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Indigenous Use of Fire and Forest Loss in Canaima National Park, Venezuela. Assessment of and Tools for Alternative Strategies of Fire Management in Pemón Indigenous Lands

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Abstract In Canaima National Park (CNP), Venezuela, a protected area inhabited by the Pemón people, socio-cultural and demographic changes have contributed to the apparent unsustainable use of fire, leading to forest and habitat loss. This over-use of fire, together with increased forest vulnerability to fire as a result of global climate change, could put both ecosystems and human well-being at risk. The conflict over fire use derives from the fact that whereas the Pemón depend for their livelihood on the use of fire for shifting cultivation and hunting, the policy of the CNP government agencies is fire exclusion (although this is not effectively enforced). Nevertheless, recent ecological studies have revealed that the creation of a mosaic of patches with different fire histories could be used to create firebreaks that reduce the risk of the wildfires that threaten the vulnerable and diverse savanna-forest transition areas. This technique imitates the traditional cooperative savanna burning strategies of the Pemón. By linking research on knowledge systems with management policies, the impasse over fire in the CNP might be avoided.

Keywords Fire ecology · Canaima National Park · Venezuela · Indigenous Pemón · Savanna-forest transition

Introduction

Canaima National Park (CNP) is at the center of the geologically ancient Guyana Shield in Venezuela (Fig. 1). Because of its geological and physiographical uniqueness, coupled with its many biological and cultural values, CNP was declared a UNESCO World Heritage Site in 1994. The CNP's 30,000 km^2 comprise an important part of the headwaters of the Caroní River, the main generator of hydroelectric power for the country (80%), helping to ensure its hydrological stability and conservation. The strategic and geopolitical proximity of this park to Guyana and Brazil, as well as the inclusion of a considerable part of the territory of the Pemón Amerindian indigenous people, were all important criteria for the creation of the CNP; however the ensuing confluence of a diversity of institutions and interests has created several management challenges (Rodríguez 2004a).

Although humid forest represents the dominant ecosystem in the CNP, it also contains a region characterized by a mosaic of savanna and forest ecosystems (Fig. 2a) called the *Gran Sabana* (Huber 1990; Huber and Febres 2000; Huber 2006; Delgado *et al.* 2009). The frequent occurrence of human-ignited fires in the Gran Sabana suggests that the savannas have an anthropogenic origin. For this reason, fires are considered a threat to the ecosystems since they may trigger forest substitution by treeless savannas, thus affecting the well-being of Pemón indigenous communities, the hydroelectric industry and activities carried out by other institutions and stakeholders in the CNP.

While many prominent stakeholders in Venezuela view fires as detrimental to the CNP's ecosystems, elsewhere in the world the last decades have witnessed a paradigm shift in perspectives on fire (Myers 2006; Shlisky *et al.* 2009). In short, at least in some ecosystems, fire is no longer considered harmful but part of the vegetation dynamics. Research in tropical savannas, in particular, has shown that although fire exclusion often results in a transition from savannas to closed forests, fire

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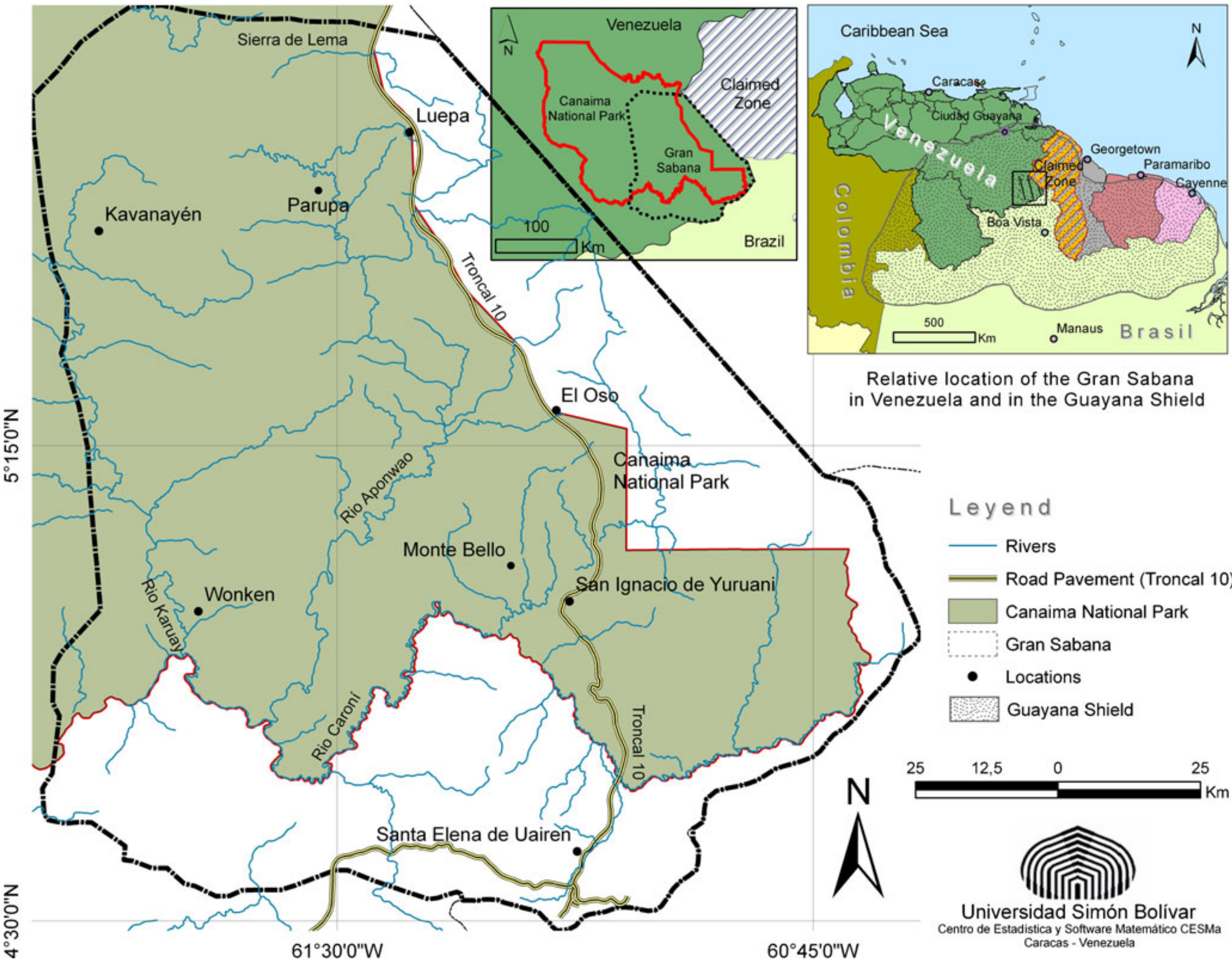

