Spatio-temporal Dynamics of bush fires in Mont Péko national Park (West-Côte d'Ivoire)

***Sidibe Oumane*,**
University Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire
***Kouassi Kouadio Henri*,**
University Jean Lorougnon Guédé, Daloa, Côte d'Ivoire
***Kouassi Konan Edouard*,**
University Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire

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Abstract

Following the 2016 break-out of illegally settled populations in Mont Péko national Park due to the political-military crises of 2002 to 2011, the phenomenon of uncontrolled wildfires reached alarming proportions. The purpose of this study was to determine, from the combined use of remote sensing and geographic information systems, the evolution of the intensity and the spaces traversed by the fires in this protected area between 2016 and 2018. For this purpose, two Landsat 8 satellite images from 2016 (before fires) and 2018 (after fires) were used. The results of this work reveal that 49.63% of the total area of the protected area, located in its North and South-East part, was covered by fires. Analysis of the distribution of fires across the different land use classes reveals a greater occurrence of fires in the crop and fallow class (10 519.38 ha) compared to the forest class (3 963.87 ha) and the class of bare soils and rocky outcrops (538.02 ha). Overall, the severity of fires in the park following the study period is moderate.

Keywords: Fire severity, Normalized Burn Ratio; burned areas, Mont Péko, Côte d'Ivoire

Introduction

In Africa, for millennia, bush fires have been common phenomena in guinean and sudanese savannahs. In these environments, regular fire passage is a regulatory factor for the ecological system (Valea and Ballouche, 2012). Thus, fire has always been integrated into environmental management and plays a major socio-cultural role in many West African societies living in savannah areas (Dugast, 1999; Luning, 2005). However, today, with climate dryness and changes in bush fire practice (Valea and Ballouche, 2012), uncontrolled fires are increasingly occurring in forested areas. Despite the important ecological role of fires in savanna ecosystem dynamics (Fournier, 1991; Maire *et al*., 1994), they are disturbance factors that significantly alter ecological processes and ecosystem services of forests (Bowman *et al*., 2009; Franklin *et al*., 2016). In forests, fire has a negative impact on the structure and composition of vegetation, soil, wildlife and landscape (Jacquet and Cheylan, 2008). Due to the impact of fires on the core components of the ecosystem, accurate monitoring of fire effects is one of the central issues of ecology and natural resource management.

In recent years, remote sensing data have become an essential tool for detecting forest disturbances resulting from fires (Margono *et al*., 2012). Numerous studies have been conducted on fire regimes and their severity in places such as Australia, California and South Africa. But very few fire studies based on satellite data have been carried out in West Africa, particularly in Côte d'Ivoire. Since fire is recognised as a determining factor in the selection of floristic species, the triggering of which causes profound changes in the flora of an ecological zone, it is necessary to carry out work on its dynamics in ecological environments in general and in forest environments in particular in order to better control it. The purpose of this study is therefore to help fill this gap by focusing on the dynamics of uncontrolled wildfires in Mont Péko national Park (MPNP), after the people who had illegally settled there in the wake of the crises took off in 2016. Indeed, with the resumption of the activities of management and supervision of this protected area which escaped the control of the State due to the political-military crisis of 2002 to 2011, all forms of anthropogenic pressure have been significantly reduced or even disappeared for some, except for uncontrolled bush fires (Ousmane et al., 2018). These fires, once limited in the mountainous areas of the northern part of the park, began to gain ground in the southern part. The overall objective of this study is to assess the dynamics of uncontrolled wildfires in the MPNP from two Landsat satellite images from 2016 and 2018. Specifically, the first step was to identify the burned surfaces, then map them, and then characterize the severity of the fires through the difference in the Normalized Burn Ratio (NBR) and to analyse the distribution of burnt areas according to the type of land cover.

Materials and Methods

Study area

Mont Péko national Park (MPNP) is located in the western part of Côte d'Ivoire, more specifically between 6°53' and 7°08' N and between 7°11' and 7°21' W (Figure 1). Administratively, the MPNP is located in the Guémon region and straddles the departments of Bangolo in the North (about two thirds of its area) and Duékoué in the South (about one third of its area). The Creation

