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Contribution of sentinel-2 images to the mapping of anthropogenic activities in the Dibon Classified Forest (DCF), Tuy province, Burkina Faso

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Abstract

The Dibon classified forest (DCF), like other forests in Burkina Faso, is subject to strong anthropic pressures. By processing three (03) Sentinel-2 satellite images of 2016, 2017 and 2018 through a supervised classification using the maximum likelihood algorithm, coupled with phytosociological revelations, we identified land use types and assessed the impact of anthropogenic activities on the vegetation cover of the DCF. Spatial structure indices were calculated to assess the state of degradation of the DCF. The results revealed that the vegetation cover represented 72.43% of the total area of the DCF in 2018 compared to 75.86% in 2016. This regression in vegetation cover was for the benefit of anthropogenic areas, which increased from 24.11% in 2016 to 27.43% in 2018. The analysis of the DCF landscape identified two processes of vegetation cover degradation, namely dissection and creation. The horizontal structure of the vegetation indicated a predominance of young individuals. This study allowed the establishment of a cartographic base that can constitute a valuable management tool for this protected area.

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Introduction

Forests are essential to life on earth and cover about 30.6% of the Earth's land (FAO, 2015). They are huge reservoirs of biodiversity and play a major role in water cycle, soil protection and carbon dioxide sequestration (Gadant, 1992). However, with the effect of climate change combined with human activities, forests are experiencing an unprecedented level of degradation.

Indeed, according to many authors, anthropic activities such as agriculture, livestock farming, illegal logging and mining are the major cause of land cover destruction in sub-Saharan Africa (Kambiré *et al.*, 2015; N'Da *et al.*, 2015; Sawadogo, 2006). In Burkina Faso, the rate of deforestation is currently estimated about 0.9% per year (FAO, 2018).

This loss of forest areas is the consequence of strong demographic growth, leading to the need of extension of crop areas to increase production and reduce the food deficit (Gnoumou, 2013). This strong pressure on forest resources has not spared the country's protected areas (Ouoba, 2006; Tankoano *et al.*, 2016), impacting negatively on environment more globally and on biodiversity in particular. This is the case of the Dibon Classified Forest (DCF), which is part of the Deux Balé National Park. It is therefore essential to develop strategies for the sustainable management of protected areas, which are the main relics of biodiversity in the country. Indeed, the lack of information on the level of degradation of the DCF and vegetation data limit its sustainable management.

Several studies (Crutzen, 20017; Jofack-Sokeng *et al.*, 2016; Kpedenou *et al.*, 2017) have revealed that very high-resolution satellite imagery technology is widely used to analyze the vegetation cover of protected areas. Thus, this technology was employed in the present study entitled "Contribution of Sentinel-2 images to the mapping of anthropogenic activities in the classified forest of Dibon (DCF), province of Tuy, Burkina Faso". The overall objective was to assess the impact of human activities on the woody cover of the Dibon Classified Forest.

Material and methods

Study site

Dibon classified forest (DCF) is located in the province of Tuy on the National Road 1 connecting the two main cities of the country, Bobo-Dioulasso and Ouagadougou axis (Fig. 1). The area belongs to the Southern Sudanian climate type (References). The forest extends between 11° 50' and 11° 59' north latitude and between 2° 83' and 3° 08' west longitude, covers about 24,000 ha of area and is crossed by the Mouhoun River fed by the Grand Balé and Petit Balé rivers (Coziadom, 2009). The vegetation is dominated by savannahs, with some open forests and gallery forests alongside the rivers. The soils are mostly of the tropical ferruginous type, leached and little leached on sandy, sandy-clay and clay-sandy materials and hydromorphic soils (DREP-Ouest, 2001).