Fig. 1 Location of the CNP and *the Gran Sabana*, showing the study site and other localities cited in the text

suppression also leads to an increase in fuel loading, predisposing these areas to high intensity fires (Bilbao *et al.* 1996). Unfortunately, this view is ignored by most stakeholders and government agencies in Venezuela at least with reference to management policies in the CNP.

Here we review and analyze the present state of knowledge about the main causes of fires, the demographic and cultural changes that have caused a shift from traditional fire practices and the impacts of these alterations on forest cover. The assessment of the current state of the fire problem in the CNP is followed by a discussion of the results obtained in the savanna fire experiment, which could lead to the formulation of alternative strategies for fire management in the park. Results show that linking traditional and scientific knowledge seems to be the only way forward for the formulation of effective environmental policies that enable successful fire management in the CNP.

Background Information to the Fire "Problem" in the CNP: Indigenous Populations, the Role of Fire in Forest Loss, and Conservation Policies

The Pemón Population in the CNP

The Pemón Amerindians (belonging to the Carib linguistic family) are the traditional inhabitants of the CNP. Their name is self-designated and stands for "people" and was used in the first instance to distinguish them from neighboring ethnic groups (Armellada 1989; Colson 2009). The Pemón people consist of three sub-groups: Kamaracotos, Arekuna and Taurepán, located in the northwest, center and southeast of the CNP respectively.

According to the National Institute of Statistics, the total Pemón population in Venezuela in 2003 reached 27,000 (INE 2003). Over the last decades there has been a considerable increase in Pemón numbers as a result of both intrinsic population growth and immigration from neighboring areas. The overall population growth rate was estimated at 67% for the period 1982–1992. More than three quarters of the Pemón population live within the borders of the CNP with 17,000 of them located in the Gran Sabana region. CNP is thus the national park with the largest number of inhabitants in Venezuela (Medina *et al.* 2004). Because the Pemón Amerindians have a long history of occupation in what is now the CNP, at least for the past 400 years when their presence in this region was first documented (Armellada 1960), they consider this region as their own territory.[1]

Causes and Uses of Fire

Fire is one of the main and most widespread drivers of modern landscape dynamics in the Gran Sabana with frequencies of 2,000–3,000 fire events every year that burn an area of approximately 5,700–7,500 ha (Gómez *et al.* 2000; Ablan *et al.* 2005). Nearly 70% of detected fires start in savanna areas, but some cross the savanna-forest boundary causing forest degradation (Dezzeo 1994; Hernández 1999; Fölster *et al.* 2001; Dezzeo *et al.* 2004a, b). Fires in the CNP, as in other places in the tropics, are mainly of anthropogenic origin. Indeed, lightning strikes are not considered a significant cause of fire in the tropics because thunderstorms take place principally during the rainy season.

Fire plays an essential role in the Pemón way of life since many of their subsistence activities are associated with the use of fire. Some fire practices are related to everyday activities including: clearing the forest for cultivation, cleaning and removal of vegetation for the creation and maintenance of paths, visual communication, to keep dangerous animals away, and hunting and fishing (Galán 1984; Gómez *et al.* 2000). The use of fire also has an inherent cultural significance due to the aesthetic value of fire, its magical properties and environmental importance (Rodríguez 2004a, 2007; FIEB 2007; Sletto 2008). The Pemón use fire in three ways in the CNP: 1) Fires within forests, which are essentially prescribed burns where fire behavior is controlled. These slash-and-burn practices represent the base of a shifting cultivation system, whereby fires take place in small plots cleared inside the forest (called "*conucos*"). Fire behavior is controlled by: site choice (proximity of rivers, forest species composition, topography, etc.), the time of year when the fires are started (generally near the onset of the dry season), cutting practices of forest vegetation destined for burning (spatial disposal of major fuel materials, trunks, and minor fuel items such as branches and leaves). 2) Fires are also started along savanna-forest borders during hunting activities to capture deer and other large prey species. These fires are less controlled, although Sletto (2008) describes some very complex temporal and spatial patterns of savanna burnings that are cited later in the text. 3) Fires in treeless open savannas occur at any time of the year throughout Pemón territory. Although the Pemón cultivate crops in forested areas, they build their houses in the open treeless savannas. Thus, savanna fires are used for various purposes, e.g., visual communication, and the cleaning of paths and house surroundings. These types of fires do not necessarily have a subsistence purpose, since fire is also used to cure human illnesses and to make the savannas look pretty and green (Rodriguez 2004a, 2007). Decisions regarding the use of fire are based on a rich and extensive knowledge that has been accumulated over generations. The Pemón rely on this ancestral knowledge to handle fires so as to avoid letting them run out of control and cause catastrophes in the forested areas.