Decree N° 68-79 of 9 February 1968 gives it an area of 34 000 ha that prove to be inferior on the land, due to the erroneous delineation of the park in 1974 (Ousmane *et al*., 2018). The relief of the park is mainly characterized by barely hilly plateaus of 300 to 500 meters of altitude and three well individualized summits in the northern part. These are Mount Péko (1010 m), Mount Kahoué (1115 m) and Mount Guéhi (918 m; Avenard, 1971). The climate of the region is sub-equatorial wet in two seasons, with rainfall from March to October and dryness from November to February (Eldin, 1971). Vegetation consists of semi-deciduous wet forest, degraded forest and fallow land resulting from human activities (Ousmane *et al*., 2020). Owned by the Guinean Forests of West Africa Hotspot, one of 36 tropical areas of global importance for their biodiversity (Michael et al., 2016), the park is home to high conservation value wildlife and florists such as *Chrysophyllum azaguieanum* J.Miège (a plant at risk), *Picarthates gymnocephalus* Lesson 1828 (a rare bird species) and two large endangered mammals: *Pan troglodytes* verus Blumenbach 1776, the Common Chimpanzee and *Loxodonta cyclotis* Matschie 1900, the forest elephant (Goné Bi *et al*., 2013 ; Lauginie, 2007).

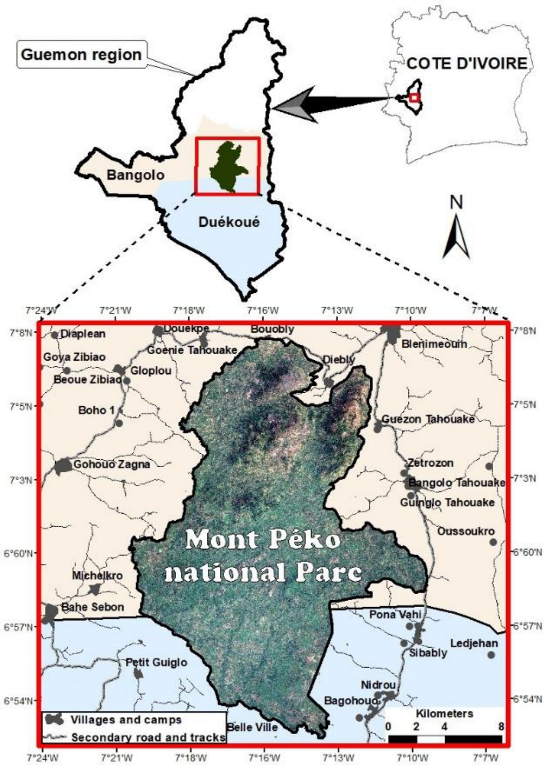

Figure 1: Presentation of the study area (Mount Péko National Park)

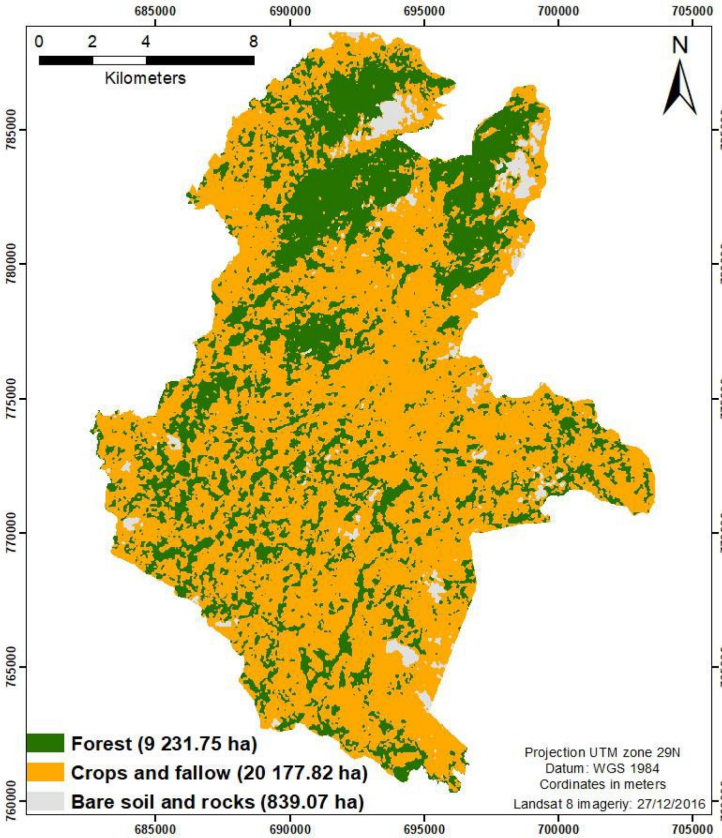

Figure 2: Map of land use types in Mont Péko National Park (Ousmane *et al.*, 2020)

Data

This work involved the use of two Landsat 8 bands OLI satellite images from scene 198/055 dated 27/12/2016 and 16/02/2018, downloaded free of charge from https://earthexplorer.usgs.gov. Also, GPS points recorded during the various prospecting missions in the park in March 2018 were used to realize and validate the classification of satellite images. The data processing in this study was performed with the software ENVI 5.0, which was used for calibration and processing of satellite images and the software Arcgis.10.0.0, which made it possible to make analyses and cartographic returns.