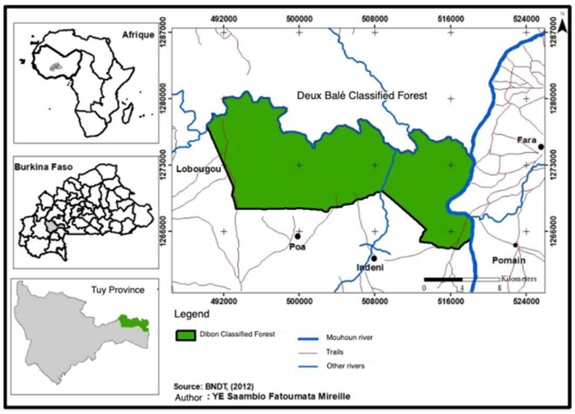


Fig. 1. Location of the Dibon Classified Forest.

Material

For the implementation of this study the following material was used: (i)Three Sentinel-2 satellite images (Path 196 scene, Row 52) of 03/2016, 05/2017/ and 05/2018 were downloaded for free from the United States Geological Survey platform (https://earthexplorer.usgs.gov); (ii) Software used: Qgis, MiniTab 14; (iii) Forest inventory material: GPS, inventory sheets, tapes, stakes, Arbonnier flora

Methods

Satellite image processing

The processing of the satellite images followed the steps below:

- Pre-processing: the images were first subjected to atmospheric correction, performed in Qgis software version 2.18.18. Then, a mosaic of the T30PWT and T30PVT tiles was made to cover the whole study area and the SCP extension of Qgis was used to group the bands or "stacking layers" 2, 3, 4, 8 of 10 m resolution. Finally, the extraction of the DCF was carried out;

- Colour compositions and vegetation index: the 8-4-3 colour composition was chosen because it allowed the types of land use units to be highlighted more clearly on the different images. The training plots were digitized with 30 plots per land use type. The image of 2018 was used as ground truth for the classification of the other two images. The land use unit types in the DCF in 2018 are the same as those identified in 2016 and 2017. The Normalized Difference Vegetation Index (NDVI) was calculated according to the formula below:

$$NDVI = \frac{PIR - RED}{PIR + RED} = (B8 - B4)/(B8 + B4)$$

- Verification of the quality of the training plots: the verification of the separability of the training plots was carried out by the Jeffries-Matusita Distance statistical test. According to (Guiro *et al.*, 2012), it is the most appropriate test for judging the possibility of inter-class confusions for classification directed by the maximum likelihood algorithm. The separability index of this measure is between 0 and 2 ;
- Image classification: after testing the separability of the training plots, we proceeded to classify the images by applying the maximum likelihood algorithm ;
- Validation of the classification: the accuracy of the classification was evaluated by the overall accuracy index and the Kappa index. The overall accuracy is the proportion of well classified pixels and the Kappa index is the ratio of well classified pixels to the total pixels surveyed (Skupinski *et al.,* 2009). In addition to this statistical validation, a second validation operation called "field verification" was carried out during which data were collected in the field as suggested in remote sensing work (Provencher et Dubois, 2007) ;
- Post-classification processing: once the classification was completed, post-classification operations such as filtering, vectorization and cloud extraction on the image are performed to generate statistics for each land cover class in 2016, 2017 and 2018. Thus, this statistical information was used to assess the dynamics of the CDF between 2016 and 2018. The average annual rates of change for each 2018 were carried out. Finally, the extraction of cloud areas was performed on the 2018 image with a cloud cover of more than 10%.

Vegetation covers dynamics of the DCF

The vectorization of the classified images allowed for a land cover class was calculated according to the formula of (FAO, 1996) modified by (Puyravaud, 2003) (equation 1).

$$TC = \left(\frac{S_2}{S_2}\right) \times \left(\frac{1}{t-1}\right) \times 100$$

Composition and spatial configuration of the DCF landscape

The latter involves ten spatial transformation processes (Fig. 2). To differentiate the process of fragmentation from that of dissection, it is necessary to make a comparison between t and t_{obs}. We have adopted the threshold of t=0.5 proposed by (Barima *et al.*, 2009) and t_{obs} is calculated according to the following formula: t_{obs}= a2018/a2016. There is fragmentation when t_{obs}< 0.5, and dissection when $t_{obs >}$ 0.5.

Composition and spatial pattern of the DCF landscape

The spatial transformation process is a complementary approach for landscape dynamics study (Toyi *et al.*, 2018). The assessment of the spatial configuration of the landscape was carried out through the determination of spatial structure indices: number of patches, total area, average area, dominance, fragmentation rate and the decision tree of (Bogaert *et al.*, 2004) was used to describe the landscape configuration.