Recent Demographic and Social Changes and their Impact on Fire Management Practices

Although burning has occurred in the Gran Sabana for at least the past 400 years, when the presence of the Pemón people was first documented in southeastern Venezuela (Armellada 1960), evidence suggests that fire regimes have changed in recent decades in association with settlement pattern changes. In the past the Pemón were semi-nomadic with highly dispersed settlements and low population densities (1 person per 4.1 km^2 in 1973, according to Thomas (1982) and Kingsbury (2001)), a strategy necessitated by traditional use of forest resources. However, cultural changes associated with the arrival of religious missionary groups in the 1930s and contacts with *criollos* (non-indigenous people) have altered these traditional patterns markedly. The Pemón started to settle near missions where they had access to goods and services (schools, hospitals, etc.), resulting in a more congregated and sedentary lifestyle. The opening of a broad road complex throughout their territory in the 1970s and 1980s has increased this tendency, and has resulted in the replacement of many small and scattered villages with a few densely populated towns (from 100 to 2,000 people) near roads and missions. The settlement of people in small towns and villages together with the increase in population has resulted in a higher demand for and pressure on scarce resources (forest products, game, etc) and increased forest loss in the areas near towns over the last 30 years; a prime example is the mission town of Kavanayén (Kingsbury 2001).

[1] The antiquity of human presence in the Gran Sabana is still a matter for speculation. Only two archaeological sites are known from neighboring regions, where stone and jasper knives, axes, scrapers have been found, estimated to be around 9,000 years old (Schubert and Huber 1989; Gassón 2002).

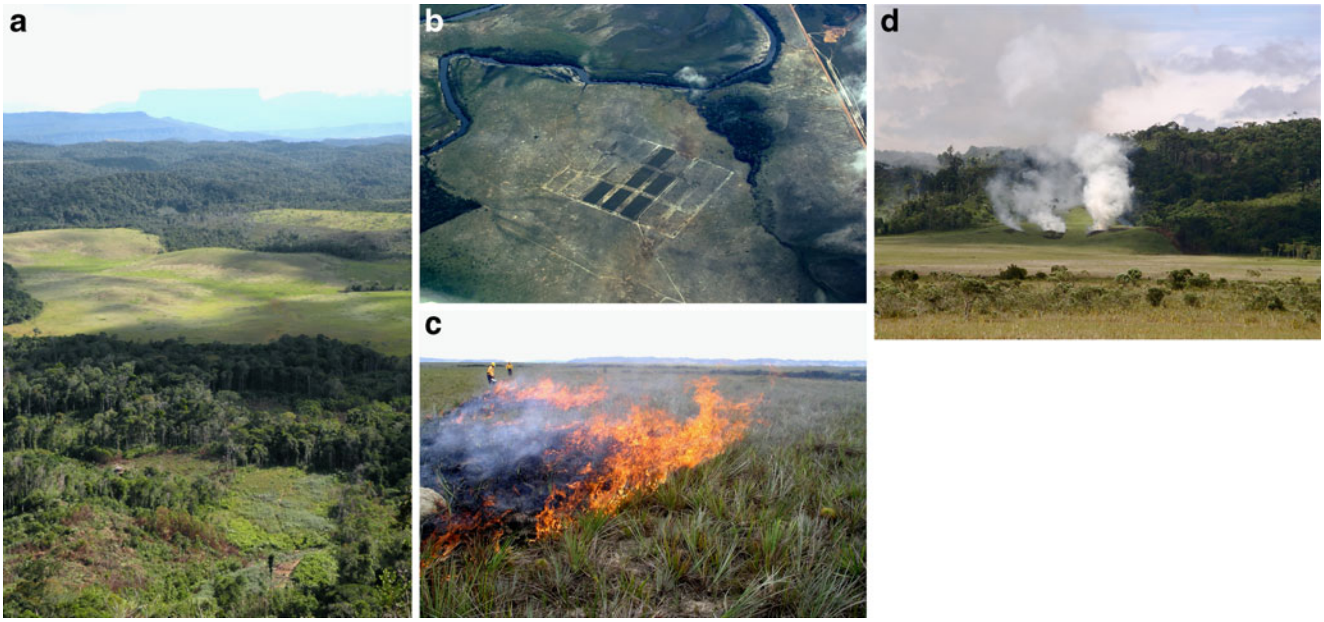

Fig. 2 View of the study site: (**a**) Forest-savanna mosaics of the Venezuelan Guayana uplands (Gran Sabana), (**b**) Aerial view of the experimental plots, (**c**) Controlled fire in experimental plots started by the "Brigada de Ataque Inicial Carlos Todd", EDELCA, (**d**) Pemón system of controlled burns in small patches of savanna to avoid catastrophic fires along forest-savanna transitions (photos: 2 (**a**) by S. Flantua; 2 (**b**) by the "Brigada de Ataque Inicial Carlos Todd", EDELCA; 2 (**c**) and (**d**) by B. Bilbao