Preprocessing of Landsat satellite images

The acquired images were first calibrated radiometric and atmospheric using the FLAASH (Fast Line of Sight Atmospheric Analysis of Spectral Hypercubes) tool implemented in the "Atmospheric correction" module of the ENVI software. The corrections consisted first of converting the digital accounts (DN) of each scene into TOA reflectance (top of the atmosphere) using reflectance rescheduling factors provided in the Landsat OLI metadata file. Next, the dark pixel subtraction method was used to perform atmospheric correction to obtain surface reflectance. Then, the study area was extracted from satellite images from a shapefile made available by the Ivorian Office of Parks and Reserves (OIPR).

Normalized Burn Ratio (NBR) Calculation and Fire Severity Estimation

In this study, the NBR index (Key *et al.*, 2002) was used to locate burned areas. It was calculated from the images before and after the fires using bands (7) SWIR 2 (2.11 -2.29 μ m) and (5) NIR (0.75 to 0.90 μm). This index is calculated by subtracting the reflection factor of Band 7 from Band 5 of Landsat 8 according to the following equation:

NBR= [Band 5 (NIR) - band 7 (SWIR)] / [Band 5 (NIR) + band 7 (SWIR)]

NBR is sensitive to the changes in live green vegetation, moisture content, and some soil conditions which may occur after fire and takes values ranging between -1 and 1. Positive values correspond to high amounts of biomass, while negative values are related to exposed soil and reduced leaf moisture.

The fire severity estimate was evaluated using the difference in the 2016 pre-fire and 2018 post-fire NBR, according to numerous publications (Key and Benson, 2006; Meng and Meentemeyer, 2011; Vogelmann *et al.*, 2010). The equation is as follows:

$$\Delta NBR = NBR_{pre\text{-}fire} - NBR_{post\text{-}fire}$$

For this study, the NBR was multiplied by 1000, resulting in a ranking between -500 and 1300. The NBR value indicates the extent to which the vegetation of a landscape has changed, with high positive or negative values indicating a greater magnitude of change (Key and Benson, 1999).
Following the procedure of Key and Benson (2006) and knowing that burn severity ranges are flexible, the ΔNBR ranges have been fixed with the values are shown in Table 1.

Table 1: Burn Severity Ranges

Severity level	Δ NBR range
Unburned	[-500 – 99]
Low severity	[100 – 259]
Moderate severity	[260 – 659]
High severity	[660 – 1300]

Burn Area Mapping

In this study, the NBR difference was first used to distinguish areas burned between 2016-2018 and areas not burned. As a result, fire perimeters were quickly interpreted and digitized "on-screen by GIS". Then, a colored composition of the spectral bands 7/5/4 of the 2018 image was made to better discriminate the different spots of burnt areas (Figure 2). Following the interpretation of the colored compositions, two classes were identified in the perimeter of the lights:

- burned surfaces (variations from purple to pink)
- unburned vegetation (green variants)

"Training plots" were defined for each of them and then characterized using GPS surveys during the exploration missions conducted by the research team in March 2018 with the assistance of OIPR officers. The classification was performed using the maximum likelihood algorithm. A total of 120 training plots were used for the classification and verification of remote sensing results. The performance of classifications was analyzed through the global accuracy indices and the Kappa coefficient (Girard and Girard, 1999). To eliminate isolated pixels in order to improve classification rendering, a 3x3 median filter was applied to the different processed images. Analysis of the light distribution across the different types of land cover was performed using a crossing of the layers of the most recent occupancy map (Ousmane *et al.*, 2020) and the fire severity class map from the ΔNBR image map.

Results

NBR difference and color composition to identify areas burned

The NBR index difference map (ΔNBR) calculated and the color composition made on the basis of the 7/5/4 bands for the 2018 image made it possible to determine the perimeter of the fires and to highlight the different types of major colorations corresponding to the burnt surfaces; and unburned (Figure 3). It was thus possible to discriminate the unburned vegetation and stains of the burned areas.

