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Impacts of fires on the woody stratum of Mbam and Djerem National Park (Cameroon)

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Abstract— *In Cameroon, the recurrent and uncontrolled use of bush fires, causing damage to the ecosystem, and constitutes a worrying situation for protected area managers. . The Mbam et Djerem National Park (PNMD) is threatened by bush fires and particularly by uncontrolled late fires which compromise all of its biodiversity and the future of the park. Faced with this increasingly high occurrence of fires and the insufficiency of basic data, it becomes urgent to assess the impacts of fire on the woody and grassy stratum according to the fire regime and at the end of proposing fire management strategies at PNMD level.*

To do this, experimental plots were installed, the impacts of fire on vegetation according to fire regimes were assessed.

The results reveal that: 74% of the trees examined are barked by fire and the proportion of these barked trees varies according to the species of tree, which constitutes entry points for termites and bees in the trees. Adults are significantly more skinned (70%) than young people (30%) (variance = 32.447 df = 1, $\chi 2 = 103.014$*,* $p = 0.004$*). The intensity of the fire is significantly different from one fire regime to another (*$p = 0.0154$*). The rate of regrowth is different between treatments (ANOVA,* $p = 0.005$*). High (apparent) mortality is observed for class 2 individuals (35%), i.e. juveniles suffering from late fires.*

Remote sensing therefore appears to be a more valuable tool for monitoring and analyzing space and time for strategic and operational planning and for early warning in the management of bush fires.

Keywords*— *Savannah, Impact, Bush fire, Remote sensing, Woody stratum.

I. INTRODUCTION

The impact of fire on vegetation and its use by populations appear from the first documents relating to the study of savannah vegetation in Africa (Monnier, 1968, Bruzon, 1990; Ouédraogo M., Delvingt W, 2003). In Africa, recent fire studies are relatively abundant. Most of the studies, however, have focused on the herbaceous layer and fauna / pasture relationships (Yaméogo, 1999; Afelu*and al*., 2015; N'dri, 2011; Konaté and Konaré, 2012, Houinato*and al*., 2013, Eriksen , 2007; Poilecot and Loua, 2009; King *and al*., 1997; Kathryn *and al*., 2014; Savadogo*and al*., 2008; Dadem*and al*., 2018). Depending on their period of realization, we distinguish: fires early (November-start of dry season), intermediate fires (January-February, mid-dry season), late fires (April-May at the end of the dry season) and counter-season fires (June-July in full rainy season) .Fire is a constant element in the Mbam and Djerem National Park (MDNP). Sometimes spontaneous, sometimes controlled, it is considered to be an essential factor in the management of MDNP ecosystems. Is fundamental for understanding the relationships between animals and their habitats, evolution food availability as well as monitoring the distribution of wildlife and poaching control. On woody plants, the objective is to assess woody regrowth and the evolution of phenophases according to the types of fire applied to a certain number of species.

II. MATERIALS AND METHODS

2.1 Study area

The specific vulnerability of savannahs in protected areas (PA) led this study to focus on the PNMD, which are considered priorities at the national level. The choice fell on this protected area to respond to: a request from the NGO Wildlife conservation society (WCS) which is funding the PNMD / WCS Development Support project; at the request of park managers who consider fire as one of the tools for land management and protection (Grégoire*and al*, 2003); scientific questions that the same managers are asking about the impact of fires on the nature and structure of plant cover. The Mbam et Djerem National Park is located between 5 ° 30 'and 6 ° 13' north latitude, and 12 ° 13 'and 13 ° 10' east longitude. This park extends over the Center, East and Adamaoua regions, in the heart of Cameroon. It is located at the southern limit of the Adamawa plateau and on the northern edge of the dense forest of the Congo Basin (Figure 1). There is both the equatorial rain forest (to the south and east) and areas of savannah-guinean type with a rainfall of 1800 mm Created in January 2000, the park covers a total area of 416 512 ha , half of which is lowland tropical forest. The other half of the savannah is wooded and wooded. Between the two, there is a large belt of ecotone, that is to say overlapping of the two contiguous zones. This overlap provides the Mbam and Djerem national park with a great diversity of habitats and therefore a great biodiversity (MINFOF, 2016).

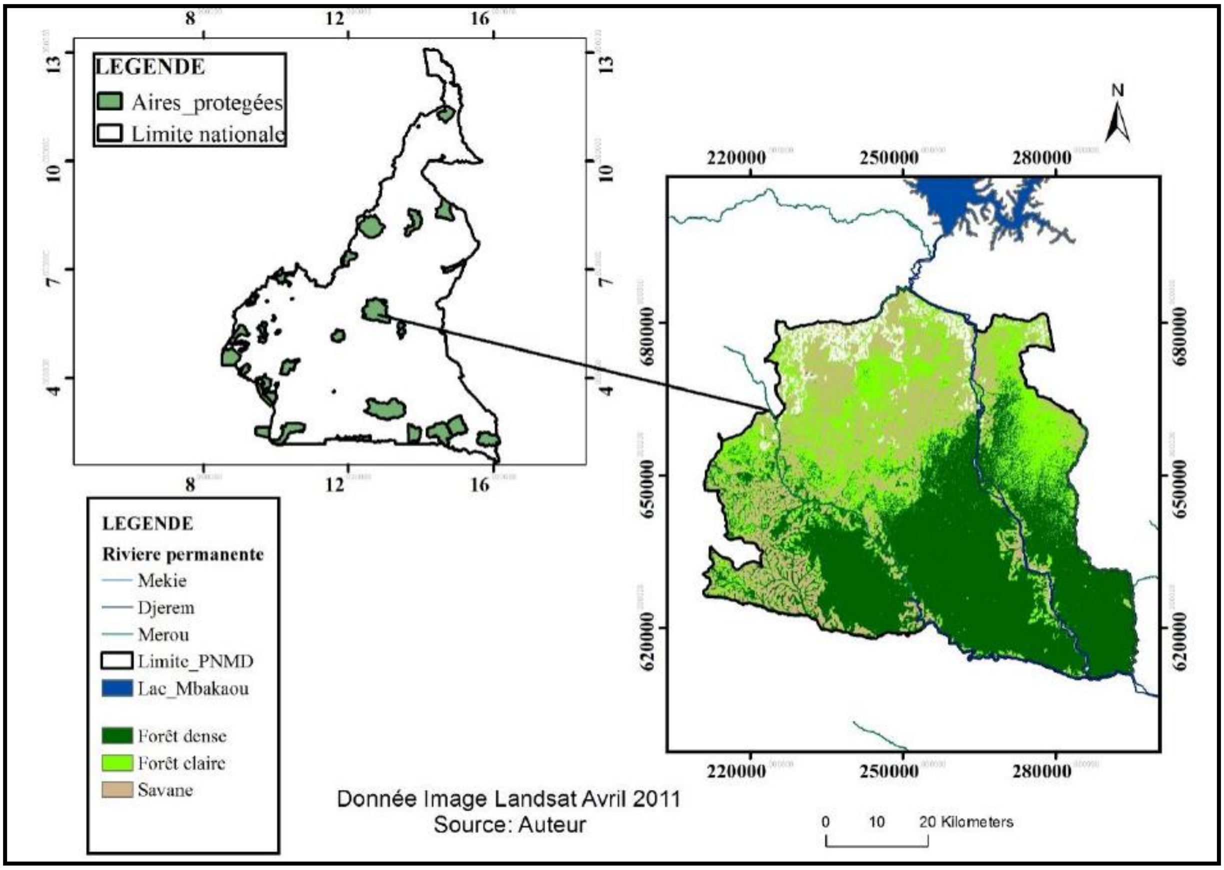

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Fig.1: Geographical location of the study area

