
- Some Indigenous people have detailed knowledge on fire management that could help prevent large-scale and destructive wildfires and associated land use change.
- Although there are examples of 'robust' Indigenous fire management, it is 'declining' in many areas leading to the increase of inappropriate and damaging fire occurrence. This is a result of the interplay between loss of Indigenous knowledge, a breakdown of social relationships and cohesion, and conflicts (particularly of worldviews) between Indigenous and non-Indigenous stakeholders.
- Incentive and market-based approaches run the risk of focusing on the management of isolated issues e.g. carbon storage, without adequate understanding of inter-relationships and inter-dependencies and thereby simplifying the complexities of Indigenous fire management. Associated perverse financial incentives could also 'crowd out' community cohesion and intrinsic values which are essential for effective Indigenous fire management. Requirements (from donors, states) for monitoring and reporting could remove control of fire management from Indigenous communities.
- Current fire policies, and associated institutional structures, strongly focus on suppression and fire-fighting, with Indigenous participation mostly in the form of institutionalised and 'professionalised' rangers/brigades. This runs the risk of marginalising the wider community, disrupting traditional modes of knowledge transfer and therefore loss of Indigenous knowledge, and conflicts between different sectors of the community.
- Attempts to institutionalise Indigenous fire management have focused on the use of early dry season fires at the expense of the complex and sometimes continuous burning throughout the dry season and in the wet season.

We can see from this that Indigenous fire management is being incorporated into policies through already established and clearly defined government schemes; *disincentivising*, command-and-control methods of fire-fighting through the creation of Indigenous fire brigades, and *incentivising* approaches focused on prescribed early dry season burning. Our contention is that although fire-fighting and early prescribed burning are necessary as part of an overall fire management strategy, there needs to be *enabling* policies which focus on legitimising and strengthening Indigenous fire management as a community owned solution. Critically, as community owned fire management is intricately linked with Indigenous survival strategies, so too must fire-fighting and prescribed burning be grounded in local social-ecological systems. We believe it is necessary to define long-term actions to support the integrated functioning and survival of Indigenous communities as a whole, rather than focusing on isolated issues (e.g. carbon retention) or benefits for some individuals (e.g. hiring Indigenous firefighters).

The 'State of the World's Indigenous Peoples' report [68] provides an insight into the differences in perspectives between worldviews. John Bamba, an Indigenous Dayak from Kalimantan, Indonesia, summarises the underlying principles for living a good life, based on the Dayak's traditional cultural values as sustainability, collectivity, naturality, spirituality, process-orientation, domesticity and locality. These are contrasted with prevailing modern values – productivity, individualism, technology, rationality, efficiency, commercialism, and globalisation – that have become predominant principles in present-day social and economic development and can undermine a balanced human-nature relationship. What we want to do is not promote one over the other, but encourage decision-makers to engage with, and appreciate, Indigenous perspectives and worldviews on fire management. Community owned solutions acknowledges collectivity, spirituality, process-orientation and locality, whereas many expert-led fire management interventions often result in promoting individualism, ethnocentrism, rationality, efficiency, commercialism and globalisation. The question we raise is this: can the 'community owned solutions' approach be the mechanism through which Indigenous perspectives can be represented within fire management?

Our aim now, focusing on Venezuela, Brazil and Guyana, is to bring together all parties involved in the fire decision making process - Indigenous people, policy makers, scientists, park managers, and private landowners – to share perspectives, and respect and support Indigenous survival strategies within which fire management is embedded, while at the same time contemplate the needs and constraints existing in the system to be managed, and develop action plans to make change. This process to integrate Indigenous fire practices within government fire management policy focuses on 'enabling' policies centred on legitimising and strengthening Indigenous fire management as a community owned solution in order to promote the empowerment of Indigenous communities and their active participation in decision making. Actions have to be aimed at encouraging Indigenous communities more autonomy with respect to implementing policies, including the leadership and funding of fire management programs.

Competing interests

We have no competing interests.

Authors' contributions

J Mistry led the drafting and finalising of the manuscript. B Bilbao and A Berardi contributed to sections, commented, edited and supported the writing process. All authors gave final approval for publication.

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Discussion

CRISTINA SANTIN (Swansea University, UK). During your presentation you emphasised the need of supporting Indigenous fire practices within government policies. Could you please comment on the fact that some of the Indigenous communities nowadays, especially the young generations, are evolving towards more Western life styles and, therefore, leaving behind fire as a traditional tool? Don't you think that the Western ideal of "leaving them like they used to be centuries ago" may contradict, sometimes, their actual wishes of moving towards a new type of society?

JAY MISTRY, BIBIANA BILBAO AND ANDREA BERARDI: It is important to make it clear that the 'community owned solutions' approach to fire management does not intrinsically favour fire management like it "used to be centuries ago" or prevent communities from evolving their fire management practices. Community owned solutions is essentially about control: who fundamentally decides which practices should be considered and applied within a locality? Is it non-Indigenous experts or is it Indigenous communities that depend on the local environment for their livelihoods? The approach in no way prevents communities from experimenting and adapting their practices. Indeed, the system viability framework which underpins the approach [69-70] encourages communities to explore the tensions between: resisting to temporary change or adapting to permanent change; becoming very efficient and successful at specialised practices or maintaining a wide variety of practices in a heterogeneous environment; focusing on self-interest or cooperating with others. The key is that any practice that emerges can be sustained by the community itself and is shown to provide long-term benefits for the community and its surrounding environment. This is what community owned solutions does. Communities are placed at the centre of the decision-making process rather than at its periphery. It might help to provide a Western example to bring home the point. One of the paper authors is Italian. Italians have been using tomatoes in their cooking since the fruit was bought from Indigenous communities in South America in the 16th century. Does cooking with tomatoes make Italians less Italian because they are using an Indigenous ingredient? Does that mean that Italians, at least in their cooking, have been 'Indigenised'? In fact, it's the opposite. Italians have elevated the use of tomatoes in cooking to a new level and have made it an integral part of their culture. And so too can 'Western' ideas and technologies for fire management be adopted and applied by Indigenous communities to successfully make them their own.

Table 1. Uses of fire by the Wapichana and Makushi people of the South Rupununi, Guyana (modified from Rodríguez et al.²⁶).

Use	Detail
Domestic	Cooking, heating and preserving food, warmth, light, cleaning around homes, burning rubbish, making and burning clay bricks
Medicinal/healing and spiritual	Preparing traditional medicines, healing (smoking out evil spirits), ceremonial practices, chasing away dangerous spirits or in some cases calling them (e.g. the rain spirits)
Safety	Clean paths, clear around houses, chase away dangerous animals (jaguars, snakes and mosquitoes),
Animal husbandry	Produce fresh green grass for grazing cattle, prevent cows from straying far away, find lost animals such as pigs, getting rid of ticks, branding cows, herding cows
Agriculture	Open new farms, fertilise and clean (weed) farms, chase away ant pests
Hunting and fishing	Flush out animals; as light
Gathering natural resources	Burn along swamps before cutting palm leaves to create space for drying leaves, smoking bees before collecting honey, stimulating certain trees to fruit
Protection	Prevent large fires entering forest-islands, farming areas, palm areas, homes, no-go zones; fight large hazardous fires when approaching (fighting fire with fire); burn potentially dangerous overgrown swamps and savannas
Communication	Signals in hunting, grazing, emergencies
Crafts	Shaping crafts e.g. heating, bending and straightening arrow canes, bows and fishing rods

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Figure 1. Map showing the geographical context for the Venezuelan, Brazilian and Guyanese Indigenous communities discussed in this article (kindly drawn by Jenny Kynaston).