The decision tree consists of ten spatial transformation processes (Fig. 2). To differentiate the fragmentation process from the dissection process, it is necessary to make a comparison between t and t_{obs}. We adopted the threshold of t=0.5 proposed by (Barima *et al.*, 2009) and t_{obs} is calculated according to the following formula: t_{obs}= a_{2018}/a_{2016}.

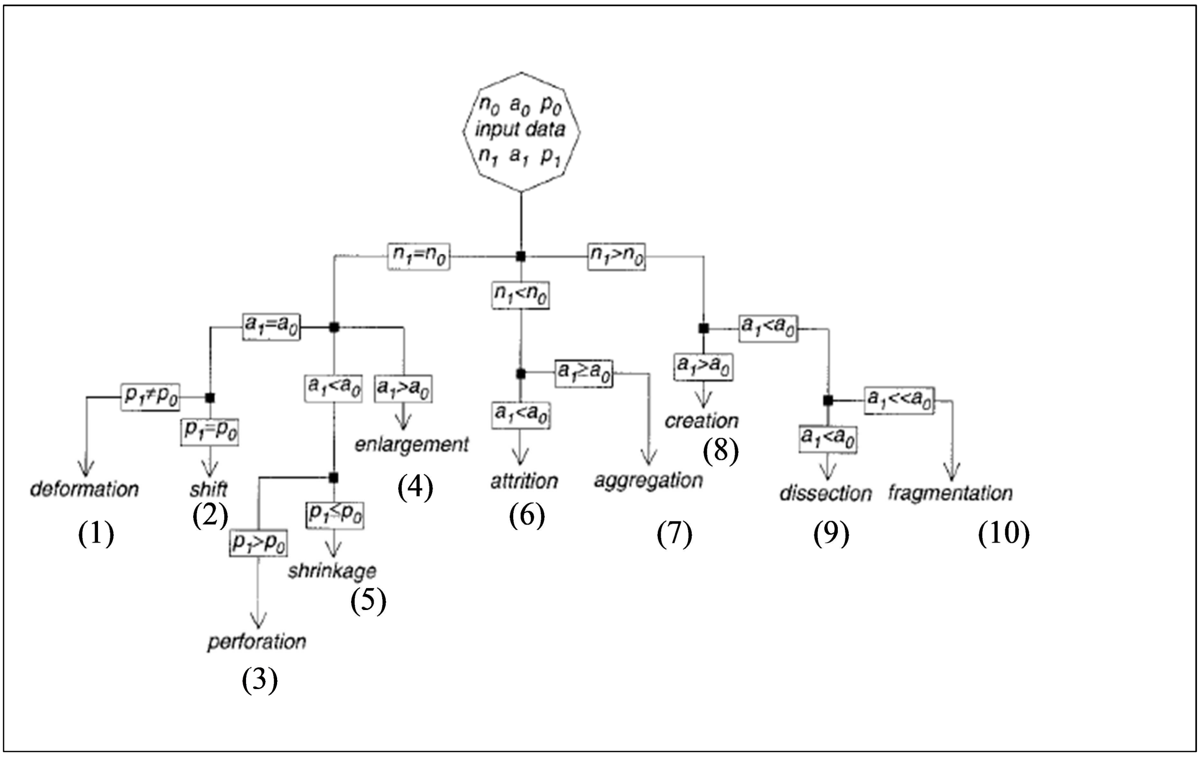


Fig. 2. Typology for the identification of landscape transformation processes by Bogaert.

Horizontal Structure and Floristic Composition of the DCF

In the field, 24 sample plots were set up. Circular plots of 900 m² were installed in the savannahs, agrosystems, and rectangular plots of 500 m² were installed in the gallery forest. On these plots, the GPS coordinates, the type of vegetation according to Yangambi's typology (Aubreville, 1957) and the circumference of the woody plants at 1.30 m from the ground were noted. The woody plants concerned were those with a circumference greater than or equal to 16 cm. The species collected were partly identified in the field using the identification guide (Arbonnier, 2009) and those which identification on field was not possible were taken to the Laboratoire des Systèmes Naturels, Agrosystèmes et de l'Ingénierie de l'Environnement » for laboratory identification.