2.2 Device and species studied

2.2.1. Experimental apparatus

This study was carried out as part of the PAAPNMD / WCS project from 2014 to 2017, on three sites in shrub savannah. These sites were chosen based on accessibility, proximity to the forest-savannah transition zone and the periphery of the park. A system of 1.89 ha (1.5 ha of plots and 0.39 ha of firewall) has been defined by site. Each device includes three 40 x 125 m (1/2 ha) plots separated by 5 m wide firewalls (Photo 2). A 5 m wide firewall surrounds the device to limit the spread of fire strictly to the experimental plot. Each corner of the plots was marked with the help of the markers (the 2 m poles and signed with the marking strip (fluorescent tape, sign plate) and the GPS points of each corner were also noted (Photo 1). Three (3) plots per device receive one of the following three treatments:

- “early fire” (FP), lit in mid-December (17);
- “late fire” (FT), lit in mid-February (15);
- "no fire" (PF), which constitutes the witness.

This fire parameters recording device was repeated over two dry seasons (2015-2016 and 2016-2017) on the same sites.

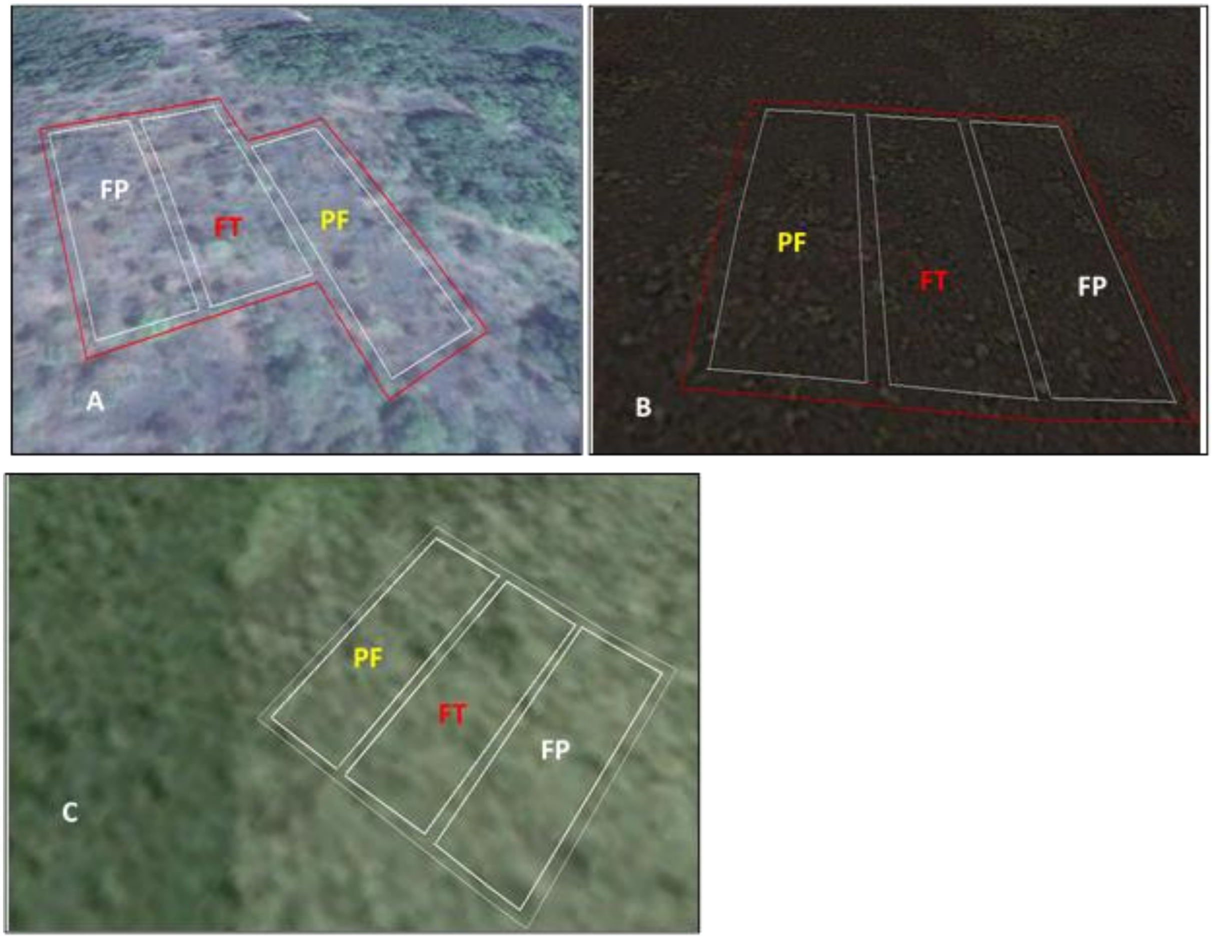


Photo 1 :Photograph showing the arrangement of the experimental plots

Legend: A = Miyere device, B = Debiro device, C = Kpayere device, FP = early fire, FT = late fire, PF = no fire

2.2.2. Measures

Fire intensity rating

Determining the intensity of the fire depends on certain factors that are well known to authors working on bush fires (Afelu, 2015).

Assessment of combustible biomass

The 1x1 m^2 plots have been set up at the 40 x 125 m^2 plots. These plots are intended for the collection and evaluation of herbaceous biomass. The biomass is taken by radial method and at the center of the plot, i.e. 7 plots (a, b, c, d, e, f, g) per plot before the fire. This measurement was taken again after the fire had passed over the same plot, to assess the biomass consumed by the fire. The biomass water content was assessed after air samples taken before the fires were air dried. The height of the herbaceous layer was evaluated by noting the average height in each square of biomass. The biomass is weighed using a balance and expressed in mass per unit area (g / m^2).

$HRC = ((CH-CS) / CH) x100$ with

HRC: Relative Humidity of the Fuel, CH: Wet Fuel and CS: Dry Fuel

The biomass drying rate was calculated using the following formula $TA = ((HRCo-HRC7) / HRCo) \times 100$ where TA is the evolution of the humidity rate.