Before most Pemón changed their settlement pattern to a more congregated and sedentary one, the area of burnt savannas could have been considerably larger than today. Through the centuries the Pemón have developed a complex system of savanna burns that entails the cooperative burning of small patches (Fig. 2d), producing a savanna mosaic with patches in different states of re-growth. As a result, savanna patches that were burnt more recently serve as fire-breaks. Patches of short, green and humid vegetation will extinguish a fire. In many interviews Pemón explained that it is important to avoid savanna grasses from reaching critical levels of dead biomass, because this could favor the occurrence of uncontrolled and catastrophic fires along forest-savanna transitions. According to Sletto (2008, and 2008 personal communication) the more congregated settlement pattern of the Pemón today leads to a high fire frequency near towns and villages, but very low fire frequencies in the savannas that are located far away from population centers. Because only savannas near towns are burned, while those savannas several kilometers apart have been gradually abandoned, these unburned (and thus unmanaged) savannas have accumulated high fuel loads, increasing the risk that any ignition source may produce large, catastrophic wildfires.

Fire and Forest Loss in the Gran Sabana

The Gran Sabana landscape is characterized by a high diversity of plant communities, distributed in a mosaic pattern, with complex floristic and environmental transition zones. Treeless savannas dominated by grasses and sedges are one of the most extensive vegetation types in the Gran Sabana, whereas in general, riparian and *terra-firme* forests are patchily distributed (Fig. 2). The origin of this large treeless savanna in such a humid area has been controversial. Some authors have postulated an anthropogenic origin based on intensive fire regimes (Christoffel 1939; Dezzeo *et al.* 2004a, b). This hypothesis is based on a lack of evidence of fires caused by non-human ignitions in modern times; communities are unlikely to have experienced fires over the evolutionary time needed to adapt to the high fire frequency to which they are subject today. Dezzeo (1994); Hernández (1999); Fölster *et al.* (2001) and Dezzeo *et al.* (2004a, b) have argued that periodic burnings of the savanna and forest in slash-and-burn agriculture can escape control and penetrate some meters into forest, resulting in forest retraction under successive burns, especially in dryer years. Thus, the actual vegetation cover in the region is considered to be a transitional stage in a long-term process of savannization, originally produced by fires and conditioned by the intrinsic low resilience of the forest, soil chemical stress caused by Ca deficiency, Al-toxicity and episodic drought stress. However, Rodríguez (2004a, 2007) maintains that this view provides a short-term picture of savanna–forest dynamics in the Gran Sabana and that scientific research has supported the biased view of fire as a detrimental component of the CNP.

The controversy over the origin of the savannas in the Gran Sabana is more than just an academic debate since it has consequences for conservation policies. While most scientists and stakeholders perceive the Gran Sabana vegetation mosaic as "unnatural" and human made, the Pemón see the mosaic of forest patches in the savanna matrix as being the natural state of their homeland (Rodriguez 2007; Sletto 2008). Paleoecological research, although scarce and fragmented, has given some support to this idea. If the savannas of the Gran Sabana are mainly anthropogenic and recent in origin, the record of vegetation change at the centennial scale should show predominant forest cover in the near past, which has been quickly replaced by the current treeless savannas. Nevertheless, available evidence for the last 4,000–5,000 years suggest treeless savannas were prevalent as the dominant vegetation (Rull 1991), with the exception of a single record of the region 12,000 years ago, when it was dominated by forest during the first two millennia recorded at the Pleistocene/Holocene boundary (Rull 2007). Paleoecological research also suggests that gallery forests experienced a slight reduction during the late Holocene in some localities of the southern part of the Gran Sabana. Thus, although the current configuration of the landscape has existed since the middle and possibly the early Holocene, forest patches found today are apparently smaller and less numerous than those found several centuries ago. The reduction and disappearance of gallery forest patches during the Holocene has also been found by Méndez (1999) and by Leal (2010), in the northern part of the Gran Sabana, so it is possible that a regional process of gallery forest degradation has been occurring during the last millennia. Rull (1991, 2007) cites climate as the main driver behind vegetation change in the Gran Sabana at the millennial time scale. However, the role of fire on shaping the regional vegetation during the Holocene has not been sufficiently studied to allow the rejection of fire as a possible factor in the process of forest reduction. Moreover, direct indicators of anthropogenic activity and its impact on the landscape are not available, as discussed recently by Rull (2009) and Rodríguez *et al.* (2009) in this Journal (doi: 10.1007/s10745-009-9286-6). Nevertheless, the controversy surrounding the origin of the savannas in the CNP will continue until the history of human occupation can be reconstructed and the relative weight of each driver (anthropogenic fire and climate) in the vegetation dynamics of the Gran Sabana assessed. Nevertheless, it is worth bearing in mind that human activity in South American rainforests could possibly be proved to be more intensive and widespread that was previously supposed (Heckenberger *et al.* 2003).

Thus, based on the current state of knowledge we suggest that forest degradation in the CNP is apparently a long-term process (operating at the millennial time scale) that has been enhanced and accelerated by human activities. This holds especially true for the last decades, when many social and cultural changes have led to a higher demand on forest goods and services, as well as driving important alterations in the traditional use of fire, leading to the unsustainability of the socio-ecological system in the CNP. As might be expected, the degradation of the gallery and terra-firme forest increases the vulnerability of the Pemón since they depend on these forest patches for their livelihood and the maintenance of their culture. Moreover, the more fragmented and degraded the forest patches, the more vulnerable they become to drought episodes and other climatic anomalies, which are likely to become more frequent within a global environmental change scenario.