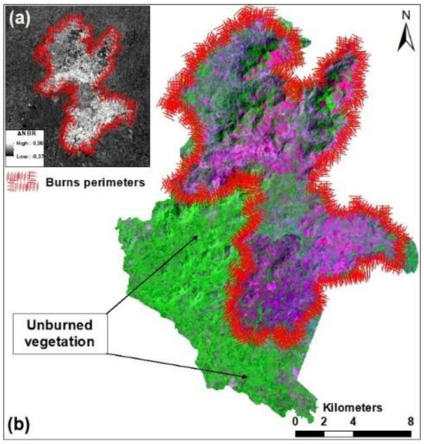

Figure 3. Discrimination of the perimeter of fires in the MPNP between 2016 and 2018: (a) ΔNBR of the picture of 2016 and 2018 or the light grey coloring marks the perimeter of the fires; (b) Colored composition using in order the bands 7/5/4. In the perimeter of the lights, light and dark green characterizes the unburned surfaces and variants from violet to pink the burned surfaces.

Mapping of Burned areas

The total area burned within the MPNP between December 2016 and February 2018 is 15 014.04 ha (Figure 4). All burned areas are located in the North and South-East part of the park. In total, it is estimated that 49.63% of the vegetation burned in this protected area during the period from 29 December 2016 to 27 September 2018.

The supervised classification, with an overall accuracy of 97.31% and a Kappa coefficient of 0.94, indicates a good discrimination between the different spots of burned surfaces (Pontius, 2001).

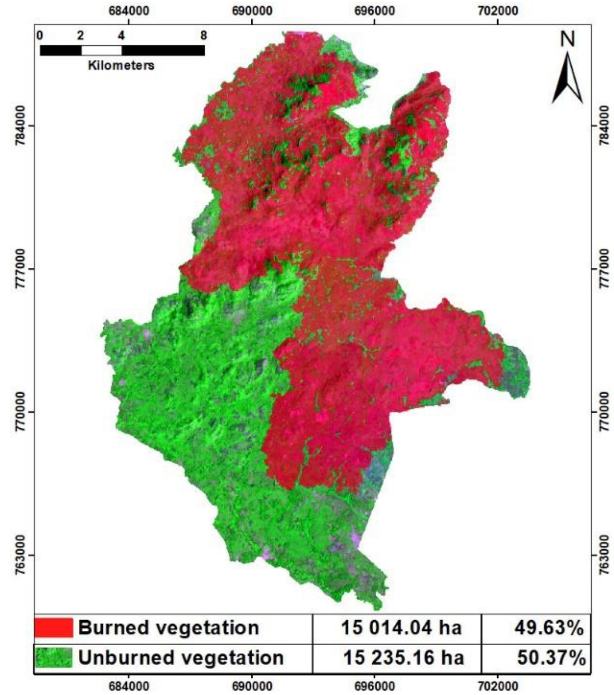

Figure 4. Area burned in the MPNP between December 2016 and February 2018.

Estimation of Fire Severity

Estimating the severity of fires through the ΔNBR difference from the 2016 and 2018 Images distinguished the low, moderate and high severity classes in fire affected areas (Figure 5). Of the 15 014.04 ha burned in the MPNP, 58.19% and 49.80% had recorded respectively low and moderate intensity fires. In total, fires in the MPNP burned more surface, but were generally less severe.

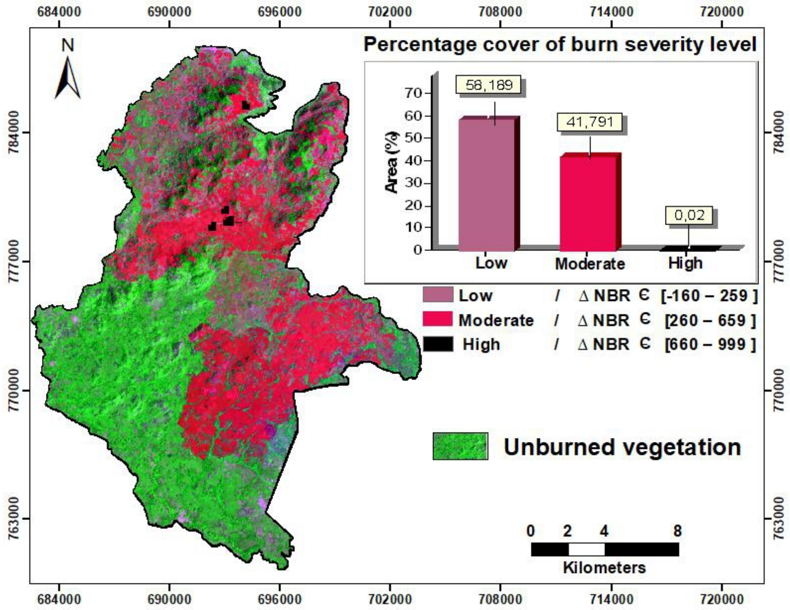

Figure 5: Fire severity map using the ΔNBR difference derived from the Landsat OLI scenes before the fires (27-12-2016) and after the fires (16-02-2018) in the MPNP in Côte d'Ivoire.

