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# **Savanna fire regimes assessment with MODIS fire data: their relationship to land cover and plant species distribution in western Burkina Faso (West Africa).**

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**Original version before submission**

## ***Summary***

The West African savannas are subject to changes in fire regimes related to land use intensification, which may infer significant biological modifications. We investigated the efficiency of MODIS fire products to account for the variability of fire regimes in relation to changes in land cover and savanna vegetation. The specificity and complementarities of both MODIS active fire (MOD14A2 and MYD14A2) and burned area (MCD45A1) products were assessed in order to characterize fire regimes and to relate them with land cover. In addition the distribution of plant species between landscape units characterized by specific fire regimes was assessed. The calculation of the mutual information made it possible to set apart species more frequent in landscapes little or not at all subject to fires and species more frequent in burnt areas. The first group is the expression of the nature of the unburnt land-cover units, mainly constituted by the agricultural areas dominated by fields and fallows. It consists of more potential threats (weeds, encroachers, invasive species etc.) than the second group, which is more typical of sudanian savannas. It thus appears that unburnt landscape units are currently more sensitive and vulnerable to some biological threats than the burned savannas, where fire provides the long-term stability needed to preserve the ecosystem.

## ***Introduction***

Fire is a main determinant of the West African savannas, thus changes in fire regimes, i.e. the intensity and frequency of fire, may infer significant biological modifications (Menaut & César 1982, Gillon 1983, Frost & Robertson 1987, Louppe et al. 1995a & b, Getzin 2002, Govender et al. 2006, Nielsen et al. 2003). Severe changes in vegetation types and in floristic composition can indeed be expected, as demonstrated by various investigations made in different fire-prone vegetation worldwide (Aubréville 1953, Goldammer & Price 1998, Hoffman 1999, Moreira 2000, Wheaton 2001, Williams et al. 2002, Whitlock et al. 2003,

Backer et al. 2004, Dellasala et al. 2004, McKenzie et al. 2004, Bond et al. 2005, Doe 2008, Moretti et al. 2008, Pausas et al. 2008, Roitman et al. 2008). Such changes can have social and economic consequences, notably because of the importance of pastoral and wild resources for the sudanian rural societies. Fire regimes may therefore reveal land cover patterns and related land uses (Dolidon 2005, 2007); detecting spatial or temporal changes in fire regimes can then help to detect underlying environmental changes (Morgan et al. 2001, Kasischke & Turetsky 2006).

The assessment of fire regimes across broad territories is carried out efficiently by means of data obtained by remote sensing (Kerr & Ostrovsky 2003, Mayaux et al. 2003, Lentile et al. 2006, Chuvieco et al. 2008) such as MODIS fire data, that are specifically designed for this purpose (Justice et al. 2006). The MODIS products are currently downloadable free of charge and can thus be very generally used. Many studies highlighted potentialities and limitations of the MODIS active fire product (De Klerk 2008), which maps fires detected four times a day when the satellites pass overhead (Justice et al. 2002). For MODIS burnt area products (which maps the spatial extent of recent fires), of which only a provisional version is available up to now for evaluation purposes, such studies are however few (Giglio 2005, Giglio *et al.* 2005, Roy et al. 2005, Roy *et al.* 2008). The results provided by the two products may diverge for some areas, but they also may be complementary (Roy et al. 2008). Therefore, ascertaining the accuracy of MODIS fire data in relation to various local conditions is currently required (Giglio et al. 2009).

In the savanna biome, fire regimes are closely related to the amount of standing herbaceous phytomass that varies in quantity and composition over space and time according to topography, land use, herbivores pressure and climatic variability (Mbow et al. 2000, Mbow et al. 2003, Van Langevelde et al. 2003, Hennenberg et al. 2006). Changes in land use and climatic variability are likely to change the fire regimes that modify the effects of fire on ecosystems; in particular this may alter the balance among *taxa* according to their fire tolerance. In fire- adapted ecosystems plant life histories appear fine-tuned to particular fire regimes linked to specific sites (Glover 1968, Moreira 2000, Bond et al. 2005 Keeley & Bond 2001).

In the West African sudanian zone, the contrast between the pyrophytic flora of savannas and a former endemic flora of dry forests, still persisting in some place free of fire, was often reported (Aubréville 1947, 1949, Devineau 1984, 2001, Swaine 1992, Neumann & Müller-Haude 1999). The capacity of some of these so-called dry forest species to colonize unburnt areas had also been demonstrated, so that some wooded areas may be recent (Larrue 2002). In

addition the removal or alleviation of fire may favour the establishment of exogenic and wide-ranging species (D'Antonio & Vitousek 1992). For example, in the zone studied these latter species are more abundant in the agricultural areas, which can result from, among other possible causes, a reduction in the activity of fires (Devineau et al. 2009). Up to what point such a disappearance of fire or such a reduction of the associated constraints can allow this dry forest (endemic) flora or, on the contrary, an exogenic flora of wide-ranging species to substitute for the savanna flora can therefore be questioned. The interrelations between savanna fire regimes and vegetation dynamics are indeed complex; they are constrained by various climatic, biotic and anthropogenic factors involving various feedbacks (Scholes, & Archer 1997, Hoffmann et al. 2002, Van Langevelde et al. 2003, Beerling & Osborne 2006,) and they are still not well understood either in their ecological or in their human aspects (Laris 2002, Wiegand et al. 2006).

This study aims at evaluating how fire regimes — characterized from the MODIS fire data — are related to land-cover variability and which differences in floristic composition can be connected to these regimes. Taking into account what is known about the ecology of plants of West African savannas, the assessment of the mutual information between the fire regimes and the presence of the species within the landscapes affected by given fire regimes will help to specify both the accuracy of the MODIS data and the impact of fire regimes on phytodiversity.

### **Study area**

The zone studied extends from 11° to 12° 2' latitude North in western Burkina Faso (in the provinces of Houet, Tuy, Balé, Mouhoun and Sanguié). The climatic and ecological conditions range from South sudanian with 900 to 1 100 mm annual rainfall and 5 to 6 dry months (with under 50 mm rainfall) to North sudanian with 800 to 900 mm annual rainfall and 6 to 7 dry months (about November and October to April) (Fontès & Guinko 1995) (figure 1).

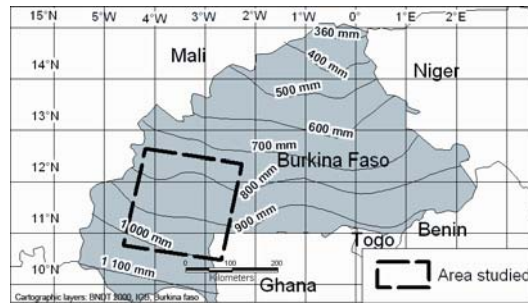


Figure 1 -Localisation of the area studied (Landsat ETM+ 196\_052 scene)

The whole zone is part of the “cotton area”, with agriculture based mainly on sorghum, millet, groundnuts and some legumes; but the agricultural production in the South sudanian zone is more intensive and more varied, especially as a result of the cultivation of yams and of perennial crops (mangos, citrus fruits, cashew nuts, etc.). The region studied includes many protected areas that succeed one another along the Mouhoun river and a South-North climatic gradient from the “Mare aux Hippopotames” Biosphere Reserve to the Tiogo “Forêt Classée”. Fire-prone savannas cover the whole zone, but due to increasing climatic dryness various floristic and physiognomic changes are observed: patch forests or gallery forests become scarce northward, while deciduous trees become more abundant, e.g. the higher frequency of *Acacia* species (Wittig et al. 2004).

Strict laws provide for the regulation and management of fire in the rural areas and watchwords against the abusive cutting of wood, the divagation of animals and the bush fires were even given during the “three fights” period (1985) in Burkina Faso. In spite of that, fire indeed remains a fundamental characteristic of the savanna ecosystem in the West of Burkina Faso, as more generally in African savannas (Ampadu-Agyei 1998). More pragmatic legal approaches were subsequently adopted by distinguishing management and customary ritual fires from bush fires (Government of Burkina Faso 1998, Grégoire et al. 2003, Laris & Wardell 2006). Nowadays bush fires, defined as uncontrolled, are prohibited; the other types are tolerated, but in a precise framework. The management fires must be under the control of their perpetrators; they are typically clearing fires and “early” fires lit in order to settle or clean cultivation fields. They also include technical management fires such as for the maintenance of pastoral areas and for the conservation of protected areas (national parks, game reserve, state forests). Ritual fires, which may be lit in different places as part of customary ceremonies, must be supervised both by the State and the traditional authorities and, most of all, controlled. This new realistic legislation is more consistent with everyday practices in most countries in West Africa, since rural populations use fires as a working tool for agricultural purposes, for pasture management and for hunting (Bruzon 1994). In addition,

ritual fire is a still deeply rooted practice, as shown by Dugast (2006, 2008) who put in light the social and symbolic character of the yearly ritual burning of holy sites among Bwaba (Burkina Faso) and Bassar (Togo) societies.

## ***Materials and methods***

### **Acquisition and calculation of MODIS data**

We used the 1 km resolution 8- day summaries of the MODIS active fire data (MOD14A2 and MYD14A2). Products were downloaded thanks to the NASA Land Processes Distributed Active Archive Center (LP-DAAC) anonymous FTP server (<ftp://e4ftl01u.ecs.nasa.gov/> ). The period studied goes from 2000.03.05 to 2008.06.30 and the zone studied was extracted from the tile h17v07.

We also downloaded the Monthly Tiled 500 m Burned Area Product (MCD45A1) from the ftp server <ftp://ba1.geog.umd.edu/> . Data acquired (the last on 2008.06.27) goes from 2000.09 to 2008.04, but 2004.09 to 2004.12 were missing.