Soil humidity at the time of ignition

Soil samples were taken from the plots before the fires were started. In the 4 corners and in the center of each plot, the soil cores were taken from two horizons (0-5 cm) and (5-10 cm). These samples were first weighed when they were taken and then air-dried to determine the water content of the soil during ignition.

HRS = ((SH-SS) / SH) x100 HRS: Relative soil humidity SH: Wet soil SS: Dry soil

Ignition and recording of the propagation speed of the flame front

The experimental fire was started during a calm wind period (8h 30 min) to avoid the influence of wind speed. The plots of each device treated with the same fire regime were burned simultaneously. The speed of propagation of the fire was estimated from the time taken by the flame front to travel a distance of 10 meters. The fire was started on one side of the plot. After firing, a stopwatch followed the front of the flames, noting the time it takes to travel the distance of 10 meters (Photo 4C). On the site, three plots underwent these early fires on December 17, 18, 19, 2015 and 2016 and three other late fires on February 15, 16, 17, 2016 and 2017.

Flame height

The height of the flames was measured as follows: along one side of the plot where the fire was started, at an interval of 10 meters, 7 trees or shrubs were targeted before the fire. After the fire, the height of the last leaf burning trees was recorded. The height of the flames is obtained by averaging the heights recorded at the level of each tree.

Area covered by fire

It was estimated after the fire had passed over the plots. The area covered is obtained by noting the proportion of area burned in the 25 plots in each plot. The codifications used for this purpose are those of Guiguindibaye (2013)

The codifications used for this purpose are:

0 = the plot is not affected by the fire;

1 = 1/4 of the plot is affected by fire;

2 = ½ of the plot is reached by fire;

3 = 3/4 of the plot is reached by fire;

4 = the whole plot is affected by fire.

Intensity of fire

It refers to the heat released per unit of time and per unit of distance traveled by the flame front. It is calculated by the formula of Byram (1959): I = H × W × R

Where I is the intensity of the fire in KJ / s / m, W is the biomass consumed in kg / m, R is the speed of progression of the flame front in m / s. H is a constant giving the calorific yield of the biomass in KJ / Kg. A value of 18700 was used based on literature data (Alexander, 1982).

2.3. Assessment of the impact of fires on the woody stratum

2 .3.1. Phenological monitoring of woody plants

Five (5) woody species were selected taking into account their densities on the device. They are *Piliostigmathonningii*, *Strychnosspinosa*, *Ximeniaamericana*, *Crossopteryxfebrifuga and Pteleopsissuberosa*. The individuals of each species were divided into 3 height classes and 10 individuals per class were selected. The classes follow the detailed distribution for the wood inventory (regeneration, juveniles, and adults).

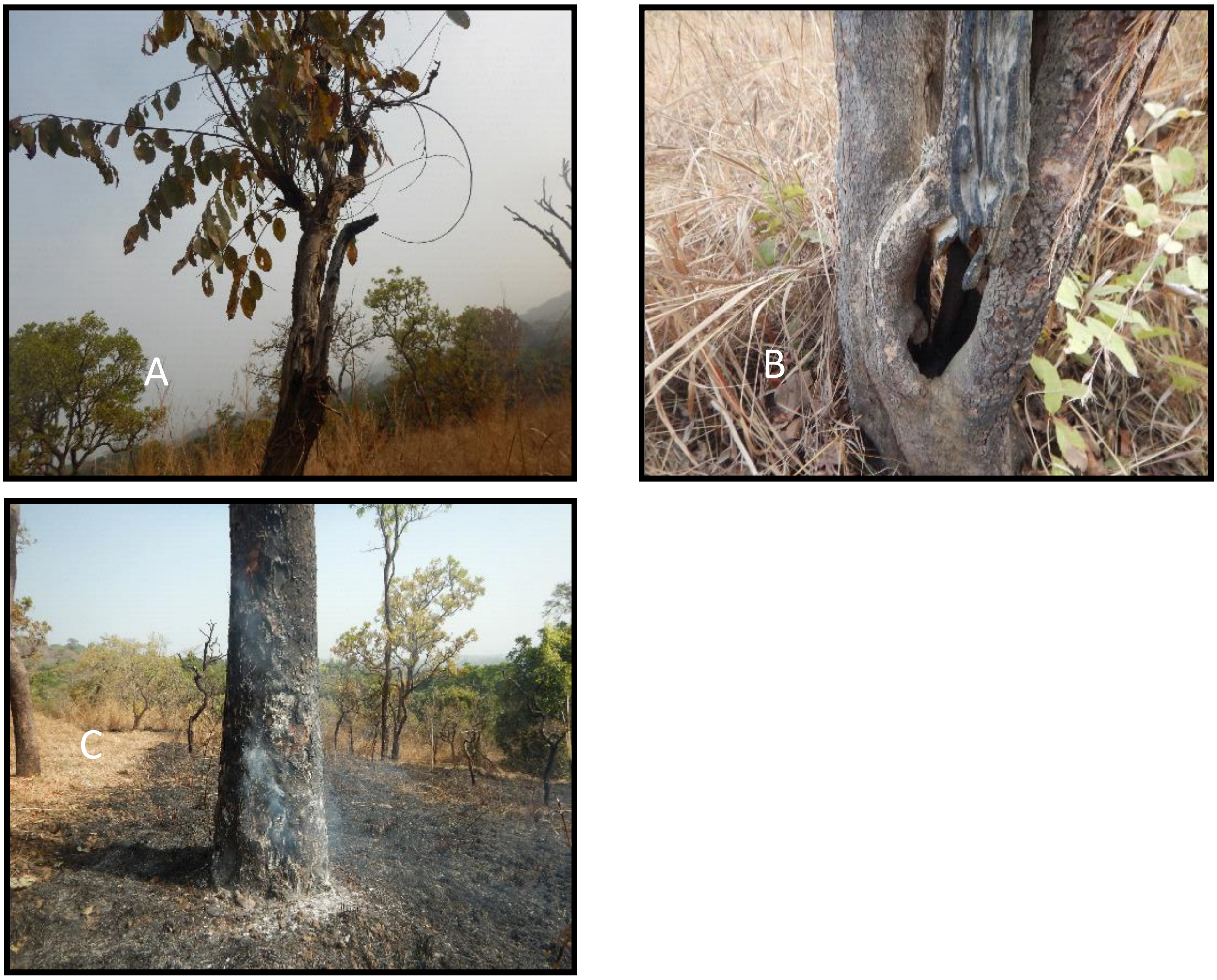
The individuals were chosen and marked with wooden stakes and their coordinates (X and Y) noted. The lights were then applied (12/15/15) and phenological observations were made on the following dates: 1/25/16, 2/27/16 and 3/30/16. The parameters noted are the phenophase of the individual before the fire and the evolution of this phenophase after the fire. Phenophases respond to the same subdivision as in the woody inventory.