Results

Land cover dynamics

Validation of the classification

The statistical values of the quality of the supervised classification indicated that the overall accuracy values were 87.38%, 96.60% and 93.04% in 2016, 2017 and 2018 respectively (Tables 1, 2, and 3).

A relative high confusion between some land cover classes was observed in 2016. Indeed, 20.68% of the pixels of the clear tree savannah were classified within the dense tree savannah, while 32.47% and 24.09% of the pixels of the wooded savannah were classified within the clear tree savannah and dense tree savannah classes respectively (Table 1).

Table 1. Confusion matrix of 2016.

	Classes	Reference data						Overall accuracy	Kappa
		WB	GF	WS	OWS	DWS	ABS		
Classification data	WB	95.94	0.23	0	0	0.02	0		
	GF	1.12	91.37	3.19	0.07	0.22	0.11		
	WS	0.09	5.40	92.12	32.47	24.09	1.28		
	OWS	0.35	0.14	2.65	55.55	20.68	1.66	87.38%	77.15%
	DWS	2.25	2.86	1.08	11.57	54.97	0		
	ABS	0	0	0.96	0.32	0.01	96.95		
	Total	100	100	100	100	100	100		

Legend: WB: Water bodies, GF: Gallery Forest, WS: wooded savannah, OWS: Open wooded savannah, DWS: Dense wooded savannah, ABS: Anthropised areas and bare soil

Table 2. Confusion matrix of 2017.

	Classes	Reference data						Overall accuracy	Kappa
		PA	FG	SB	BAG	SAD	SAR		
Classification data	PA	92.49	0	0	0	0	0		
	FG	0	96.44	2.48	0	0	0		
	SB	0.97	3.52	96.72	2.09	0.05	0.37		
	BAG	0	0	0.05	91,55	5.04	1.10	96.78%	92.30%
	SAD	6.22	0	0,04	6.31	94.91	0		
	SAR	0.32	0.04	0.70	0.05	0	98.53		
	Total	100	100	100	100	100	100		

Table 3. Confusion matrix of 2018.

	Classes	Reference data PA	FG	SB	BAG	SAD	SAR	Overall accuracy	Kappa
Classification data	PA	100	0	0	0	0	0	93.04%	90.20%
	FG	0	98.11	6.03	0	0	0		
	SB	0	1.89	88.70	0.54	0.93	1.50		
	BAG	0	0	1.17	97.34	1.29	0.06		
	SAD	0	0	0.01	0	97.78	0		
	SAR	0	0	4.10	2.12	0	98.44		
	Total	100	100	100	100	100	100		

Legend: WB: Water bodies, GF: Gallery Forest, WS: wooded savannah, OWS: Open wooded savannah, DWS: Dense wooded savannah, ABS: Anthropised areas and bare soil.

Land use status of the DCF in 2016, 2017 and 2018

Analysis of the land cover maps (Fig. 3, 4 and 5) showed that the vegetation of the DCF is mainly composed of savannahs and that wooded savannah is in the majority compared to the other land cover classes. Also, all types of vegetation formations have experienced a regression in their area. The most affected was the dense wooded savannah with a loss of 362.38 ha. The gallery forest was the least affected, with a loss of 39.18 ha. At the same time, the water bodies and anthropised areas-bare soils classes surface increased. The latter increased by almost 777.21 ha (Fig. 6).

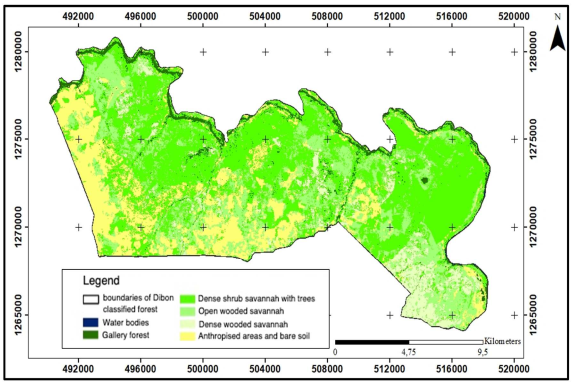


Fig. 3. DCF land use map of 2016.