Thanks to the MODIS Reprojection Tool (MRT v4.0), the MODIS “hdf” files were transformed into a GEOTIFF format to be worked with the MAPINFO software.

For MOD14 and MYD14, we considered pixel class higher than or equal to 7 as fire pixel. For MCD45A1 data, we considered pixel with a value of approximately Julian day of burning as burnt and all others as not burnt.

We compiled data according to four periods during the dry season: very early (Julian days (JD) 249-304), early (JD 305-365), late (JD 001-064) and very late fires (JD 065-151).

These limits are generally accepted for the area studied (Bationo et al. 2001 a et b, Laris, 2005, Ouédraogo & Delvingt 2007), they take into account the shortening of the dry season from the South to the North of the area (Nielsen & Rasmussen 1997, 2001) and are in accordance with the climatic seasonality and the phenological rhythms of the vegetation (Fournier 1991, 1994, Devineau 1997, 1999). In addition we compiled data on an annual basis.

We calculated 1) fire density as the number of pixels that got fire within given areas (the entire zone studied, specific areas such as protected areas, and the various land-cover and landform units) and 2) fire frequency as the return interval of fire (i.e. the number of years a pixel got fire relatively to the number of observed years). The fire return frequency per year was calculated considering together active fire and burnt area data.

## **Establishing relationships between surface variables and MODIS data**

### ***Crossing MODIS fire data with land cover units previously established from ETM+ satellite data***

The zone studied is exactly delimited by the 196-052 ETM + satellite scene of which three images on June 3, 2001, June 22, 2002 and December 28, 2001 were previously analysed. This former study defined eleven land-cover units according to vegetation cover and soils, both assessed by way of ETM+ remote sensing satellite data (Devineau et al. 2008). The land cover characteristics of each MODIS fire pixel can therefore be assessed as the proportion of ETM pixels (28,5 meters) classified in the eleven land cover units. The relationships between occurrences and frequencies of fire and land cover units can then be summarised in term of contingency tables (i. e. frequencies of ETM land cover classes belonging to MODIS fire classes) whose statistical significance can be evaluated by Chi<sup>2</sup> tests and then factorized by correspondence analyses.

### ***Linking MODIS fire data to terrain surveys***

Terrain data are 635 vegetation relevés of a georeferenced database established for the area (Vidal *et al* 2006) and 50 supplementary observations ascertaining pre- and post-fire conditions in September and December 2008 for some precise MODIS fire classes. The vegetation relevés were founded on the classic phyto-sociological method of the homogeneous area. The sample-plot size (generally 40\*40m plots) was in practice a compromise that guaranteed a valid representation of the woody species diversity and made it possible to ensure the physiognomic homogeneity of the stand with regards to the physiognomy of the woody species community and dominant herbaceous species (Devineau 2005). The vegetation plots were investigated in every vegetation type along tracks distributed in the whole of the area studied, inside and outside protected areas. Each plot was geo-referenced and could be associated with a MODIS fire class and with an ETM+ land-cover class as well. Because of the small size of the ETM pixel, the correspondence of the latter with terrain observations was always carefully verified.

The Mutual Information (MI) (Godron 1968, Daget & Godron 1982, Steuer et al. 2002) and also a Chi<sup>2</sup> test were calculated between species frequencies (considering presence data) and MODIS fire classes with the ADE4 software (Thioulouse et al. 1997). As MI and Chi<sup>2</sup> don't give fully corresponding results as to the significance of co-occurrence, we considered that a link between a species and a fire regime could be established only when the MI of the species

was equal at least to the lowest MI value corresponding with a significant Chi<sup>2</sup> test (0.05). As both tests strongly differ in their discriminating efficiency they appear to be complementary. As a normalized value, the Chi<sup>2</sup> is not reliable for low-frequency species, while the MI measures the connection between two variables whatever the number of individuals of the population, but doing so, the assessment may be biased towards rare species.

In order to know something of the opinion of villagers about fire change, questions were asked of 15 persons (croppers and herders) in ten localities between Bondoukuy and Dédougou (80 km apart) in September 2008. This informal enquiry aimed only at giving some clues for interpreting remote-sensing data.

## **Results**

### **Correspondence of fire regimes assessed by MODIS data with land-cover units**

#### *Differences between active fires and burned areas data*

The ability of active-fire-data and of burnt-area-data to account for areas affected by fire is somewhat different. During the whole period of observation, 42 % of the area were indeed detected by both MODIS products as having been affected by fire and 26 % as not having been burnt; but 24 % of the areas affected by fire were detected only by active-fire-data and 8 % only by burnt-area-data. These differences can however be related to land cover characteristics. The crossing between ETM land cover units and MODIS either burnt or active-fire-data shows that both are dependent (Chi<sup>2</sup> test was significantly different from random distribution beyond the 99.9% level; this is also the case for all the following relationships among land cover, fire frequencies and seasonality and that will not be repeated). Unburnt areas correspond to the agricultural domain (fields, fallows of slopes and bottom-slopes) and to bare soils, in contrast active fire and burnt areas were detected together mainly on bushy savannas on gravelly soils and hardpan (figure 2). Areas only detected as burnt were mainly tree or open savannas, particularly on upperslopes that usually have a continuous herbaceous stratum but a low phytomass. Areas only detected as active fire places were mainly savanna woodlands of wet places, usually with high herbaceous phytomass, but typically fragmented.



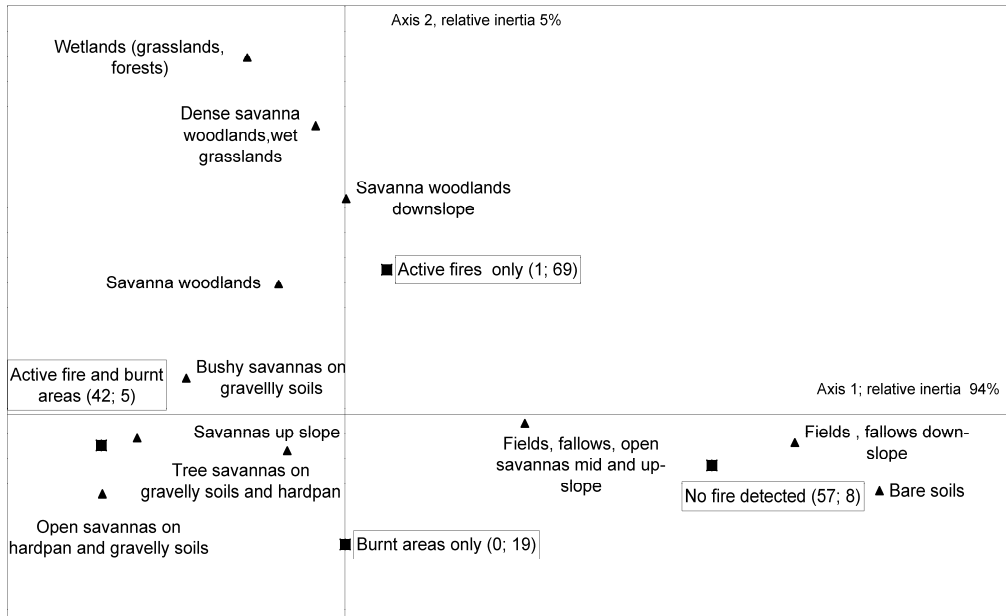


Figure 2 – Correspondence analysis between land cover units and type of fire detection: active fire or burnt areas (Western Burkina Faso). (Between brackets: absolute contribution of fire type to respectively the first and second axis)

Additional field observations confirmed these results. Areas where active fires were detected were characterised by high herbaceous biomasses and areas where active fire and burnt areas were jointly detected corresponded mainly with savannas on gravelly soils and hardpan complexes. Areas only detected as burnt areas had a rather continuous herbaceous stratum of lower biomasses. Areas where no fires were detected were mainly agricultural zones or village neighbourhoods characterised by very open treed savanna (parklands) or herbaceous fallows. Fires are however not always absent from such areas, where they can affect sparse patches of not very dense vegetation, but they are neither strong enough to be detected as active fire nor large enough to be detected as burnt areas. As an example, no fire was detected on a wide part of the South-West of the Sorobouly state forest, that corresponds to the illicit or tolerated establishment of fields; but between these fields, many small burnt areas were observed, which correspond to small places with a herbaceous cover of low biomass (e.g. patches of *Loudetia togoensis*, *Elionurus elegans* in scattered clumps and *Michrocloa indica* forming a low continuous cover) or to the burning of the leaf-litter of woody species under shrubby thickets.

### *Land cover and fire seasonality*

In order to study the variability of the seasonal density of fires according to landcover, we took into account the four seasonal periods (very early, early, late, and very late fires) and some of their combinations (these last ones taking into account the return of fire in several seasons on the same pixel). The great majority of the surface of the area studied was burnt between November and February, early fires (November-December) being obviously more dense and frequent (figure 3).