2.3.2. Assessment of fire damage on sites

The purpose of this start is to assess the debarking caused by fire on trees in order to correlate it to the intensity and regime of the fire. These are damages identified during woody inventories before and after firing.

Before the fire, the impact of fire on adult and young individuals of all species and their main branches was assessed by detecting the areas debarked by fire Photo 2 (A and B). Fire can cause injury in all directions to straight trees (Gill, 1974) or to the underside of the angled branch or trunk (N'dri*and al*., 2011).

When the trunk or branch is debarked or has an external hollow, it has been noted if the tree is inclined and if the debarking and / or the hollow is on the underside of the trunk and branchinclined. A tree is considered tilted if it leans more than 30 ° from the vertical. According to studies by Perry *and al.*, (1985), Gibbons and Lindenmayer (1997), Whitford (2002), Whitford and Williams (2002) and as observed by N'dri*and al.*, (2011), these parts bark could constitute entry points for termites in trees to damage them *and al*so surfaces likely to burn easily during the next fires because they are not protected by bark. According to the scenario proposed by N'dri*and al.*, (2011), the external hollows observed on the trees would begin with the debarking which would allow the termites to enter the trunk of the trees to settle there. Once the tree is hollowed out by these termites, the fire exposes the internal hollows, which weakens the mechanical resistance of the trees (N'dri, 2011).



Legend: A = Different stages of fire damage. B = debarkingfollowingseveralfires C = debarking of the year

2.4 Statistical analyzes

The analysis of the data was carried out with Excel software version 2013 for the calculations and the confection of graphs and the software R (http://www.r-project.org/) for the tests of Student and simple ANOVA or multiple. (Significance threshold <0.05; Significant. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1). The linear model (lm) was used to analyze the intensity of the fire as a function of its regime (early and late). The generalized linear model made it possible to analyze the frequency of debarked trees according to different species and stages of development. The georeferencing maps of the experimental plots were produced in ArcGIS 10.1 under the WGS84 UTM Z33N projection.

III. RESULTS

3.1. Assessment of the impact of fires on the woody stratum

3.1. 1. Damage caused by fire on the woody stratum before the fire

The debarking of the year observed in 2015-2016, following the early fire, shows that a single fire rarely causes bark on trees. The barking observed, resulting from several fires evaluated, shows that 74% of the trees examined are debarked and that the proportion of these barked trees varies according to the tree species.

In addition, adults are significantly more skinned (70%) than young people (30%) (variance = 32,447 df = 1, $\chi 2$ = 103,014, p = 0.004). Older damage, resulting from several previous fires, Figure 30 shows the proportion of barked trees on the sampled trees. This figure shows that 74% of the trees examined are barked by fire. In addition, adult trees are more significant. (10%) young trees (35%) (deviance = 34.443, df = 1, χ 2 = 108.014, p = 0.004).

67% of the main branches examined are debarked. The directions in which these branches are peeled are not due to chance; in fact, most branches (88%) have their debarking on the underside of the inclined branch ($\chi 2$ = 189.57, df = 1, p <0.001). In addition, 69% of the inclined branches have external hollows; the majority of these branches (78%) have their hollows on the underside of the inclined trees. This observation is statistically significant ($\chi 2$ = 91.61, df = 1, p <0.001).

In the long term, fire causes the debarking of 48% of the trees. These barked areas are entry points for termites (N'dri*and al*. 2011) and bees in trees. These termites, once in the tree, will cause internal hollows which will subsequently be exposed by the recurrent action of fire. According to Mattheck and Kubler (1995), the external hollows thus created weaken the mechanical resistance of the trees. Like the debarked parts of the branches, the slots are generally located on the underside of the inclined trees, which clearly shows the link between debarking and external hollows (N'dri, 2011)

3.1. 2. Response of woody plants to fire on the devices

Five (5) woody species were monitored. The results are summarized in Table 1 taking into account the height categories (seedlings, juveniles and adults).

Table 1: Behavior of some woody species under the effect of fire in the PNMD

Woody species	Categories	phenophase Before the fire	Fire damage				Phenophase after fire		
			FB	CA	TC	IM	25/01/16	27/02/16	30/03/16
Crossopteryxfebrifuga	seedling	Fe3	+	+	+	+	Fe0	Fe1 (rejet)	Fe2
	juveniles	Fe3	+	+	+/-	-	Fe0/Fe4	Fe1	Fe2
	adults	Fe3	+	+/-	-	-	Fe4	Fe4/Fe1	Fe2,4/Fe2
Piliostigmathonningii	seedling	Fe3	+	+	+	+	Fe0	Fe1 (rejet)	Fe2
	juveniles	Fe3	+	+	+/-	-	Fe4	Fe1,4	Fe2,4
	adults	Fe3	+	+	-	-	Fe4	Fe1,4	Fe2,4
Combretumfragrans	seedling	Fe3	+	+	+	+	Fe1	Fe2	Fe2
	juveniles	Fe3	+	+	+/-	-	Fe1,4	Fe2	Fe2
	adults	Fe3	+	+/-	-	-	Fe1,4	Fe2	Fe2
Strychnosspinosa	seedling	Fe3	+	+	+	-	Fe4	Fe4	Fe4/Fe1,4
	juveniles	Fe3	+	+	+/-	-	Fe4	Fe4	Fe4/Fe1,4
	adults	Fe3	+	+/-	-	-	Fe4	Fe4	Fe4/Fe1,4
Ximeniaamericana	seedling	Fe3	+	+	+	+	Fe2	Fe1	Fe2,4
	juveniles	Fe3	+	+	+/-	-	Fe1,4	Fe2, 4/Fe2	Fe2,4
	adults	Fe3	+	+	-	-	Fe1,4	Fe2,4/Fe2	Fe2,4

Damage: FB = Burned leaves; CA = Crown reached; TC = calcined trunk (blackened); lM = Apparently dead individual. +: the damage is effective; •: no damage; +/-: the damage is only effective in some of the individuals. Leafing legend: Fe1 = beginning leafing; Fe2 = full leaf; Fe3 = Senescence and falling leaves;

Fe4 = burnt leaves on the tree; Fe1.4 and Fe2.4 = combination of leafing stages on the same individual

At Crossopteryxfebrifuga

The leaves are burnt to the top of the tree, exception is made for some adults who are not affected in height. The damage "blackened stem" by the passage of fire is only clearly visible at the level of small individuals (class 1) who often appear dead during the first dates of observations. As for the evolution after fire, we observed:

- Three months after the passage of fire (03/30/16), all class 1 individuals (even those who appeared dead) reject new leafy stems at their bases. Class 2 individuals also completely lost their old leaves and issued new leaves. Some haveeven well-developed leaves. For class 3, the new leafing is only effective in half of the individuals. The rest (especially those not reached in height by the fire) still carry the old leaves;

- in August all individuals, all classes combined, bear new, well-developed leaves. However, some individuals in the adult class also have old burnt leaves. In addition, it was found that individuals in the seedling class which had escaped the fire, did not start to lose their old leaves and start new leafing until mid-March. We also observe that individuals who had their fruits burned in the passage of fire, kept these fruits in the state and gave new flowers.