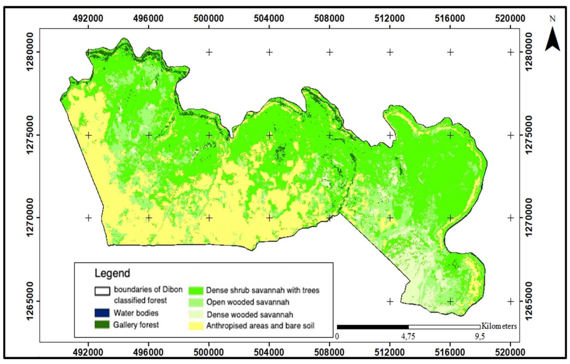


Fig. 4. DCF land use map of 2017.

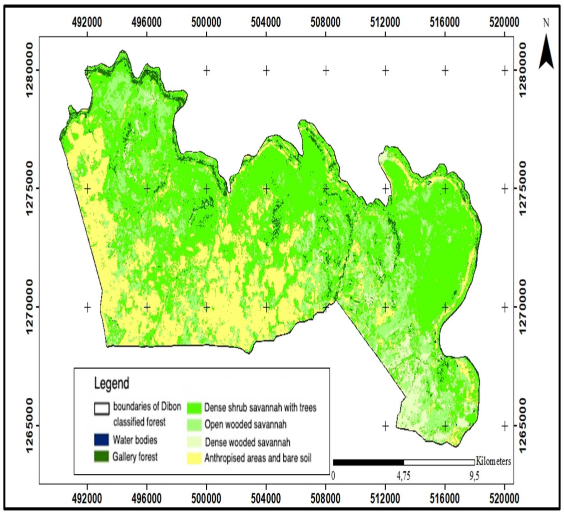


Fig. 5. DCF land use map of 2018.

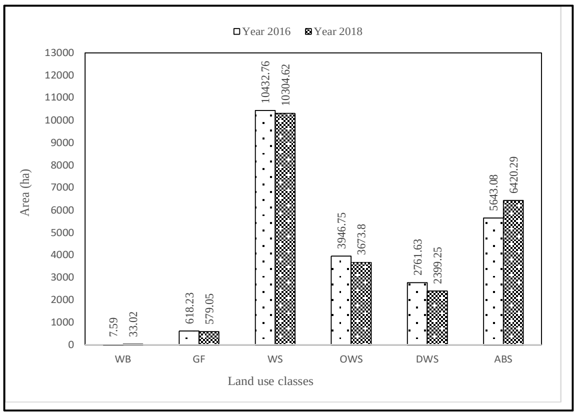


Fig. 6. Changes in land cover types between 2016 and 2018.

Landscape configuration

Spatial structure indices calculated for the years 2016 and 2018 were used to characterise changes in spatial structure (Table 4). From 2016 to 2018, we observed an increase in the number of patches and a regression in their total area for all vegetation classes. For the water bodies and anthropised areas /bare soil classes, the number of patches and the total area in 2018 was higher than in 2016.

We also observed a general regression of the average area (am) for all land cover types. According to Bogaert's decision tree, we ended up with three transformation processes, namely fragmentation, suppression and creation. The t_{obs} is higher than 0.5, meaning that there was a process of dissection and not fragmentation of the landscape.

Table 4. Spatial structure index in 2016 and 2018 in the Dibon classified forest.