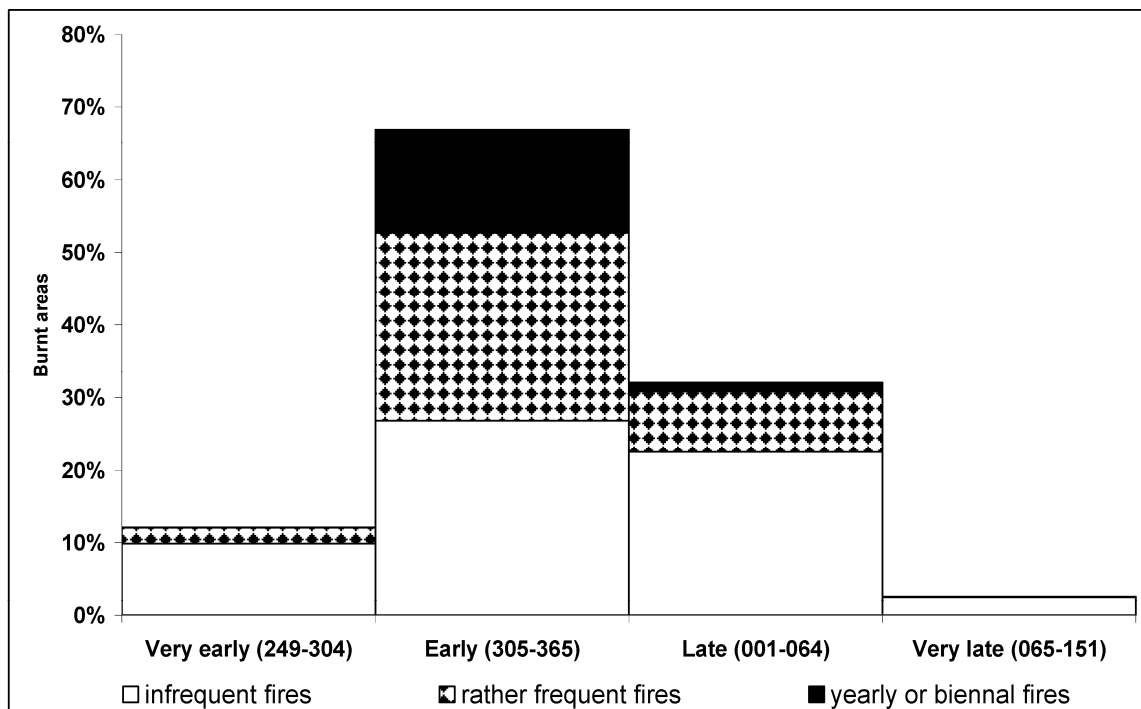
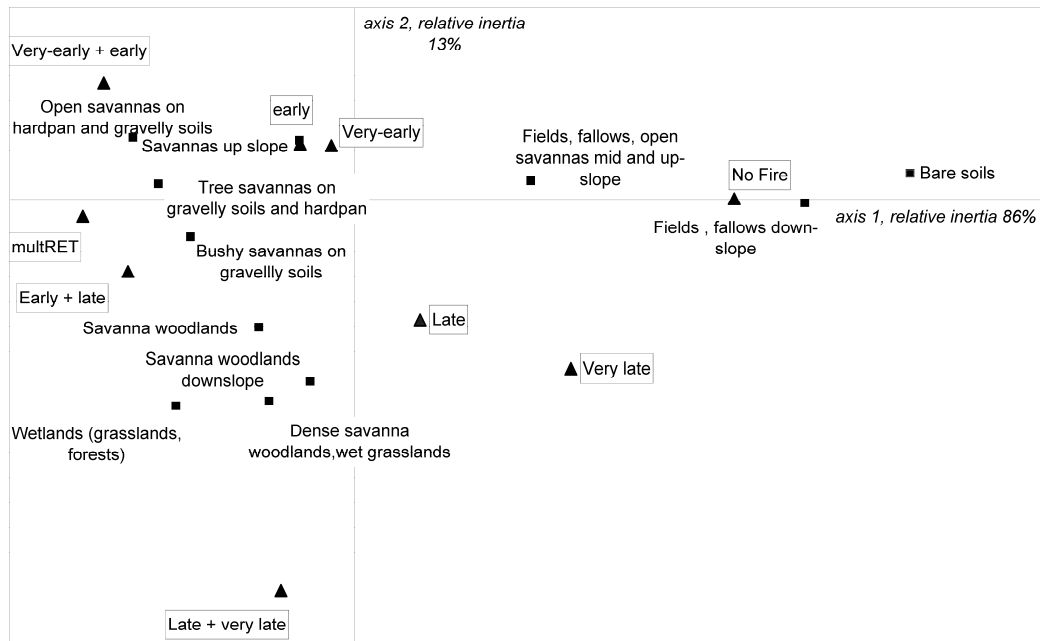


Figure 3 – Seasonal distribution of fires on the studied area in Western Burkina Faso (proportion of MODIS pixels that got fire during each season; data compiled from 2000 to 2008).

The seasonality of fires varied markedly however according to land cover. Agricultural zones on slopes and bare soils on bottom slopes appeared again as not burnt areas. Very early fires affected mainly open or herbaceous savannas on gravelly soils and hardpan. Seasonal fires return on the same pixels were observed mainly for tree and bushy savannas on complexes of gravelly soils and hardpan, whereas late and very late fires featured wet places (dense savannas and savanna woodlands on downslopes, wet grasslands etc.) and also some cultivated areas (e. g. fields and fallows on downslopes) as shown by the median position of the modalities “late” and “very late” relative to the positive part of axis 1 and to the negative part of axis 2 (figure 4). In addition fires occurred earlier in the drier parts of the area studied,

in relation with the beginning of the dry season, but the pattern of fire seasonality according to land cover was nevertheless similar over the whole area.



1 Figure 4 – Correspondence analysis between land cover units and seasonal occurrence of fires  
 2 (Western Burkina Faso)

***Variability of fire frequency according to land cover and land use***

The most frequent fires (yearly or biennial) were observed mainly on hardpan and gravelly soils. Fairly frequent fires were observed in all savanna formations, but fires were infrequent or missing on agricultural lands, in particular on lowlands, where cultivation is more intensive and fallows are sparser and shorter (figure 5). As a rule, yearly or biennial fires predominated in protected areas (table 1) but fires were however scarcer in those including wide areas poorly covered, in particular in the northern part of the zone studied (figure 6).

1 Table 1 - Fire's regimes occurrence within and without protected areas (West Burkina Faso,  
 2 area delimited by the 196-052 ETM + scene)

	inside protected areas	outside protected areas
No Fire	8.2%	29.4%
Infrequent fires	13.1%	22.4%
Fairly frequent fires	31.3%	27.2%
Yearly or biennial fires	47.4%	21.0%

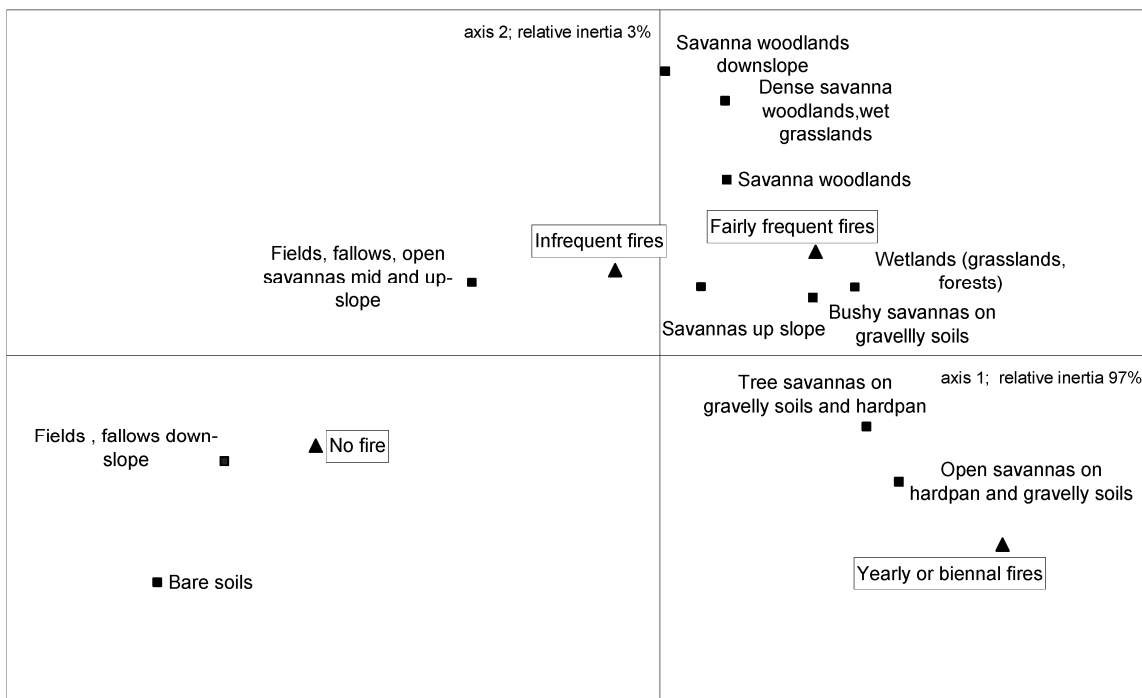


Figure 5 – Correspondence analysis between land cover units and fire frequencies (Western Burkina Faso)