At Piliostigmathonningii

The behavior with respect to the damage sustained by the fire is almost the same as before. With the difference that the individuals whose crown is spared are rare. This is due to the fact that this species is smaller in size than *Crossopteryxfebrifuga*.

Monitoring the evolution also proves that the mortality observed in a few class 1 individuals was only apparent. Indeed, all rejected in early February. On this date, the young leaves are also effective for all individuals of classes 2 and 3. However, the latter bear, in addition, old burnt leaves. In mid-March, it is full leaf for all individuals of the three classes, but only class 1 is completely rid of the old burnt leaves. A new flowering has not been observed for individuals with burnt fruit.

-At Combretumfragrans

The difference observed here, for fire damage, is that mortality in class 1 is often not apparent. In fact, 5 individuals (out of 7 appearing dead at the start) remained as they were.

In this species, already a month after the passage of fire, new leafing had started in all individuals. However, the large individuals carry, in addition, old burnt leaves which they will lose only in early February. Here too, no new flowering has been observed for individuals whose fruit has burned.

- ***At Strychnosspinosa***

There is no mortality observed in small individuals. The new leaves are very slow to appear. Indeed, until mid-March, only half of the individuals in each class begin the new leafing. All individuals still carry the old burnt leaves. The class criterion does not seem to have an effect here. Flowering has been observed in a few class 2 individuals.

- At *Ximeniaamericana*

The small size of this species explains why all the individuals burned to the top.

One month after the fire, the small, leafless individuals reject at the base. Large individuals begin new leafing while maintaining their old burnt leaves.

In early February, it is full leaf for all individuals with some large individuals which still maintain, in addition, their old leaves. It was observed at this date, that a large part of the individuals were in flowering. In mid-March, we get the impression that the new leaves of large individuals are starting to dry out. Everything happens as if the leaves, which appeared after the fire, did not resist the heat (sun). Some individuals are in fruit.

Only the leaves located high in some large individuals escape the fire. The damage to the stem was remarkable, especially in small individuals who often remained dead (*Combretumfragrans*).

In each species, the reaction to fire (emission of new leaves) is all the more rapid the individual belongs to a small class. An exception is made for *Combretumfragrans* which does not seem to show any difference between the classes.

In terms of speed in the ability to provide new leaves after the fire, on the basis of our observations, we classify the studied species as follows: *Combretumfragrans, Ximeniaamericana, Crossopteryxfebrifuqa, Piliostigmathonningii, Strychnosspinosa.*

3.1. 3.Assessment of the damage caused by the experimental fire on the 3 sites

Figures 2, 3,4 and 5 show by area, by date of fire and by height class, the proportion of individuals suffering damage due to fire: burnt leaves (2), crowns affected (3), blackened trunks (4), apparently dead individuals (5).

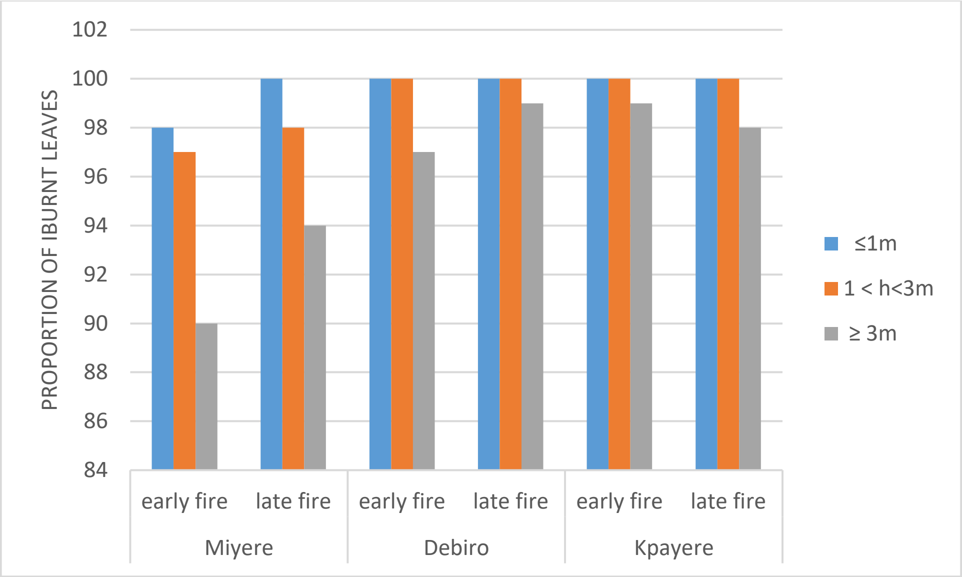


Fig.2: Fire damage: "burnt leaves" in PNMD

Generally only the leaves of some large individuals are spared from fire. This is explained by the fact that these leaves are located in height and therefore it takes high flames to reach them. Small individuals escape fire if they are in portions of space not covered by fire.

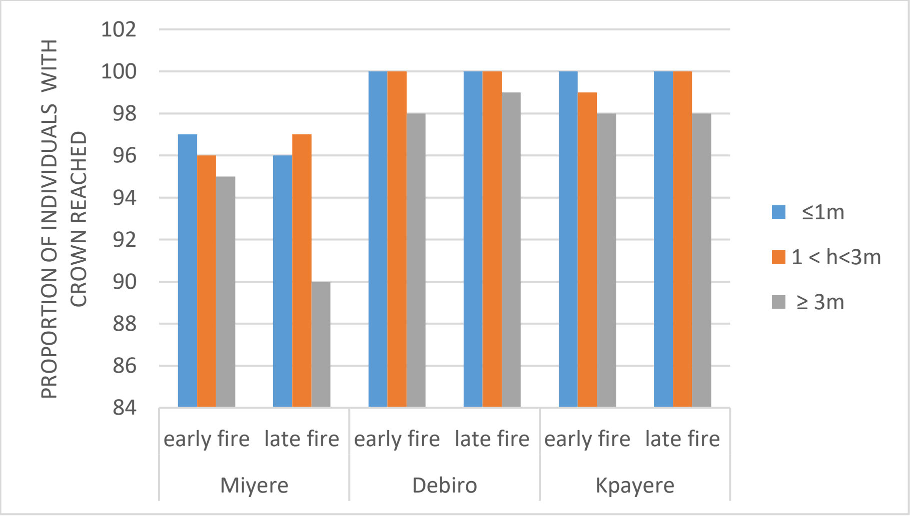


Fig.3: Fire damage: "peak reached" in the PNMD

For small individuals (class l), the damage "burnt leaves" implies at the same time, "crown reached". In large individuals, there is an increase in the number of crowns spared. However, this number is still very low compared to the burning tops.