Current Policies for Dealing with the Fire Problem in the CNP

As Rodriguez (2004a, b, 2007), and Sletto (2008) point out, the conservation policies undertaken in the past few decades in the CNP largely ignore the perceptions, expectations, and knowledge of its inhabitants, which has led to serious conflict between the Pemón people and government agencies. Fire exclusion has been and still is the main fire management strategy adopted by government agencies and park administrators. However, this has not been effectively achieved since the Pemón use fire in their daily activities, and they will not and cannot abandon its use, as they consider it an essential part of their cultural identity (FIEB 2007). Also, the use of fire allows them to fulfill their basic needs (such as acquiring food), which is not possible under any other available strategy. Thus, fire cannot be totally suppressed.

As an initiative to control fires, in 1981 EDELCA (the regional hydro-electric company) created a system to detect, fight, and prevent fires in the region. This system is implemented by the "*Brigada de Ataque Inicial Carlos Todd*" formed by firefighters and other specialists (Gómez *et al.* 2000). The program has the widest reach and best organization for the combating of fires at the national level. However, in spite of enormous fire suppression efforts, only 13% of the total numbers of fires are brought under control and extinguished, partly due to the large area and partly to the high number of fires (Gómez *et al.* 2000; EDELCA 2004).

The current high incidence of fires in the CNP and their detrimental effects on the area's ecosystems suggest that stakeholders need to change their focus from fire suppression to fire management. A new form of governance for the management of fire in the CNP is required that provides space for the deliberation and discussion of different perceptions surrounding the use and impact of fire. To this end, a multidisciplinary project was started in 2007, *"Risk factors in the reduction of habitats in Canaima National Park: vulnerability and tools for sustainable development,"* designed to provide the analyses of ecological, social, and institutional vulnerability and resilience over the medium and short term required for the sustainable management of the CNP. Project objectives include research on the articulation of knowledge systems that involve different perceptions of the fire problem in order to generate a shared vision for the formulation of environmental policies that enable effective and sustainable fire management in the region. The project also intends to improve formal knowledge about the ecosystem dynamics in the Park at different time scales. As Rodriguez (2004a) states: "little attention has been paid to gathering sets of data on the processes of landscape change in the short, medium and long term." Data have also been lacking with regard to soil characteristics, vegetation, fire behavior, savanna combustibility, and the ecological role of fire in vegetation dynamics. There is, in short, a paucity of formal knowledge about fire ecology in the Gran Sabana that is necessary for the management of savanna areas which are the origins of fires that cause forest degradation.

Fire ecology studies in the Gran Sabana have mainly focused on the characterization of fuel material (Entralgo 1983; Todd 1985; Stock 1994) and fire behavior (Todd 1985; Galán 1986). Most of these studies are, however, preliminary, confined to a small study area and none was carried out over a long period. On the basis of these considerations, a long term experiment entitled *Atmosphere Biosphere Interactions in the Gran Sabana, Bolivar State, Venezuela Project* (IAB as per the Spanish acronym), simulating traditional methods of fire management by the Pemón was initiated in 1999 by the Laboratory of Community Dynamics and Ecological Processes at the Universidad Simón Bolívar, and continued by the *Risk Project*. This ecological experiment has generated long-term research results of fire behavior and its impact on the atmosphere, vegetation and soil, the most important of which are described in the next section. We suggest that these findings could be considered as an appropriate ecological base on which to develop and implement future management plans.

Fire Experiment in Savanna Plots: Insights into Fire Behavior for Alternative Fire Management Strategies

Study Site, Experimental Design and Sampling

In the IAB project we simulated traditional Pemón fire management methods by burning a series of plots of savanna at different intervals (treatments) over a seven-year period (Fig. 2). The fire experiment was done near the Parupa Scientific Station (5°43′N, 61°35′W, 1,226 masl) (Figs. 1 and 2), in an open, treeless savanna, adjacent to an evergreen gallery forest patch forming a large area of savanna-forest transition characteristic of the northern Gran Sabana landscape (Huber 1986; Huber and Febres 2000). Due to the higher sensitivity of forest to fires and the complete absence of trees in the Gran Sabana savannas, it seems that the occurrence of fire controls the advance or retreat of the forest in the savanna—forest transition, rather than tree density in the savanna areas, as for other tropical savannas. The establishment of the plots in the savanna-forest transition zones allowed us to observe the behavior and impact of the fire just before it penetrated the forest.

Pemón perform their traditional prescribed burns in savanna-forest transitions, what the Pemón call the "turetakata," the last few meters of grasslands before the beginning of the forest. As Sletto (2006 and 2008) comments: "The dense vegetation in these grassland communities may either facilitate or prevent fire entry into forest patches: high fuel levels may allow slow-burning surface fires to reach dangerous speeds and high temperatures; low fuel levels will cause surface fires to stop. The principle behind this 'burning so that fires don´t enter forests' *(apokwomu namaituretatak)* is thus to reduce the level of combustible grasses near forests and to form a firebreak *(apokwako nin)*."