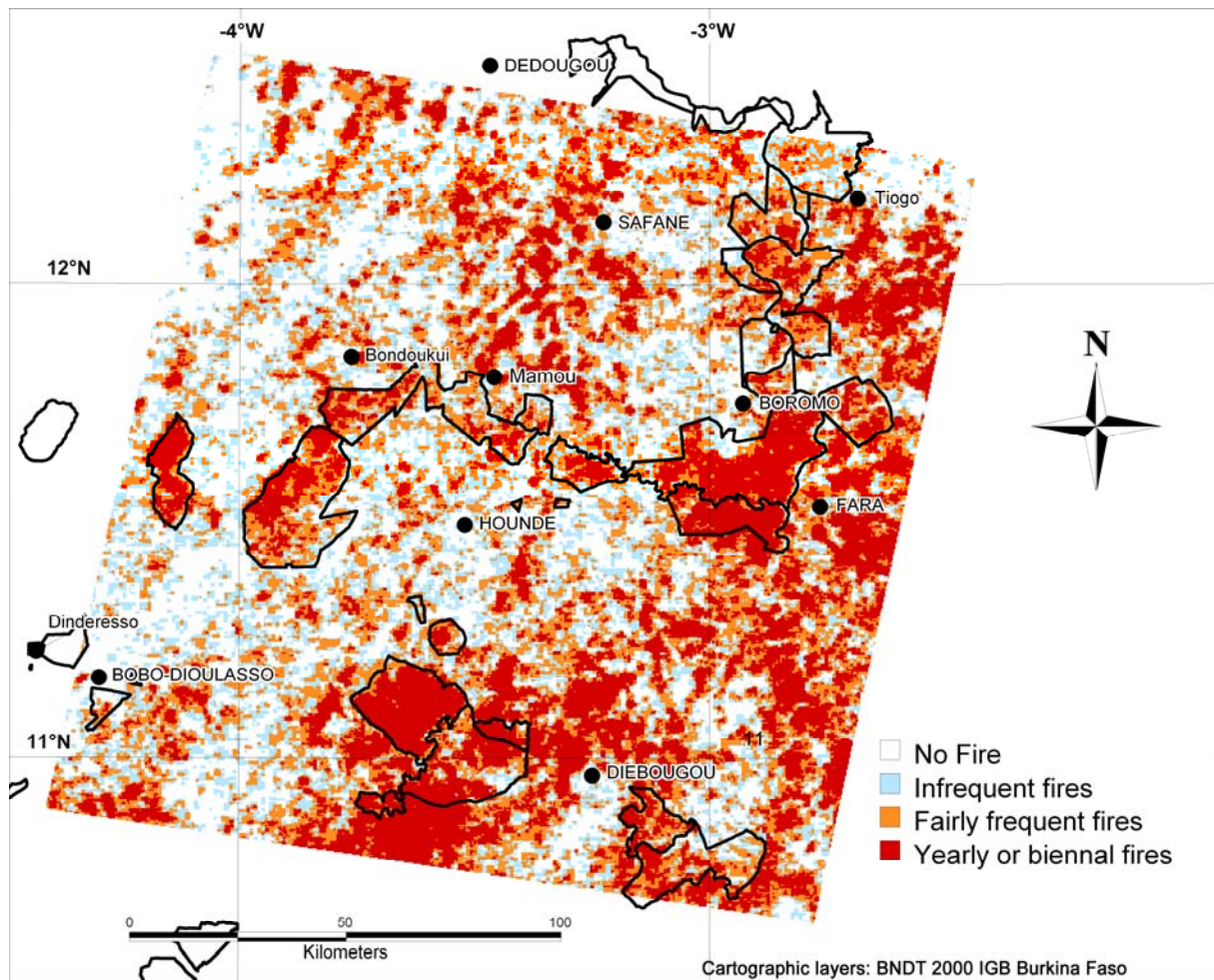


Figure 6 – Fire’s frequency distribution in the area studied (protected areas are framed)

### Plant species distributions according to the fire regimes

The assessment of mutual information showed up as statistically significant and ecologically meaningful links between the distribution of species and the fire regime units could be established by means of MODIS data. Fifty- one out of the 204 species studied were thus statistically significantly linked with fire units (see electronic supplementary data). The correspondence analysis of the frequency distribution profiles for these 51 species enables the characterisation of the species distributions according to fire regimes. It clearly appears that species distributions are organized according to two main groups, the first related to annual, biennial and fairly frequent fires, the second related with infrequent fires and the absence of detected fires (figure 7). With the exception of *Vetiveria nigriflora* (a species of stream-sides and swampy areas), the second group consists of species with not very specific habitats or related mainly to open savannas and fallows in agricultural zones (table 2).

Table 2. Species significantly linked with landscape fire's regimes in Western Burkina Faso (highest mutual information and H0 probability  $\leq 0.05$ )

<b>Frequent , yearly, biennial fires</b>		<b>Infrequent fires or no fire</b>	
<b>Woody</b>		<b>Grasses and sedges</b>	
<i>Azelia africana</i>	Afaf	<i>Aristida sieberana</i>	Arsi
<i>Bombax costatum</i>	Boco	<i>Bulbostylis abortiva</i>	Buab
<i>Burkea africana</i>	Buaf	<i>Ctenium newtonii</i>	Ctne
<i>Entada africana</i>	Enaf	<i>Cyperus rotundus</i>	Cyro
<i>Prosopis africana</i>	Praf	<i>Cymbopogon schoenanthus</i>	Cysc
<i>Pterocarpus erinaceus</i>	Pter	<i>Digitaria debilis</i>	Dide
<b>Grasses</b>		<i>Euclasta condylotricha</i>	Euco
<i>Andropogon tectorum</i>	Ante	<i>Microchloa indica</i>	Miin
<i>Diheteropogon hagerupii</i>	Diha	<i>Paspalum scrobiculatum</i>	Pasc
<i>Hyparrhenia smithiana</i>	Hysm	<i>Vetiveria nigriflora</i>	Veni
<i>Loudetiopsis kerstingii</i>	Loke	<b>Forbs</b>	
<i>Schizachyrium sanguineum</i>	Scsa	<i>Amorphophallus aphyllus</i>	Amap
<b>Forbs</b>		<i>Cochlospermum tinctorium</i>	Coti
<i>Raphionacme daronii</i>	Rada	<i>Crotalaria retusa</i>	Crre
<b>Sub-shrubs</b>		<i>Curculigo pilosa</i>	Cupi
<i>Cochlospermum planchonii</i>	Copl	<i>Evolvulus alsinoides</i>	Eval
<b>Climbers</b>		<i>Fadogia agrestis</i>	Faag
<i>Asparagus africanus</i>	Asaf	<i>Gladiolus gregarius</i>	Glgr
<i>Cissus populnea</i>	Cipo	<i>Indigofera stenophylla</i>	Inst
<i>Baissea multiflora</i>	Bamu	<i>Lantana rhodesiensis</i>	Larh
<b>Infrequent fires or no fire</b>		<i>Pandiaka involucreta</i>	Pain
<b>Woody</b>		<i>Schwenckia americana</i>	Scam
<i>Azadirachta indica</i>	Azin	<i>Spermacoce chaetocephala</i>	Spch
<i>Diospyros mespiliformis</i>	Dime	<i>Spermacoce radiata</i>	Spra
<i>Gardenia erubescens</i>	Gaer	<i>Spermacoce stachydea</i>	Spst
<i>Grewia barteri</i>	Grba	<i>Tephrosia pedicellata</i>	Tepe
<i>Guiera senegalensis</i>	Guse	<i>Waltheria indica</i>	Wain
<i>Ozoroa insignis</i>	Ozin	<b>Climbers</b>	
<i>Terminalia avicennioides</i>	Teav	<i>Cissus diffusiflora</i>	Cidi
		<i>Cissus lelyi</i>	Cile

The first group contains relatively more trees, perennial herbaceous species and endemic species (soudano-zambesian) than the second group where shrubs, herbaceous annuals, widespread species, weeds and potential invaders are more numerous (figure 8).

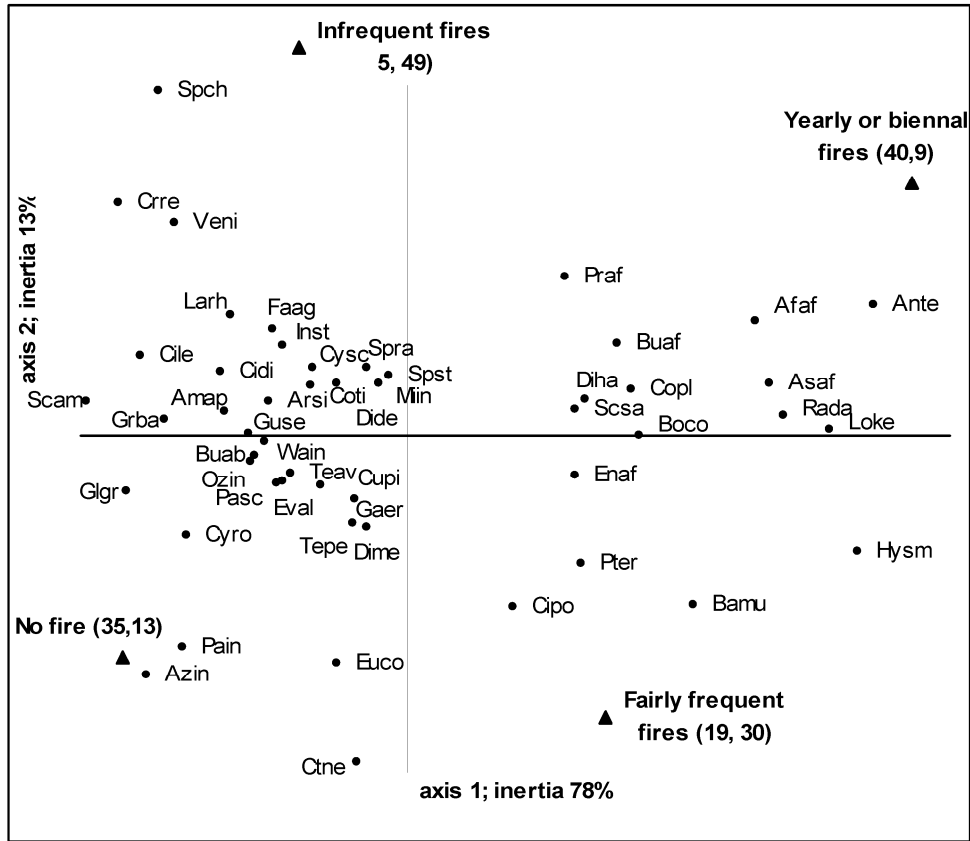


Figure 7 – Correspondence analysis between species and fire frequency (species significantly linked to fire’s regime) (between brackets: absolute contribution of fire frequency regimes to respectively the first and second axis)