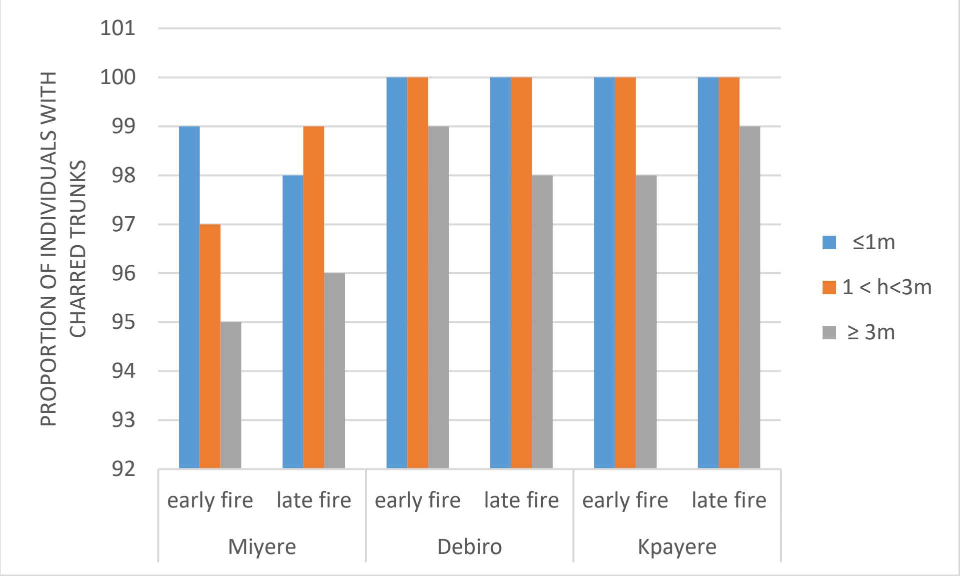


Fig.4: Fire damage: "blackened trunk" in PNMD

The majority of individuals have blackened trunks when the fire passes. The trunk being in contact with the ground, it is spared fire only on portions of spaces not burning. The height class of the individual here has no effect.

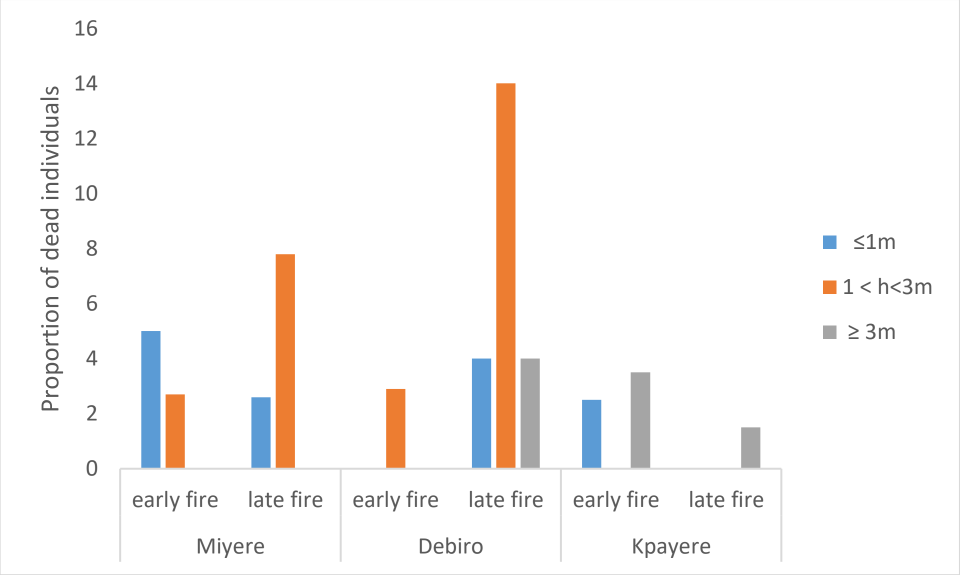


Fig.5: Fire damage: "apparently dead individuals in PNMD

High (apparent) mortality is observed for class 2 individuals suffering from late fires. In summary, the severity of the fire seems proportional to the size of the individuals. The size and state of drying of the herbaceous layer influences the height of the flames and its intensity.

The calculated fire intensity values change depending on the fire regime (early fire and late fire). César (1971 and 1992) has shown that the impact of fire on tree mortality is linked more to the physiological stage of the tree than to the intensity of this fire. This is why late fires are not recommended.

The late fires (April) are more destructive because they occur at a time when the vegetation has resumed its normal rhythm; indeed, in agreement with César (1971 and

1990) and Riou (1995), this period being characterized by the emission of young leaves, the fire obliges the tree to emit a second leafing which thus causes a physiological disturbance.

Tree mortalities are far higher than those initially observed in the savannah. The proportion, in particular of dead discharges (35%) which are forms of fire resistance, is greater in our study (1 to 2 orders of magnitude) than the values reported by Bond and Midgley (2001), Gignoux*and al.* , (2009), Wigley*and al.*, (2009) and Clarke *and al.*, (2010).

3.1. 4. Estimated contribution of woody plants to forage availability at the three sites.

Figure 6 shows the proportion of woody individuals in full leaf by area, by period of • fire and by date of monitoring.