The 31 experimental fires were set up in 21 plots of 0.5 ha each, arranged in three blocks in a randomized design with three replicates (Fig. 2b) according to the following scheme: 1) first fires; 18 plots burned during 2000–2003, 2) second fires; carried out in 13 plots during 2003 and 2004, 3) unburned plots. In order to evaluate the effects of fire frequency, fires were started in plots with 4–7 years of fire exclusion and then re-burnt 2–4 years after the first experimental fire. Fires were set up with an east-west orientation in line with the prevailing wind and were controlled by EDELCA firefighters (Fig. 2c). All the decisions with respect to the time of the day, adjustments to meteorological conditions and the initiation of ignitions were made by Pemón from different communities who were members of the EDELCA firefighters.

Savanna areas are dominated by grasses (*Trachypogon spicatus* (L.F.) Kuntze, *Axonopus anceps* (Mez) Hitch) and sedges (*Lagenocarpus rigidus* (Kunth) Nees, *Bulbostylis paradoxa* (Spreng.) Lindm); woody elements are virtually absent. The climate is typical of the region: isothermal, with a mean annual temperature of 20.6°C, and humid (mean annual precipitation between 1,600 and 2,200 mm) with a slight dry season between December and March.

The study of the long-term recovery of post-fire biomass was carried out by frequent collections of plant biomass during the experimental period. Several results of the fire behavior experiments have already been published in Bilbao *et al.* (2006, 2009, 2010), where a complete description of experimental design and general methods are given. Here, the results of fire frequency, post-fire vegetation recovery and their relevance to fire management policies in the Park are presented and discussed.

Results of the Fire Experiment and Their Relevance for Fire Management Strategies

Our main findings from the fire experiment are summarized below:

- Fires can occur under a wide range of weather conditions and fuel characteristics.
- The series of fires observed during the 31 experimental fires indicate the high variability of fire behavior (82% of variation for fire line intensity and 40% for burning efficiencies).
- Wind speed, live/dead ratio of plant biomass, and fine fuel load (biomass of leaves and thin culms of grasses and sedges) constitute the principal factors driving fire behavior.
- The majority of the fires showed very low fire line intensities (152–1,200 kW m^{-1}) and burning efficiencies (8–31%).
- Fires did not occur until the total fuel load reached 600 g m^{-2} of total fuel (Fig. 3) and when dead/live ratios were less than 1 (Fig. 4).
- Due to the low recovery rates of the vegetation biomass after fire, the conditions given above were reached 2–3 years after a single fire and 4 years or more after a subsequent fire (or second fire in this study) (Figs. 3 and 4).
- Thus, fires did not occur annually (frequencies of one fire per year) because it was impossible to re-burn plots in the year following a fire in any of the experimental plots due to the limited amount of fuel. Our experiment demonstrated that fires never reach an annual frequency, but can occur every 3 or 4 years, or rarely, every 2 years.
- To summarize, the heterogeneous conditions generated by fire behavior variability in the northern part of the Gran Sabana could lead to a variety of grassland environments as regards the amount of biomass (176–1271 g m^{-2}), live/dead ratios (0.36–3.60) and biodiversity (species abundance and composition) produced by the exposure to burning over time in different areas.
- Fire regime analysis suggests that the savanna vegetation in the CNP could support the creation of a mosaic of patches with different fire histories that could be used as firebreaks, reducing the risk of hazardous wildfires, especially in the vulnerable and diverse savanna-forest transitions. This technique is referred to as patch mosaic burning (PMB).

These results concur with traditional Pemón practices in the use of fire for the sustainable management of the savanna–forest boundaries described in the previous section. Furthermore, they invalidate several misconceptions and unwarranted assumptions shared by key decision-makers from the institutions that manage the environment in the region, stakeholders, popular knowledge and several members of the scientific community. Some examples of these misconceptions are:

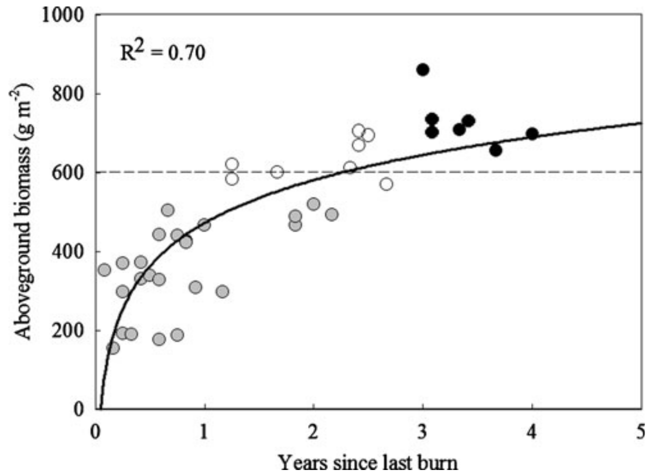

Fig. 3 Recovery of the aboveground biomass after fire over the 4 year sampling period. Plots were re-burned 3 or 4 years after the last fire when aboveground biomass reached >600 g m^{-2} (area above the dotted line), and the dead:live ratio of vegetation was >1 (black points). The white points show plots where the total aboveground biomass was hypothetically enough to support a re-burn, but the biomass was too green to allow fire propagation (i.e. the dead:live ratio was <1). The grey points show plots that did not have enough total biomass or dead material to re-burn