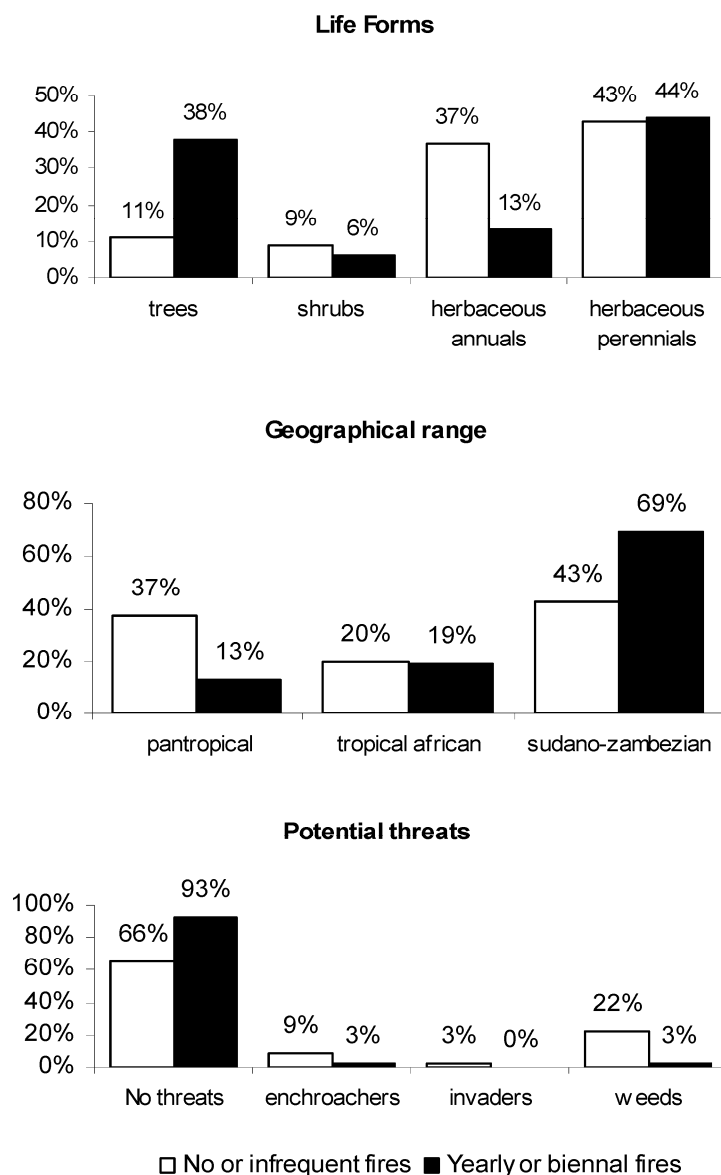


Figure 8 – Life traits of species significantly linked to fire's regime units.

## Discussion and conclusion

The current study shows how joining MODIS active fires and MODIS burnt areas data can be helpful to understanding the link between fire and landscape type in sudanian savannas. Active fire data successfully detects some sparsely patched flammable environments too small to be identified by burnt area data. On the other hand, burnt area data reveals not very productive environments, barely visible for the active fire sensors. Both types of data are thus needed as complementary tools to characterise the savanna fire regimes.

On the basis of fire seasonality and frequency, we established landscape fire units and assessed then their dependence on land cover and land use. As quoted by Nielsen & Rasmussen (2001) the higher the land use intensity, the lower the fire frequency: indeed our



results attest the high frequency of fire inside protected areas and on gravelly soils and hardpan complexes unsuitable for agriculture. They also confirm that the majority of fires take place in savanna-woodlands as shown by previous studies (Nielsen & Rasmussen 2001, Clerici 2006, Grégoire & Simonetti 2007). Overall, our results confirm that fire occurrence is influenced primarily by land use practice (Hudak et al. 2004). Conversely the decrease in the herbaceous standing crop, due to the shortening of the fallow period (Fournier 1991, Fournier 1994, Fournier & Nignan 1997, Fournier et al. 2001), the extension of cultivated and cleared fields, and more generally the increment in landscape discontinuities limit the spread of fire and the size of burnt areas (Devineau 1986, Clerici 2006, Dolidon 2007). Because of the high impact of agriculture in the area studied (cotton zone) the area burnt annually is relatively limited outside protected areas (21 %) whereas 29 % appeared as not burnt. Conversely 47 % of the protected areas are burnt and only 8 % unburnt. These values are similar to those of Menaut et al. (1991) who found that 25–50 % of the sudanian savanna in West Africa was burnt annually or with those of Eva and Lambin (1998b) who found that 28 % of the sudanian savanna of Central Africa had been affected by fires during a year.

The comparison of active fire and burnt area data indicates that fire frequency and intensity are thus related mainly to the herbaceous layer continuity and phytomass. Fire density peaks in November-December; however fire seasonality depends on vegetation hygrophily, very early fires mainly affect savannas on gravelly soils and hardpan whereas late and very late fires are observed in wetlands, but also on agricultural lands in accordance with previous observations by Bruzon (1990) or Nielsen & Rasmussen (2001). Moreover fire begins all the more early as the climate is dry. Field enquiries revealed a tendency towards fires later and later in agricultural areas because of a growing difficulty in controlling people in such increasingly crowded landscapes; the need for limiting fires was also reported several times (mainly by herders). With physical and biological changes in environment, this feeling could explain the observed patterns of fire distribution. Fire rarefaction in degraded savanna could indeed be due to changes in land management, in particular for pastoral activities for which burning annual grasses is rather prejudicial, contrary to the burning of the perennial grasses of the former “true” savanna (Fournier 1996 and September 2008 enquiries).

Furthermore, species frequency relationships with landscape fire regimes were established. Due to the initial pixel size (1 km<sup>2</sup>) the fire's type units however relate to savanna landscape fragments that juxtapose various biotopes or plant species habitats. Although the probability of exposure to fire for a species can be assumed to be a function of the density and the intensity of fires in the landscape matrix, the difference in scales in our studies does not make

possible a direct approach of the sensitivity of the species to fire. The surfaces used for the observation of presence of a species in a habitat, and those used to characterise the type of fire in the landscape matrix in which this habitat is included are too different. Moreover the reasons for the more frequent presence of species in landscape fire units are indeed varied; they may express fire-regime preferences, but also situations of refuge.

In the cotton zone of western Burkina Faso, the influence of fire on the environment is more marked within than without protected areas. These state forests, parks etc. are protective of the sudanian savannas biotopes and hence undergo frequent fires (generally annual) that are one of their distinctive features. As expected, plant species statistically linked with frequent fire landscape units are typical of sudanian savanna: many are endemic to the sudanian area, many are perennial grasses –the constituent life form of sudanian savannas (Fournier 1991 p. 11 et 248), some are woody species typical of sudanian woodlands e. g. *Prosopis africana*, *Afzelia africana* (Stark 1986, De Wolf 1998, Bationo et al. 2001, Onana & Devineau 2002). However some species regarded as rather fire sensitive e.g. *Anogeissus leiocarpus*, *Tamarindus indica* do not appear to be linked to any fire landscape units, because they are frequently hosted in refuge habitats (thickets, groves, termite mounds etc.) in fire-prone landscapes (Traoré et al. 2008, Liberski et al. 2009), which counterbalances their presence in rarely burnt or not burnt areas. Furthermore the preference of *A. leiocarpus* for the best lands (chemically rich) (Aubréville 1950, Von Maydell 1983), would explain its rarefaction in certain strongly exploited agricultural lands : in such conditions it occupies mainly gravelly soils and hardpan complexes (Devineau 2001, Liberski-Bagnoud et al. 2009). A seeming lack of specialization of a species can thus result from its elimination from its preferential habitats by a harmful disturbance. Two grass species give another example of a certain discrepancy or lack of precision in the links detected between species requirements and fire landscape units. *Andropogon chinensis* and *Schizachyrium sanguineum* are two perennial grass species typical of fire-proclimax tree savanna. *S. sanguineum* appears significantly linked to frequently burnt landscape units (table 2) but not *A. chinensis*. Certain features of these polymorphic species which have a wide distribution in the tropics can explain this. In sudanian environments they usually grow together as dominant species on sandy or gravelly soil in uncultivated areas, but their maximum abundance is on slightly to rather gravelly soils on plateaus for *A. chinensis* and on sandy and plainly gravelly soils on midslopes of hills for *S. sanguineum*. Both can also be found on old (over 20 year-) fallow land, where *S. sanguineum* comes somewhat later than *A. chinensis* in the succession. All in all the ecological range of *A. chinensis* is a little wider than that of *S. sanguineum* and is linked to soils more suitable for agriculture (Ouédraogo,

1993). *A. chinensis* is thus more likely to be found in landscape units including cultivated (and hence not burnt) lands, although its preference is clearly for savannas or very old fallow lands.

The flora of lands slightly or not affected by fires thus reflects the chiefly agricultural nature of these areas: wide-ranging species and weeds are the main constituents of their flora, whereas the fire-sensitive species of the “dry forest” –such as *Diospyros mespiliformis* –are currently poorly represented there. Previous work in the region studied indeed showed that agricultural intensification leads to the establishment of wide-ranging species, particularly weeds and that, in addition to the dominance of some shrubby species were noteworthy characteristics of such lands, where they often became encroaching plants (Devineau et al. 2009). The groups of species significantly related to fire regimes actually include many weeds and potentially invasive species linked to unburnt units, as was observed in some other semi-arid ecosystems (Macdonald & Frame 1988, Puyravaud et al. 1995). Moreover some exotic species such as *Azadirachta indica* –the Neem tree, a native from tropical South East Asia – typically linked to highly anthropized and fire-released lands can be locally naturalised or invasive. Similar observations were made in Guinean and Soudano-Guinean savannas where suppression or alleviation of fire favours exotic or invasive species such as the invasion of a fire protected savanana by *Chromolaena odorata* (Gautier 1996) or the establishment of *Gmelina arborea* and *Tectona grandis* on plots totally protected or managed with early fires (Louppe et al. 1995a & b). It thus appears that unburnt landscape units are currently more sensitive and vulnerable to some biological threats than the burnt savannas. Although disturbances are often thought to favour invaders, in the present case it is the suppression of the disturbance which seems to support threatening processes (Buckley et al. 2007). As quoted by Wright (1974), fire may indeed provide the long-term stability needed to preserve the ecosystem; it can be seen as an incorporated disturbance that enables the savanna resilience and pseudo-stability, but whose disappearance is destabilizing (Holling 1973, Allen & Starr, 1982, Bergkamp 1995, Ingegnoli & Pignatti 2007). Therefore the absence or the rarefaction of fires indicates land use intensification, but also ecosystems whose dynamics deviate from those of sudanian savannas.