Distribution of area burned by type of land cover

Analysis of the distribution of fires across the different land cover classes shows a greater occurrence of fires in the crop and fallow class compared to the forest, bare soil and rocky outcrops class (Figure 6). Overall, the severity of fires in the different land use classes is moderate and low. However, small proportions of high severity were recorded in the crop/fallow (0.02%) and bare soil/rocky outcrops (0.08%).

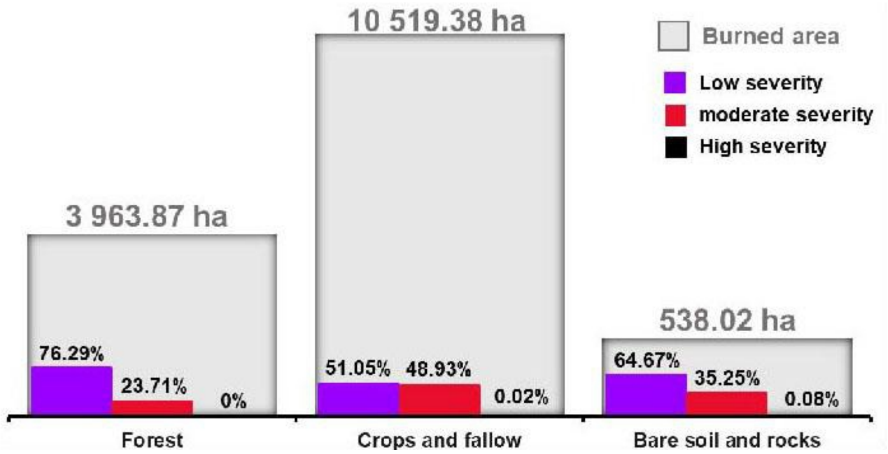

Figure 6: Distribution of area burned and occurrence of severity classes in land use types between 2016 and 2018

Discussion

Origin of Fires in the MPNP

The spatial distribution of burned areas between 2016 and 2018 highlights the importance and spread of fires in the North and South-East part of the MPNP. This situation could be explained by adverse effects of climate change, certain topographical factors, correlated with the clandestine activities of some former infiltrators as well as the operation of destruction of cocoa plantations conducted by the OIPR. Indeed, the extension of the dry season with a decrease in rainfall in the region is contributing to a reduction in the water content of plants and the relative humidity of the air. This drying out of this ecological zone leads to an increase in the flammability of vegetation during the dry season. This risk of flammability of vegetation is higher in the northern part of the park where the terrain is essentially characterized by a mountain range. According to Tir (2016), elevation influences vegetation composition, moisture content and wind exposure. The higher the terrain, the more exposed the fuels are to the sun and the intense winds, the drier they are and the fires burn faster. In this park where some ex-infiltrators (peasants and poachers) are now working in clandestinity, fires of weeding of plot, cooking or muddling of game abandoned in haste, could have turned into a real fire. Moreover, the operation of destruction of cocoa plantations by the OIPR would in itself be a cause of aggravation of the phenomenon of uncontrolled bush fires in the MPNP. Indeed, after the felling of cocoa feet, dry biomass becomes fuel. In addition, the thickets which settle on these sites are dominated by the herbaceous stratum which dries up more or less during the dry season, increasing the amount of fuel.

Distribution of Area Burned in the MPNP

Analysis of the occurrence of fires within the different types of land use has shown that all vegetation classes are affected by fires. However, most fires occur in crops and fallow land. The occurrence of higher fire in this anthropogenic class (10 519.38 ha) could be explained by the availability of large amounts of fuel (dry biomass) during the dry season and by the “fuel” (maintenance fires on agricultural plots). In forest areas, fire occurrence is low compared to agricultural areas. According to the results of the work of Kana and Etouna (2006), the decrease in fire occurrence in the forest area is linked to high hygrometry and the actual evaporation rainfall ratio, positive in favour of moisture for most of the year which limits the intensity and spatial extent of plant combustions. Thus, only areas of degraded forests and forest regrowth show a relative susceptibility to fires due to agricultural activities and the presence of large, easily flammable herbaceous mats under the woody strata which have become discontinuous or open. The occurrence of fires in the bare soil and rock outcrops class could be explained by the proliferation of thickets and readily flammable herbaceous mats during the dry season.