Savanna Vegetation is Burnt Every Year This idea has been supported by ecological research for a long time in the Gran Sabana. Nevertheless, although it is based on field observations it is not supported by empirical data, field experiments or long-term monitoring. Our experiment demonstrated that it is nearly impossible to maintain a fire in the same stretch of savanna during consecutive years. Figure 3 summarizes the recovery of aboveground biomass after fire, showing that at least 600 g m^{-2} of total fuel is needed to support a re-burn, and that this value is reached only 3 or 4 years after the last fire (Fig. 3). The same time intervals are required to attain a dead/live ratio > 1, which is necessary for a fire to occur (Fig. 4a). Probably, the nature of burning by the Pemón in small savanna patches (81% of firefighters battle fires less than 10 ha) and the high number of fires that occur annually in a large territory such as the Gran Sabana (18,000 km^2), give the impression of an annual occurrence. The low fire frequencies in the savannas in the north of the Gran Sabana are different from fire frequencies observed in other neotropical savannas. Because fire ignitions are primarily anthropogenic in the tropics, savannas near human settlements experience fires every

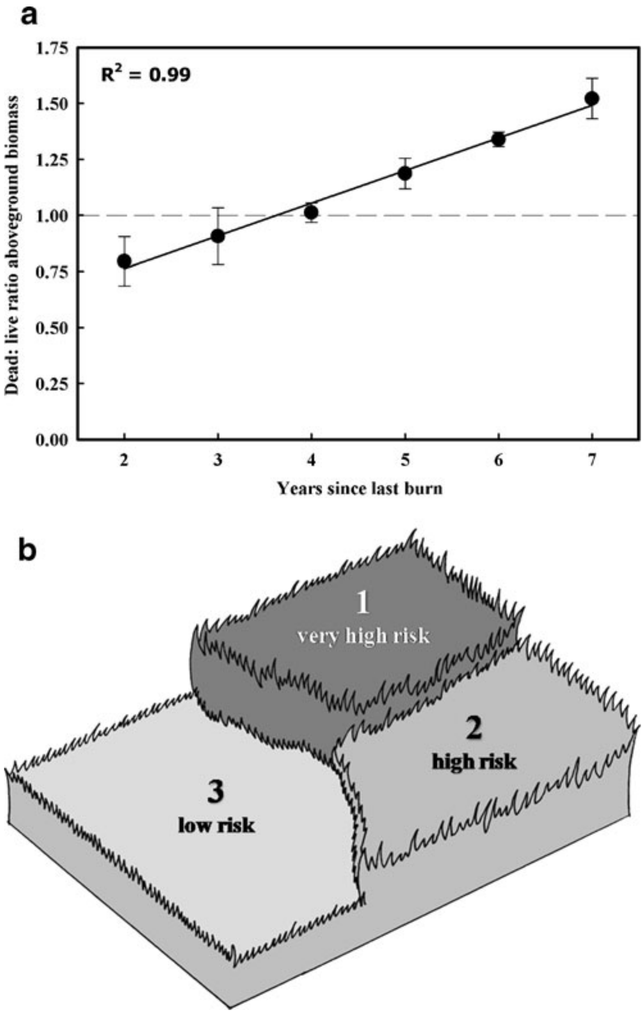

Fig. 4 **a**) Dead:live ratio of aboveground biomass in experimental savanna plots during 7 years. The accumulation of dead material is shown by the linear fit observed (R^2 = 0.99), whereby the amount of dead material is proportional to the risk of fire occurrence (area above the dotted line means a high risk of fire occurrence). **b**) Schematic view of patch mosaic burning (PMB) in the Venezuelan Guayana uplands showing a system where different ages of savanna vegetation are observed: 1) more than 4 years since last fire; savanna aboveground biomass is >600 g m^{-2} and the dead:live ratio is >1. These conditions result in a very high risk of fire occurrence. 2) Between 3–4 years since the last fire; savanna aboveground biomass is around 600 g m^{-2}, the dead:live ratio is near 1 and the probability of fire occurrence is high. A fire could spread under high wind velocity conditions even when biomass is less than 600 g m^{-2}, and/or dead:live ratio is <1. 3) Less than 2 years since the last fire; aboveground biomass has an average of <600 g m^{-2} the dead:live ratio is <1and the probability of fire occurrence is low. If a fire starts in area 1, it could spread to area 2, but not to area 3 because the amount of fuel and the continuity of vegetation cover are not enough to support a fire. Thus, area 3 could act as a firebreak to fires started in areas 1 and 2

6 months–1 year (Sarmiento 1983, 1984; Bilbao and Medina 1996). These high frequencies are only possible when the savanna vegetation has a high capacity to recover plant biomass after fire. Such is the case for the savannas of the Orinoco Llanos and the Brazilian “cerrado” in the neotropics, where the recurrence of fires occurs over short periods associated with a high accumulation of combustible material from the last burning (Eiten 1972; Coutinho 1990; Klink *et al.* 1993; Hoffmann 1998; Barbosa and Fearnside 2005).

Fires Occur Everywhere in the Savanna The limited fire frequency in the Gran Sabana savannas indicates that a patch that was burnt during one year will not be burned during the following two, three or more years. Thus, it is very common to see a mosaic of differently colored patches in the savannas associated with different fire histories (Fig. 2d). Thus, black and dark grey colors indicate patches that were recently burned, light green corresponds to the re-growth of vegetation soon after fire and different shades of dark green denote different ages of vegetation associated with increasing dead/live ratios of plant biomass (Fig. 4b). In fact, dead/live ratios of fuel increased linearly, from 0.75 in plots with 2 years since the last burning to 1.50 in older plots with 7 years without a fire (Fig. 4a). Considering that fires were only possible in plots with a dead/live ratio >1, the older the biomass of the fuel, the greater the flammability (Fig. 4b).