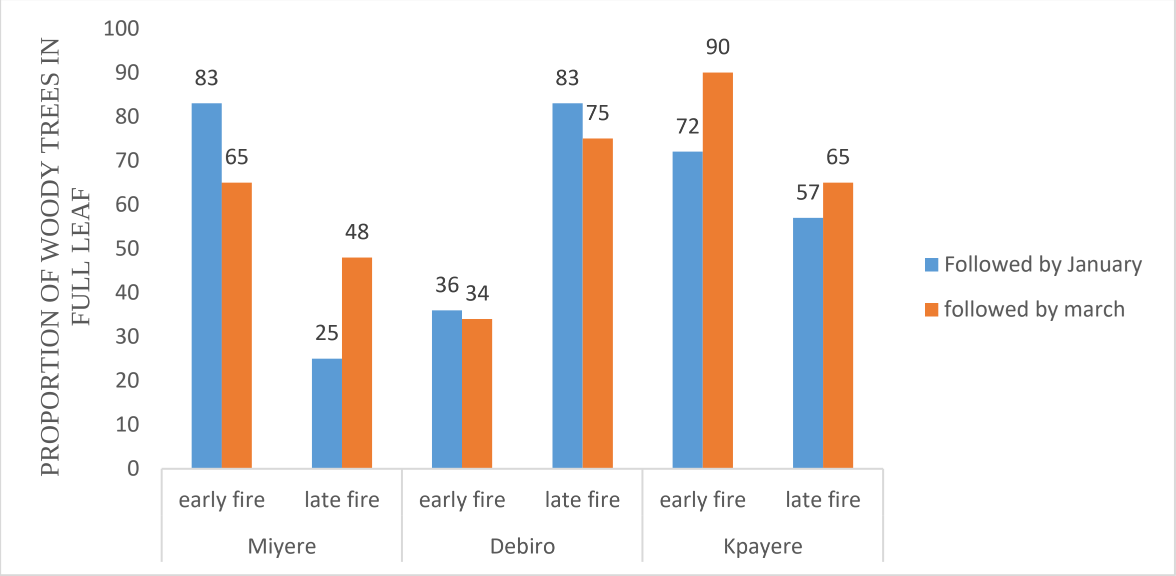


Fig.6: Proportion of individuals in full leaf in the three zones in the PNMD

We note for all the zones, for the two fire periods, that even for the mid-March follow-up (drawing towards the end of the dry period), there is a dominance of individuals in full leaf. Given the fact that this stage is the one which is qualitatively available for animals, it can be said that the crowns which have burned have a considerable contribution to the availability of woody dry season fodder. From January to March, the proportion of individuals in this leafing stage decreases considerably for the early fire in Miyere (83% to 65%) and for the early fires in Debiro (83% to 75%). It has been noted that this is due to a decrease in the number of class 1 individuals of certain species (*Piliostigmathonningii and Combretumfragrans* on the Miyere site, and *Piliostigmathonningii* at Debiro). In Debiro for early fire, the proportions of individuals in full leaf for late fire monitoring are around 34% and 32%, respectively, while defoliated individuals (FeO) dominate (75% and 83%). The bereaved individuals are mainly composed of *Terminaliasuperba*. One would therefore think that these species have a slow evolution after the fire.

For the early fire at Kpayeré, there is an increase in the proportion of individuals in full leaf (72% to 90%) between the two follow-ups. It was found that this is due to a considerable increase in the number of class 1 individuals. Also in this area, the proportions of individuals in the different stages of leafing do not vary much forearly fires. It is as if individuals progress in their phenology while maintaining the proportions.

IV. DISCUSSION

4.1 Impacts of fire on the woody stratum according to the fire regime

4.1.1. Fire behavior assessment

The calculated fire intensity values change depending on the fire regime (early fire and late fire). The intensity of the fires evaluated in this study is between 1440 and 4296 kW / m. These values are similar to the results obtained by N'dri*and al.*, (2012) who evaluated the intensity of fires in tropical savannas between 1200 and 2900 kW / m and by Afelu*and al.*, (2015) who evaluated l intensity of fires in the sub-Saharan zone between 1000 and 3000 kW / m.

The propagation speed evaluated in this study oscillates between 0.084 and 0.166 m / s and increases with the duration of the dry season, therefore with the fire regime at the three sites. The later the fire, the faster its spread. These values are close to the 0.09 m / s of N'dri*and al*. (2012) in the preforest savannas of Lamto in Ivory Coast and close to 0.1 m / s of Afeluand al., (2015) in three PAs (OKM, Abdoulaye and Togodo) than in Togo, but significantly lower than that found by Daisuke *and al*., (2014) who evaluated it between 2 and 4 m / s with peaks reaching 5, 8 m / s. This difference is explained by the fact that these latter authors took into account the influence of crown fires (canopy fires) on the speed of propagation relatively more dynamic than surface fires.

The spread of fire is significantly influenced by the fire regime, but the amount of combustible biomass is only significantly influenced by the site effect. Fire behavior is then influenced by the variation of climatic parameters from one fire regime to another (season effect) and from one PA to another (site effect) (Afelu*and al*., 2016). For a given period and an ecosystem, the characteristics of the fires vary according to the rate of drying of the biomass and the intensity of the dry season (Bassett *and al*., 2015).

The influence of the regime on the intensity of the fire was noted at the three sites studied. It emerges that the later the fire, the more its intensity increases. The three fire regimes are characterized in relation to their intensity. Mid-season fires tend to behave like late fires. Early fires are distinguished from other fire regimes with relatively low intensity. Previous studies confirm the results obtained.

These parameters do vary with the amount of vegetable fuel and the fire regime. At Lamto, the average intensity of the mid-season fire was not significantly different from that of the late fire and the mid-season fires behaved almost aslate fires and only early fires were clearly distinguished from other fire regimes by the low intensity (N'dri*and al*., 2012). Mid-season fires would exhibit the same behavior as late fires, hence the simplified distinction between two fire regimes in early fire and late fire. The biotic and abiotic factors that make it possible to clearly differentiate between different fire regimes would be increasingly disturbed by climatic disturbances which reinforce the parameters for the outbreak and spread of fires (Dosso*and al*., 2011; Kane *and al*., 2015). This upheaval is linked to an increasingly long and intense dry period, the increase in global temperature and rainfall disturbances at global and local level (Shimelmitz*and al*., 2014). This situation explains the fact that more and more mid-season fires are merged with late fires (N'dri*and al*., 2012).

The results obtained in this study have shown that the site effect and local specificities can modify the behavior of fires during their propagation. The work of Porterie*and al*. (2005) confirmed that the nature and structure of the ground cover induce sudden variations in the speed of propagation with temporal oscillations in the propagation of fire. Fire behavior is also dependent on plant biomass. But the latter does not have the same characteristics from one site to another.

According to Griffiths *and al*., (2015) the behavior of fire is also an important parameter in the design and construction of firebreaks and firebreaks in planning and protection of issues vulnerable to wildfires. Indeed, Kaiss*and al*. (2007) have shown that the design and effectiveness of fire management measures are based on a good understanding of the behavior of fire in the local context of its occurrence. The distribution of the fires revealed two directions of propagation testifying to the distinct responsibilities between PA managers and local residents. On the one hand, the outbreak of certain fires inside the PA and their spread to riparian areas. These fires are generally caused by intrusions into the PA by poachers and operators of PA resources who, from their camps or trespassing areas, cause fires to start.

As for the development lights, they can constitute dangers if the measures are not taken sufficiently to secure the interfaces and to circumscribe them strictly to the sites intended to be burned. On the other hand, the outbreak of fires in peripheral human activity zones and their progression towards the interior of the PA constitute the main part of the direction of progression of fires (Valea, 2011). These remarks are explained by the contiguity of the zones of human activity with the limits of the PA coupled with an insufficiency of specific security and fire protection measures (Van Wilgen*and al*., 2014). Since vulnerability to fire is a less well-known component, knowledge of the parameters for evaluating fire behavior makes it easier to validate models of response to fires. The results of this study confirm the approach of multicriteria and multiscale analysis of fire dynamics (Valea, 2011) and show that fire dynamics are not random but dependent on the biotic and abiotic factors of the environment which influence the behavior of fires through combustible biomass, the direction of the wind, the speed of propagation and the intensity of fires (N'dri*and al*., 2012).