Severity of Fire Characteristics

The results of ΔNBR in this study, which showed a better differentiation of fire severity classes, was also confirmed by some earlier studies recommending this variable as an operational indicator for estimating the severity of fires from satellite data (De Santis & Chuvieco, 2007; Garcia-Haro *et al.*, 2001; Key *et al.*, 2002). Field surveys also showed that the different levels of fire severity are distributed very heterogeneously throughout the study area. Fully burned areas can be found next to partially burned areas and areas with unburnt vegetation. This unequal distribution of fire spots may be due in part to sudden changes in wind direction during combustion, but can often be explained by visible field factors, in particular the variable distribution of the moisture content of available fuels, as well as discontinuities in the available fuel continuum and physical barriers such as roads, water bodies or lows-background and rocks that prevent the spread of fire (Walz, 2005; Whelan, 1995).

In analysing the severity of fires in this study, three classes were selected in order to easily distinguish the levels of fire severity and to reduce confusion between them. Each of these selected classes (low, moderate and high severity) could be adapted to the vegetation burn characteristics observed during the field visit.

Low fire severity was observed in areas where pre-fire fuels were rare or light, particularly in forests or plantations with high hygrometry and thin litter. In these areas, only a small percentage of the vegetation cover (litter), up to 30%, was consumed and vegetation mortality was minimal. Mortality of trees and shrubs was low because the leaves of trees and shrubs remained healthy and green due to the plant’s moisture. Some areas of low fire intensity were also observed in large areas of rocky outcrops or bare soils in the mountain range. Results from the work of Key and Benson (1999) showed in a previous study in North America that fires of this severity had many positive effects which can be summarised as follows: release of plant nutrients, creation of edge habitat and additional openings, stimulation of some fire-dependent vegetation species.

Moderate fire severity is defined as that in which biomass is consumed in the range of 35 to 55 %. It was found that these types of fire predominate in crops and fallow areas, followed by degraded forests, then bare soils where shrub and grass communities were moderately dense. The leaves of shrubs and grasses can be consumed in whole or in part, there are still feet of fragile and defoliated shrubs. In areas where the pre-fire vegetation was wood, brown leaves remained on the trees, but much of the bedding had been burned. As indicated by Key and Benson (1999), recovery of plant cover after moderate burning can be more rapid if fires do not occur very frequently. Frequent fires can affect the soil structure as they expose it to leaching.

High fire severity was observed in a crops and fallow area in an alluvial plain. In this area, since bedding is generally deeper, the residence time of the fire may be longer, resulting in total consumption of combustible biomass, trees, shrubs and herbaceous. That observed on a rocky outcrop would be related to the repeated passing of lights between 2016 and 2018. On mountainsides, the amount of biomass consumed by fire is very high because the vegetation is very dry and ignites easily (Landmann, 2003). If fires of this severity occur frequently in an area, the continuous erosion of organic matter in the soil can be very significant as the soil is highly exposed to wind and rain. As a result, recovery of vegetation can take a long time. This observation was confirmed by (Walz *et al.*, 2007)

Conclusion

The resumption of the management activities of the Mont Péko National Park by the OIPR, following the outcome of the political-military crises from 2002 to 2011, led to a significant drop in all forms of pressure, Even disappearance for some pressures, except for uncontrolled bush fires. This study made it possible, thanks to the combined use of remote sensing and geographical information systems, to highlight these burned areas in the park, after the people who had illegally settled there in the wake of the crises took off in 2016. The results of this study highlighted the importance and spread of fires in the North and South-East portion of the MPNP between December 2016 and February 2018. During this period, the area covered by fires is estimated at 15 014.04 ha, or 49.63% of the total area protected. Analysis of the distribution of fires across the different land use classes revealed a greater occurrence of fires in the crop and fallow class (10 519.38 ha) compared to the forest class (3 963.87 ha) and the class of bare soils and rocky outcrops (538.02 ha). Overall, the severity of fires in the different land use classes was moderate.

In view of the extent of the areas burned in the MPNP between 2016 and 2018, more detailed investigations need to be carried out urgently in order to find solutions to this phenomenon, which now threatens the conservation of biodiversity.

Thanks

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