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## APPENDIX

### Mutual information between species and fire regimes

Output of the EcoTools program from ADE4 (Thioulouse et al. 1997)

Col 2-5: number of relevés in each fire regime unit where the species is present,

**Total** : total number of presence for the species,

**Freq.:** species frequency,

**Entropy:** descriptor's entropy (Daget & Godron, 1982 p. 54),

**MI:** Mutual information between species and the descriptor (Daget & Godron, 1982. p.50),

**Khi<sup>2</sup>:** observed Khi<sup>2</sup>,

**Proba:**, probability of exceeding the actual Khi<sup>2</sup> value under the null hypothesis.

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Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennial fires						
<b>Species statistically significantly linked with fire units</b>										
<i>Guiera senegalensis</i> J.F Gmelin	56	51	33	8	148	0.233	0.783	0.033	27.81	0.00
<i>Cochlospermum planchonii</i> Hook. f.	22	51	70	32	175	0.276	0.849	0.031	26.07	0.00
<i>Andropogon tectorum</i> Schumach. & Thonn.	1	9	16	13	39	0.061	0.333	0.029	24.87	0.00
<i>Waltheria indica</i> L.	54	53	38	7	152	0.239	0.794	0.029	23.72	0.00
<i>Burkea africana</i> Hook. F.	12	41	49	20	122	0.192	0.706	0.026	19.45	0.00
<i>Grewia barteri</i> Burret	26	24	12	1	63	0.099	0.466	0.026	19.47	0.00
<i>Hyparrhenia smithiana</i> (Hook. F.) Stapf	3	4	18	10	35	0.055	0.308	0.023	20.06	0.00
<i>Amorphophallus aphyllus</i> (Hook.) Hutch.	32	25	12	6	75	0.118	0.524	0.022	19.36	0.00
<i>Terminalia avicennioides</i> G. & Perr.	42	42	36	5	125	0.197	0.716	0.019	14.69	0.00
<i>Pterocarpus erinaceus</i> Poir.	34	40	76	26	176	0.277	0.852	0.018	16.26	0.00
<i>Entada africana</i> Guill. & Perr.	25	42	66	21	154	0.243	0.799	0.015	13.27	0.00
<i>Fadogia agrestis</i> Schweinf ex Hiern	26	33	17	5	81	0.128	0.551	0.015	12.48	0.01
<i>Pandiaka involucrata</i> (Moq.) B.D. Jacks.	15	8	9	0	32	0.05	0.288	0.015	10.9	0.01
<i>Azelia africana</i> Smith ex Pers.	1	9	13	7	30	0.047	0.275	0.015	10.14	0.02
<i>Prosopis africana</i> (Guill. & Perr.) Taub.	19	27	21	21	88	0.139	0.581	0.014	14.26	0.00
<i>Bombax costatum</i> Pellegr. & Vuillet	10	22	35	14	81	0.128	0.551	0.014	11.15	0.01
<i>Indigofera stenophylla</i> Guill & Perr	19	29	18	2	68	0.107	0.491	0.014	10.97	0.01
<i>Gardenia erubescens</i> Stapf & Hutch.	46	49	53	8	156	0.246	0.804	0.014	10.43	0.02
<i>Gladiolus gregarius</i> Welw. ex Baker	12	9	5	0	26	0.041	0.247	0.014	9.83	0.02
<i>Diospyros mespiliformis</i> Hochst. ex A. Rich.	52	37	41	14	144	0.227	0.772	0.013	11.88	0.01
<i>Bulbostylis abortiva</i> (Steud.) C.B. Clarke	27	23	16	4	70	0.11	0.501	0.013	11.05	0.01
<i>Cymbopogon schoenanthus</i> (L.)	33	33	19	10	95	0.15	0.609	0.013	10.97	0.01

Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennial fires						
<b>Spreng. subsp. schoenanthus</b>										
<i>Ctenium newtonii</i> Hack	15	7	18	1	41	0.065	0.345	0.013	9.65	0.02
<i>Spermacoce chaetocephala</i> DC.	6	10	1	1	18	0.028	0.186	0.013	9.6	0.02
<i>Vetiveria nigritana</i> (Benth.) Stapf	7	12	4	0	23	0.036	0.225	0.013	9.04	0.03
<i>Cyperus rotundus</i> L.	13	10	8	0	31	0.049	0.281	0.013	8.2	0.04
<i>Loudetiopsis kerstingii</i> (Pilger) Conert	2	4	10	7	23	0.036	0.225	0.012	10.99	0.01
<i>Cochlospermum tinctorium</i> A. Rich.	29	38	27	5	99	0.156	0.624	0.012	9.96	0.02
<i>Ozoroa insignis</i> Del.	24	21	15	3	63	0.099	0.466	0.012	9.93	0.02
<i>Cissus diffusiflora</i> (Baker) Planch.	17	18	9	2	46	0.072	0.375	0.012	9.47	0.02
<i>Schizachyrium sanguineum</i> (Retz) Alston	17	36	47	17	117	0.184	0.689	0.012	9.43	0.02
<i>Aristida sieberana</i> Trin.	23	26	17	3	69	0.109	0.496	0.012	9.32	0.03
<i>Curculigo pilosa</i> (Schum & Thonn) Engl	31	33	32	4	100	0.157	0.628	0.012	8.71	0.03
<i>Crotalaria retusa</i> L.	6	9	2	0	17	0.027	0.178	0.012	8.44	0.04
<i>Cissus lelyi</i> Hutch.	9	10	4	0	23	0.036	0.225	0.012	8.07	0.04
<i>Diheteropogon hagerupii</i> Hitchc.	23	39	50	24	136	0.214	0.749	0.011	9.6	0.02
<i>Digitaria debilis</i> (Desf.) Willd.	35	47	35	8	125	0.197	0.716	0.011	9.37	0.02
<i>Spermacoce radiata</i> (DC.) Hiern.	49	65	48	16	178	0.28	0.856	0.011	9.37	0.03
<i>Lantana rhodesiensis</i> Moldenke	15	16	6	3	40	0.063	0.339	0.011	9.08	0.03
<i>Tephrosia pedicellata</i> Bak	39	39	47	7	132	0.208	0.737	0.011	8.23	0.04
<i>Azadirachta indica</i> A. Juss.	10	3	3	1	17	0.027	0.178	0.01	10.5	0.02
<i>Asparagus africanus</i> Lam.	3	6	11	8	28	0.044	0.261	0.01	9.79	0.02
<i>Evolvulus alsinoides</i> (L.) L.	24	17	13	5	59	0.093	0.446	0.01	9.31	0.03
<i>Spermacoce stachydea</i> DC.	64	84	66	24	238	0.375	0.954	0.01	9.2	0.03
<i>Paspalum scrobiculatum</i> L.	26	20	16	5	67	0.106	0.486	0.01	8.78	0.03
<i>Euclasta condylotricha</i> (Steud.) Stapf.	22	12	21	3	58	0.091	0.441	0.01	8.66	0.03
<i>Baissea multiflora</i> A. DC.	6	5	17	7	35	0.055	0.308	0.01	8.45	0.04
<i>Microchloa indica</i> (L.f.) P. Beauv.	59	73	57	21	210	0.331	0.916	0.01	8.37	0.04
<i>Cissus populnea</i> Guill. & Perr.	28	17	38	14	97	0.153	0.617	0.01	8.05	0.04
<i>Raphionacme daronii</i> Berhaut	1	5	10	5	21	0.033	0.21	0.01	7.62	0.05
<i>Schwenckia americana</i> L.	7	6	2	0	15	0.024	0.161	0.01	7.05	0.07
<b>Species not statistically significantly linked with fire units</b>										
<i>Stylosanthes fruticosa</i> (Retz.) Alston	14	10	8	1	33	0.052	0.295	0.009	7.33	0.06
<i>Tamarindus indica</i> L.	18	8	20	9	55	0.087	0.425	0.009	7	0.07
<i>Eriosperrum abyssinicum</i> Baker	16	12	12	1	41	0.065	0.345	0.009	6.96	0.07
<i>Hoslundia opposita</i> Vahl.	5	1	10	2	18	0.028	0.186	0.009	6.57	0.09
<i>Sporobolus festivus</i> Hochst. ex A. Rich.	46	55	43	14	158	0.249	0.809	0.008	7.29	0.06
<i>Acacia dudgeoni</i> Craib ex Hall	27	42	58	22	149	0.235	0.786	0.008	7.12	0.07
<i>Strychnos spinosa</i> Lam.	18	32	32	19	101	0.159	0.632	0.008	6.99	0.07
<i>Pandiaka angustifolia</i> (Vahl) Hepper	36	51	62	30	179	0.282	0.858	0.008	6.95	0.07
<i>Holarrhena floribunda</i> (G. Don) Dur. & Schinz	9	2	6	4	21	0.033	0.21	0.008	6.58	0.09
<i>Maytenus senegalensis</i> (Lam.) Exell.	45	41	43	11	140	0.22	0.761	0.008	6.57	0.09
<i>Cymbopogon giganteus</i> Chiov. var <i>giganteus</i>	7	9	2	3	21	0.033	0.21	0.008	5.54	0.13
<i>Ampelocissus grantii</i> (Baker) Planch.	18	10	11	4	43	0.068	0.357	0.007	6.8	0.08
<i>Hymenocardia acida</i> Tul.	22	19	15	4	60	0.094	0.451	0.007	6.52	0.09

Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennal fires						
<i>Brachiaria distichophylla</i> (Trin.) Stapf.	45	63	51	16	175	0.276	0.849	0.007	6.34	0.09
<i>Indigofera dendroides</i> Jacq	28	51	53	14	146	0.23	0.778	0.007	6.32	0.10
<i>Hackelochloa granularis</i> (L.) O Ktze	29	53	45	14	141	0.222	0.764	0.007	6.32	0.10
<i>Sclerocarya birrea</i> (A. Rich.) Hochst.	37	38	31	10	116	0.183	0.686	0.007	6.21	0.10
<i>Xeroderris stühlmannii</i> (Taub.) Mendonça & E.P. Sousa	10	12	25	9	56	0.088	0.43	0.007	5.99	0.11
<i>Annona senegalensis</i> Pers.	71	81	76	24	252	0.397	0.969	0.007	5.93	0.11
<i>Pteleopsis suberosa</i> Engl. & Diels.	43	58	53	13	167	0.263	0.831	0.007	5.87	0.12
<i>Tacca leontopetaloides</i> (L.) O Ktze	30	27	24	7	88	0.139	0.581	0.007	5.79	0.12
<i>Crotalaria cephalotes</i> Steud ex A Rich	12	12	8	1	33	0.052	0.295	0.007	5.48	0.14
<i>Senna singueana</i> (Del.) Lock	19	22	18	3	62	0.098	0.461	0.007	5.03	0.17
<i>Cyperus esculentus</i> L.	7	5	5	0	17	0.027	0.178	0.007	3.98	0.26
<i>Dioscorea dumetorum</i> (Kunth) Pax	22	12	20	6	60	0.094	0.451	0.006	5.81	0.12
<i>Wissadula amplissima</i> (L.) R.E. Fries	22	31	20	7	80	0.126	0.546	0.006	5.45	0.14
<i>Pericopsis laxiflora</i> (Benth.) Meeuwen	19	18	33	14	84	0.132	0.564	0.006	5.15	0.16
<i>Andropogon pseudapricus</i> Stapf.	42	61	78	25	206	0.324	0.909	0.006	5.07	0.17
<i>Sida alba</i> L.	25	24	18	12	79	0.124	0.542	0.006	4.94	0.17
<i>Crotalaria senegalensis</i> (Pers) Bacle ex DC	10	13	8	1	32	0.05	0.288	0.006	4.81	0.18
<i>Dioscorea togoensis</i> Knuth	12	6	14	7	39	0.061	0.333	0.006	4.55	0.21
<i>Kyllinga erecta</i> Schumach.	7	2	8	4	21	0.033	0.21	0.006	4.52	0.21
<i>Grewia bicolor</i> Juss.	9	4	13	5	31	0.049	0.281	0.006	4.46	0.21
<i>Albizia chevalieri</i> Harms	10	10	16	1	37	0.058	0.321	0.006	4.35	0.23
<i>Vitex simplicifolia</i> Oliv.	20	14	14	5	53	0.083	0.414	0.005	4.93	0.18
<i>Polygala arenaria</i> Willd.	5	7	5	6	23	0.036	0.225	0.005	4.73	0.19
<i>Euphorbia convolvuloides</i> Hochst ex Benth	4	8	6	6	24	0.038	0.232	0.005	4.6	0.20
<i>Vicoa leptoclada</i> (Webb) Dandy	4	8	6	6	24	0.038	0.232	0.005	4.6	0.20
<i>Khaya senegalensis</i> (Desr.) A. Juss.	14	13	8	7	42	0.066	0.351	0.005	4.54	0.21
<i>Isobertinia doka</i> Craib & Stapf	10	14	18	11	53	0.083	0.414	0.005	4.52	0.21
<i>Sterculia setigera</i> Del.	14	16	30	8	68	0.107	0.491	0.005	4.51	0.21
<i>Hibiscus asper</i> Hook. f.	20	34	24	9	87	0.137	0.576	0.005	4.43	0.22
<i>Diheteropogon amplectens</i> (Nees) W. D. Clayton	7	7	17	4	35	0.055	0.308	0.005	4.33	0.23
<i>Acacia sieberiana</i> DC.	11	22	28	9	70	0.11	0.501	0.005	4.12	0.25
<i>Brachiaria lata</i> (Schumach.) C.E. Hubbard	3	11	9	2	25	0.039	0.239	0.005	4.08	0.25
<i>Indigofera trichopoda</i> Lepr. ex Guill. & Perr.	20	34	32	17	103	0.162	0.64	0.005	4.02	0.26
<i>Parinari curatellifolia</i> Planch. ex Benth.	18	19	13	5	55	0.087	0.425	0.005	3.93	0.27
<i>Tephrosia linearis</i> Pers.	6	12	11	1	30	0.047	0.275	0.005	3.67	0.30
<i>Fimbristylis ovata</i> (Burm. f.) Kern	2	9	7	2	20	0.031	0.202	0.005	3.66	0.30
<i>Boswellia dalzielii</i> Hutch.	2	8	9	4	23	0.036	0.225	0.005	3.58	0.31
<i>Capparis sepiaria</i> L.	8	4	11	5	28	0.044	0.261	0.005	3.56	0.31
<i>Gardenia sokotensis</i> Hutch.	5	6	5	0	16	0.025	0.17	0.005	2.61	0.46
<i>Brachiaria jubata</i> (Fig. & De Not) Stapf	4	9	7	6	26	0.041	0.247	0.004	4.13	0.25
<i>Biophytum petersianum</i> Klotzsch.	7	16	9	5	37	0.058	0.321	0.004	4.01	0.26
<i>Dioscorea bulbifera</i> L.	10	5	6	4	25	0.039	0.239	0.004	4	0.26
<i>Loudetia simplex</i> (Nees) C.E. Hubbard	7	7	14	7	35	0.055	0.308	0.004	3.91	0.27



Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennial fires						
<i>Vitellaria paradoxa</i> C.F. Gaernt.	95	113	111	39	358	0.564	0.988	0.004	3.84	0.28
<i>Gardenia ternifolia</i> Schumach. & Thonn.	40	39	35	16	130	0.205	0.731	0.004	3.81	0.28
<i>Combretum fragrans</i> F. Hoffm.	20	15	22	12	69	0.109	0.496	0.004	3.73	0.29
<i>Combretum molle</i> R. Br. ex G. Don	17	24	25	15	81	0.128	0.551	0.004	3.71	0.29
<i>Strychnos innocua</i> Del.	5	12	7	2	26	0.041	0.247	0.004	3.65	0.30
<i>Lannea acida</i> A. Rich.	58	77	69	33	237	0.373	0.953	0.004	3.63	0.30
<i>Saba senegalensis</i> (A. DC.) Pichon.	23	15	23	9	70	0.11	0.501	0.004	3.63	0.30
<i>Aspilia kotschyi</i> (Sch. Bip.) Oliv.	20	15	29	9	73	0.115	0.515	0.004	3.61	0.31
<i>Sarcocephalus latifolius</i> (Smith) Bruce	8	13	8	7	36	0.057	0.314	0.004	3.6	0.31
<i>Loudezia togoensis</i> (Pilger) C.E. Hubbard	63	67	75	21	226	0.356	0.939	0.004	3.56	0.31
<i>Chasmopodium caudatum</i> (Hack) Stapf	5	14	12	6	37	0.058	0.321	0.004	3.53	0.32
<i>Euphorbia hirta</i> L.	3	3	7	4	17	0.027	0.178	0.004	3.4	0.33
<i>Securidaca longepedunculata</i> Fres.	15	20	17	3	55	0.087	0.425	0.004	3.39	0.34
<i>Schizachyrium platyphyllum</i> (Franch.) Stapf	8	10	5	2	25	0.039	0.239	0.004	3.13	0.37
<i>Cassia mimosoides</i> L.	46	53	47	24	170	0.268	0.838	0.004	3.1	0.38
<i>Mitragyna inermis</i> (Wild) Kuntze	15	17	11	5	48	0.076	0.386	0.004	3.07	0.38
<i>Acacia seyal</i> Del.	7	16	16	4	43	0.068	0.357	0.004	2.95	0.40
<i>Leptadenia hastata</i> (Pers) Decne	4	11	12	3	30	0.047	0.275	0.004	2.9	0.41
<i>Zornia glochidiata</i> Reichb ex DC	9	8	7	1	25	0.039	0.239	0.004	2.9	0.41
<i>Monocymbium ceresiiforme</i> (Nees) Stapf	4	10	13	4	31	0.049	0.281	0.004	2.85	0.42
<i>Brachiaria xantholeuca</i> (Hack. ex Schinz) Stapf	5	8	11	1	25	0.039	0.239	0.004	2.75	0.43
<i>Mitracarpus scaber</i> Zucc	3	8	5	4	20	0.031	0.202	0.003	3	0.39
<i>Andropogon fastigiatus</i> Sw	46	67	61	27	201	0.317	0.901	0.003	2.91	0.41
<i>Cyanotis longifolia</i> Benth.	11	12	10	8	41	0.065	0.345	0.003	2.88	0.41
<i>Lannea velutina</i> A. Rich.	35	29	37	12	113	0.178	0.676	0.003	2.85	0.42
<i>Pennisetum pedicellatum</i> Trin.	69	78	84	25	256	0.403	0.973	0.003	2.85	0.42
<i>Feretia apodanthera</i> Del.	34	41	37	11	123	0.194	0.709	0.003	2.84	0.42
<i>Andropogon chinensis</i> (Nees) Merr.	53	71	82	34	240	0.378	0.957	0.003	2.78	0.43
<i>Vitex chrysocarpa</i> Planch. ex Benth.	7	3	8	2	20	0.031	0.202	0.003	2.68	0.45
<i>Cissus gracilis</i> Guill. & Perr.	12	14	10	3	39	0.061	0.333	0.003	2.45	0.49
<i>Detarium microcarpum</i> Guill. & Perr.	51	75	77	29	232	0.365	0.947	0.003	2.44	0.49
<i>Elionurus elegans</i> Kunth	36	48	41	15	140	0.22	0.761	0.003	2.43	0.49
<i>Sida rhombifolia</i> L.	8	5	5	2	20	0.031	0.202	0.003	2.42	0.49
<i>Combretum glutinosum</i> Perr. ex DC.	37	49	63	20	169	0.266	0.836	0.003	2.4	0.50
<i>Sporobolus pyramidalis</i> P. Beauv	18	13	16	7	54	0.085	0.42	0.003	2.38	0.50
<i>Excoecaria grahamii</i> Stapf	22	25	23	6	76	0.12	0.528	0.003	2.34	0.51
<i>Fimbristylis ferruginea</i> (L.) Vahl	3	7	8	1	19	0.03	0.194	0.003	2.32	0.51
<i>Lannea microcarpa</i> Engl. & K. Krause	39	40	55	15	149	0.235	0.786	0.003	2.3	0.52
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	44	42	44	18	148	0.233	0.783	0.003	2.27	0.52
<i>Dioscorea abyssinica</i> Hochst. ex Kunth	20	20	20	5	65	0.102	0.476	0.003	2.27	0.52
<i>Terminalia laxiflora</i> Engl.	58	70	76	22	226	0.356	0.939	0.003	2.16	0.54
<i>Schizachyrium rupestre</i> (K. Schum.) Stapf	4	7	9	1	21	0.033	0.21	0.003	2.08	0.56
<i>Schizachyrium exile</i> (Hochst.)	28	39	37	19	123	0.194	0.709	0.002	2.2	0.54

Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennial fires						
Pilger										
<i>Cassia sieberiana</i> DC.	34	34	35	11	114	0.18	0.679	0.002	2.17	0.54
<i>Hyptis spicigera</i> Lam.	11	10	10	7	38	0.06	0.327	0.002	2.15	0.55
<i>Ipomoea eriocarpa</i> R. Br.	7	8	8	6	29	0.046	0.268	0.002	2.07	0.56
<i>Tephrosia bracteolata</i> Guill. & Perr.	24	34	35	9	102	0.161	0.636	0.002	1.96	0.58
<i>Melliniella micrantha</i> Harms	11	7	13	4	35	0.055	0.308	0.002	1.95	0.59
<i>Dactyloctenium aegyptium</i> (L.) Willd.	7	14	15	4	40	0.063	0.339	0.002	1.88	0.60
<i>Ptilostigma reticulatum</i> (DC.) Hochst.	15	18	13	7	53	0.083	0.414	0.002	1.87	0.60
<i>Grewia lasiodiscus</i> K. Schum.	31	35	49	15	130	0.205	0.731	0.002	1.72	0.64
<i>Setaria pallide-fusca</i> (Schumach.) Stapf & C.E. Hubbard	38	42	44	13	137	0.216	0.752	0.002	1.66	0.65
<i>Leucas martinicensis</i> (Jacq.) R. Br.	7	4	6	3	20	0.031	0.202	0.002	1.61	0.66
<i>Loudetia hordeiformis</i> (Stapf) C.E. Hubbard	5	8	8	1	22	0.035	0.217	0.002	1.6	0.66
<i>Parkia biglobosa</i> (Jacq.) Benth.	39	38	42	19	138	0.217	0.755	0.002	1.56	0.67
<i>Daniellia oliveri</i> (R.) Hutch. & Dalz.	35	40	42	12	129	0.203	0.728	0.002	1.53	0.68
<i>Tripogon minimus</i> (A. Rich.) Hochst. ex Steud.	20	30	30	14	94	0.148	0.605	0.002	1.52	0.68
<i>Digitaria gayana</i> (Kunth.) Stapf ex A. Cheval.	6	8	8	1	23	0.036	0.225	0.002	1.47	0.69
<i>Ptilostigma thonningii</i> (Schumm.) Milne-Redhead.	74	88	87	33	282	0.444	0.991	0.002	1.45	0.70
<i>Crossopteryx febrifuga</i> (Afzel. ex G. Don.) Benth.	41	55	65	24	185	0.291	0.87	0.002	1.45	0.70
<i>Acacia macrostachya</i> Reichenb. ex DC	44	57	64	19	184	0.29	0.868	0.002	1.42	0.71
<i>Crinum zeylanicum</i> auct.	6	6	5	1	18	0.028	0.186	0.002	1.4	0.71
<i>Cassia nigricans</i> Vahl	7	11	10	2	30	0.047	0.275	0.002	1.38	0.71
<i>Melochia corchorifolia</i> L.	3	7	8	3	21	0.033	0.21	0.002	1.38	0.72
<i>Bridelia ferruginea</i> Benth.	21	19	20	9	69	0.109	0.496	0.002	1.35	0.72
<i>Ximenia americana</i> L.	21	29	30	8	88	0.139	0.581	0.002	1.35	0.72
<i>Ctenium elegans</i> Kunth	4	8	9	2	23	0.036	0.225	0.002	1.32	0.73
<i>Triumfetta pentandra</i> A. Rich.	9	7	9	5	30	0.047	0.275	0.001	1.28	0.74
<i>Stylochiton warneckeii</i> Engl.	32	34	38	11	115	0.181	0.682	0.001	1.23	0.75
<i>Combretum nigricans</i> Lepr. ex Guill. & Perr.	35	37	38	13	123	0.194	0.709	0.001	1.21	0.75
<i>Siphonochilus aethiopicus</i> (Schweinf.) B.L. Burt	38	37	41	17	133	0.209	0.74	0.001	1.2	0.76
<i>Acacia ataxacantha</i> DC.	11	11	12	7	41	0.065	0.345	0.001	1.16	0.77
<i>Andropogon gayanus</i> Kunth	52	69	69	29	219	0.345	0.929	0.001	1.14	0.77
<i>Anogeissus leiocarpus</i> (DC.) Guill. & Perr.	41	55	55	24	175	0.276	0.849	0.001	1.14	0.77
<i>Fimbristylis hispida</i> (Vahl) Kunth.	37	44	42	15	138	0.217	0.496	0.002	0.95	0.78
<i>Trichilia emetica</i> Vahl	7	9	6	3	25	0.039	0.239	0.001	1.07	0.79
<i>Flueggea virosa</i> (Roxb. Ex Willd.) Voigt	48	51	55	19	173	0.272	0.845	0.001	1.03	0.80
<i>Striga hermonthica</i> Benth.	6	11	10	3	30	0.047	0.275	0.001	1	0.80
<i>Grewia venusta</i> Fresen.	11	10	12	3	36	0.057	0.314	0.001	0.96	0.81
<i>Lepidagathis anobrya</i> Nees	24	25	32	9	90	0.142	0.589	0.001	0.88	0.83
<i>Hexalobus monopetalus</i> (A. Rich.) Engl. & Diels	8	11	14	6	39	0.061	0.333	0.001	0.83	0.84
<i>Balanites aegyptiaca</i> (L.) Del.	14	22	22	8	66	0.104	0.481	0.001	0.82	0.85
<i>Cassia tora</i> L.	6	9	12	4	31	0.049	0.281	0.001	0.79	0.85
<i>Cyphostemma waterlotii</i> (A. Chev.) Descouings	3	5	7	2	17	0.027	0.178	0.001	0.76	0.86
<i>Schoenefeldia gracilis</i> Kunth	6	10	11	3	30	0.047	0.275	0.001	0.75	0.86

Species name	Fire regime				Total	Freq.	Entropy	MI	Khi <sup>2</sup>	Proba
	No fire	Infrequen fires	Fairly frequent fires	Yearly or biennial fires						
<i>Combretum micranthum</i> G. Don	15	13	17	6	51	0.08	0.403	0.001	0.72	0.87
<i>Lepidagathis collina</i> (Endl.) Milne-Redhead	10	13	14	7	44	0.069	0.363	0.001	0.64	0.89
<i>Swartzia madagascariensis</i> Desv.	9	13	11	4	37	0.058	0.321	0.001	0.61	0.89
<i>Cyanotis lanata</i> Benth.	14	18	23	8	63	0.099	0.466	0.001	0.56	0.91
<i>Mollugo nudicaulis</i> Lam.	4	4	5	1	14	0.022	0.153	0.001	0.41	0.93
<i>Hyparrhenia subplumosa</i> Stapf	7	6	7	3	23	0.036	0.225	0	0.42	0.93
<i>Combretum collinum</i> Fresen	41	43	51	18	153	0.241	0.797	0	0.41	0.93
<i>Terminalia macroptera</i> G. & Perr.	14	19	22	7	62	0.098	0.461	0	0.4	0.94
<i>Alysicarpus ovalifolius</i> (Schum. & Thonn.) Léonard	9	12	14	4	39	0.061	0.333	0	0.34	0.95
<i>Stereospermum kunthianum</i> Cham.	22	24	28	9	83	0.131	0.559	0	0.26	0.96
<i>Digitaria horizontalis</i> Willd.	4	4	5	2	15	0.024	0.161	0	0.07	0.99
Total number of relevés	160	188	209	78	635					

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