4.1.2.Analysis of the impact of fires on the woody stratum

The calculated fire intensity values change depending on the fire regime (early light and late fire). César (1992) points out that the impact of fire on tree mortality is linked more to the physiological stage of the tree than to the intensity of this fire. This is why late fires are not recommended (Kakadu Board of Management 1996). The period of late fires (January to April) are more destructive because they come at a time when the vegetation has resumed its normal rhythm; indeed, in agreement with César (1990) and Riou (1995), this period being characterized by the emission of young leaves, the fire forces the tree to emit a second foliage which thus causes a physiological disturbance. The present study noted that the impact of fires varies with the fire regime. This result confirms that late fires characterized by their high intensity can induce high plant mortality and reduce the availability of biomass (César, 1992; N'dri, 2011).

On the other hand, early fires are less destructive *and al*low the development of pyrophilic species. The state of a savannah (nature and abundance of species present, relative importance of woody and herbaceous species) reflects, among other things, its past in the event of fire (Fournier, 1991; Beerling and Osborne, 2006). The operating and production principles vary from one savannah to another depending on the ecological context. Local parameters, mainly the intensity of the fire and the direction of the prevailing wind, have consequences on the behavior and impact of the fire (Grégoire and Simonetti, 2007).

In the long term, fire causes the debarking of 74% of the trees. These barked areas are entry points for termites in trees (N'Dri*and al*., 2011) and bees. These termites, once in the tree, will cause internal hollows which will subsequently be exposed by the recurrent action of fire. According to Mattheck and Kubler (1995), the external hollows thus created weaken the mechanical resistance of the trees. In addition, adults are significantly more barked (70%) than young people (30%) (deviance = 32,447 df = 1, $\chi 2$ = 103,014, p = 0.004).

4.1.3. Effects of fire on the structure of vegetation

In PNMD, the effects of frequent fires on woody species in the long term are an increase in their mortality, a reduction in their size, a reduction in their cover, a reduction in the density of individuals, and a decrease in the number of woody species (Hoffmann*and al*., 2002). We find most of these symptoms in the trends of our results but with some nuances. The response of the vegetation to the passage of fire is not homogeneous: it varies in direction and in amplitude and according to the shape of the device and the year. However, the averages make it possible to identify trends which remain to be validated statistically.

The data of the device seem to show a modification of the structure of the vegetation:

1) The tall shrub strata (between 2 and 4 m) disappear completely in one case

Six following the passage of a single light and in 3 cases out of 5 following the passage of 2 lights, while they persist on the witness.

2) The low shrub strata (between 1 and 2 m) disappear completely in 4 cases out of 9 following the passage of 2 fires, while they persist on the burnt plot once and on the witness.

3) The herbaceous strata progress on the whole of the system (including control) but with a stronger average development on the plots having burned. Although visually very noticeable in the field and on the devices, these results are not sufficient to be statistically significant.

4.1.4. Effects of fire on plant composition

The fire seems to influence the floristic composition of the communities. Indeed, the woody species are the main constituents of the shrub layer and are therefore particularly affected by the passage of fire as seen above. On the other hand, after 2 years, the number of woody species tends to increase everywhere on the device, however less pronounced on the plot burned early (+0.5 woody species per rectangle on average), than on the plot burned late (+0.8) and only on the control (+1.5).

The number of herbaceous species per rectangle increased across the entire system, but slightly higher in the plots that burned (+ 52% after early fire and + 54% after control light) than on the control (+ 40%).

We also note the appearance of small annual herbaceous species of short savannah following the passage of fire, while the witness seems to be characterized by the presence of shrub species.

These trends generally correspond to the expected results, but insufficiently marked to be validated statistically.

The increase in the total specific richness stronger on the control than in the burned plots suggests that the ecosystem diversity is higher there (more ecological niches appear) and that the decrease in the increase in the specific richness on the plots having burned, on the contrary, corresponds to a homogenization of habitats. These trends are however very weak and 2 years of follow-up are not enough to confirm this hypothesis. The calculation of the Bray-Curtis distances 12 months after having known the passage of a fire indicates an increase in the differences in floristic compositions of the herbaceous layer between the control and the plots having burned, then a stabilization the following year. The passage of fire also homogenized the flora of the herbaceous strata on the two burned plots.

Finally, let us recall the striking phenomenon of the entire system: the strong renewal of species, which implies a strong effect of climatic conditions on the floristic procession present at the time of the inventory. This turnover could be at least partially at the origin of the insignificance of the statistical tests.

4.1.5. Influence of fire on invasive alien species

The potentially invasive exotic species observed on the devices represents a total of 28 observations, which is very insufficient to conclude. We simply note the presence of a species that appeared on the devices after the passage of fire: *Chromoleanaodorata.*

It is commonly accepted that fire can promote the development of invasive alien species for several years after its passage (Brooks *and al*., 2008; Coutinho, 1990), the present experiment suggests that the influence of fire on invasive alien species is little marked in the short term (2 years of follow-up).

V. CONCLUSIONS

This study reveals that the current fires are deeply degrading the forest cover in the park. The results of research conducted even for a fairly short period clearly show the differences between the treatments with early fire and with late fire. They confirm the thesis that early fires damage vegetation much less than late fires: the fire treatment in February consumed almost all of the grassy biomass.

One of the objectives of this article was to relate tree mortality to the different fire regimes practiced. To do this, all the trees were labeled and identified on the various sub-plots before setting them on fire; in addition, the stages of development have been determined. Six months after each fire regime, these sub-plots were again visited in order to identify the dead individuals. Tree mortalities are far higher than those initially observed in the savannah. The proportion, in particular of dead discharges (35%) which are forms of fire resistance, is greater in our study. However, our method of marking trees deserves to be improved before drawing rational and objective conclusions from the impact of the intensity and regime of fire on tree mortality. In fact, all stages of development (young, suckers and adults) were marked with labels that were attached directly to the trees. Once the aerial part destroyed with the label, the plant is considered dead, while the suckers can leave the burned base.

The impact of long-term fire on the trees shows that 74% of the trees examined are barked by fire. What constitutes entry points for termites and bees in trees. The passage of fire causes changes in the structure and floristic composition. This effect appears to be rather positive for open savannah ecosystems: rapid re-opening of the environment by reducing the importance of shrub strata; strong regression of certain shrub species responsible for the closure of the environment; increased recovery of the herbaceous layer and specific richness in herbaceous; appearance of small annual herbaceous savannas that have traditionally "taken advantage" of the opening of the environment to settle. It is however difficult to conclude on an arrival by dissemination or germination from the seed bank

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

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