Fire is Always Harmful to Vegetation and Soil This statement is also associated with the idea that Pemón fire practices might be considered one of the causes of deforestation. The Pemón are assumed to be responsible for intensifying forest loss in the Gran Sabana. However, as we described above, the heterogeneity generated by fire over space and time as regards the fuel biomass and dead/live ratio leads to the creation of a patchwork mosaic with different fire histories. Thus, by increasing the discontinuity of fuel accumulation and its characteristics, it should be possible to reduce fire occurrence in high risk areas and thus the propagation of hazardous wildfires (Fig. 4). Indeed, this constitutes the ecological base of the fire management technique referred to as patch mosaic burning (PMB; Parr and Brockett 1999; Brockett *et al.* 2001; Parr and Anderson 2006). Interestingly, this fire management tool closely resembles the ancestral techniques of the Pemón people for managing fires in areas of savanna by cooperative burning. Thus, small fires in different areas create a series of succession stages as has been referred to above. In addition, patchy burning creates a diversity of vegetation physiognomies across the regional landscape (Bilbao *et al.* 1996; Van-Wilgen *et al.* 1998; Roberts 2001; Parr and Anderson 2006). Furthermore, a system of auto-control exists in savannas whereby the patchiness and diversity of fuel materials affect fire behavior thereby influencing species diversity and habitat heterogeneity (Bilbao *et al.* 1996). PMB has been linked to traditional burning by indigenous peoples in other parts of the world (e.g., in Africa and northern Australia; Pyne 1997; Parr and Anderson 2006). Unfortunately, cultural and social changes since the arrival of Europeans and later migration of *criollos* have severely disrupted such practices in South America as in South Africa and Australia.

The application of the PMB strategy in savannas of the Gran Sabana could assist in the conservation of other ecosystems, such as gallery and terra-firme forests. Thus, repeated fires in areas of savannas near to forest borders could be used to avoid large and catastrophic fires that spread from the savanna into forests, especially in very dry years. The application of this traditional practice would preserve the biodiversity of different ecosystems as well as the sustainable use of natural resources by the Pemón people in the Park.

Conclusion

CNP is a protected area of great value both nationally and internationally, due to its biological and cultural uniqueness and its political and economic strategic importance. Environmental threats to the Park are thus of considerable concern for regional, national and supranational institutions. Given that CNP is the homeland of the Pemón people, environmental threats to this area, as well as its long-term conservation, are of direct concern to them, as they depend almost exclusively on the use of the natural resources within the CNP for the maintenance of their culture and livelihood.

As was discussed above, forest loss in the CNP involves a diverse set of factors with a myriad of complex interactions that most scientists and stakeholders do not fully understand. Because fire has been identified as one of the main and more widespread drivers of modern landscape change in the CNP especially in the Gran Sabana sector, fire suppression programs have been largely justified for the sake of forest conservation in the Park. However, the occurrence of fires alone does not explain the high rates of forest reduction recorded and it is obvious that a combination of many factors is causing the observed process of forest loss.

The most important achievement of environmental investigations in the CNP, especially in the Gran Sabana, has been the identification of the main factors that could increase the vulnerability of savannas and forests to fires and droughts. Nevertheless, little environmental research available has touched on the importance of recent changes in fire practices apparently due to contemporary demographic and cultural changes experienced by the Pemón people. These changes have direct implications in both the frequencies and spatial patterns of fires that we need to understand in order to comprehend the forest-savanna dynamics in this region.

The human dimension of the fire problem in the CNP has been considered by social science researchers who have studied the perceptions about fire and fire practices of the Pemón, as well as those of other actors involved in the management of the CNP. These studies have provided alternative insights into fire behavior and its effects that allow us to see beyond the apparent forest-destructive behavior of the Pemón (Kingsbury 2001; Rodríguez 2004a, b, 2007; Sletto 2008). They also suggest that traditional Pemón fire practices have changed in recent years. On the one hand, population growth has resulted in higher pressure on forest resources leading to an over-exploitation of forests near towns and villages, and a net forest loss in the vicinity of populated centers. On the other hand, the change of the settlement pattern of the Pemón from a dispersed to a more sedentary and congregated one has led to considerable changes in fire practices. The most noticeable and important of these being the disruption of cooperative burning of savannas, which involves the use of fire in the creation of a patchwork mosaic that helps to avoid large catastrophic wildfires.

Our fire experiment gives scientific support to the practice of the cooperative burning of savannas, showing that the actual fire return interval in the upland savanna vegetation is one fire every 3 or 4 years, when critical fuel loads are reached. The fact that these savannas cannot support an annual fire regime could be used as a valuable management tool, allowing for the creation of a patch mosaic burning system (PMB), where recently burned patches of savanna could serve as firebreaks in a system that closely resembles the ancestral fire management practices used by the Pemón for centuries. Furthermore, PMB fire management in savannas neighboring savanna-forest transitional communities would favor spatial heterogeneity and biodiversity in these communities and therefore could also help to conserve the highly diverse savanna-forest transitions.

The experiment also showed that the articulation of traditional and scientific knowledge is a promising strategy for the formulation of environmental policies for effective fire management in the CNP that could be more successful for forest conservation as well as conservation of Pemón cultural integrity, than the fire suppression approach. This constitutes one of the main challenges envisaged and confronted in the “Risk Project” in its attempt to articulate different forms of knowledge (technical, scientific, indigenous) in order to define long term actions for the sustainable use of natural resources in the CNP.

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