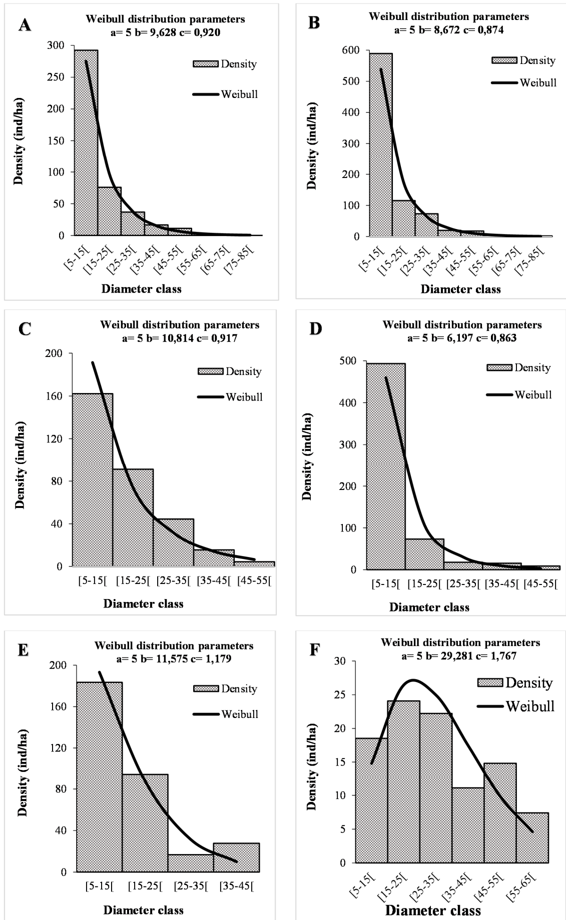
	2016					
	WB	GF	WS	OWS	DWS	ABS
Nj	4	1819	6301	5064	2126	2250
Aj	7.59	618.23	10432.58	3946.75	3761.63	5643.08
a_m	1.90	0.34	1.66	0.78	1.77	2.51
Dj (%)	74.80	55.09	42.47	15.83	18.55	37.46
F (%)	0.02	0.00	0.00	0.00	0.00	0.00
H	0.15	3.63	2.88	4.20	4.08	3.22
2018						
	WB	GF	WS	OWS	DWS	ABS
Nj	10	2048	6878	5807	2290	3848
Aj	33.02	579.05	10304.62	3673.80	2399.25	6420.29
a_m	3.30	0.28	1.50	0.63	1.05	1.67
Dj (%)	14.36	10.24	92.68	7.43	14.95	54.83
F (%)	0.01	0.00	0.00	0.00	0.00	0.00
H	4.13	5.69	1.69	5.98	4.75	2.81
t_{obs}	4.35	0.94	0.99	0.93	0.64	1.14

Legend: WB: Water bodies, GF: Gallery Forest, WS: wooded savannah, OWS: Open wooded savannah, DWS: Dense wooded savannah, ABS: Anthropised areas and bare soil, nj : number of patches, aj: total area, am : average area, Dj : dominance, F: fragmentation rate, H : Shannon Weiver diversity index, t_{obs} : observed rate.

Floristic composition and horizontal structure of the DCF

The woody vegetation of the DCF consists of 67 species belonging to 55 genera and 27 families. The main families were Fabaceae-Caesalpinioideae (13.43%), Combretaceae (11.94%), Fabaceae-Mimosoideae (10.45%), Rubiaceae (10.45%) and finally Fabaceae-Faboideae (5.97%). The 22 other families represent 47.76%. The analysis of the horizontal structure of the vegetation of the DCF shows an inverted J-shape.

This structure fits perfectly to the Weibull distribution with the shape parameter c= 0.92 (Fig. 7A). The same distribution was observed in gallery forest (Fig. 7B), clear tree savannah (Fig. 7C) and wooded savannah (Fig. 7D) all with shape parameter c less than 1. In contrast, dense tree savannah and anthropised areas showed a straight asymmetric distribution with shape parameter c of 1.17 and 1.69 respectively (Fig. 7E and 7F).



A: Dibon Classified Forest B: Gallery Forest C: Open Wooded Savannah D: Wooded savannah, E: Dense wooded savannah F: Fields

Fig. 7. Horizontal stand structure of Dibon classified forest.

Discussion

Processing of satellite images

The land cover mapping approach through supervised classification of sentinel-2 satellite images coupled with ground truth allowed the distinction between water bodies, gallery forest, wooded savannah, clear tree savannah, dense tree savannah, anthropised areas-bare soil. The high confusion between clear tree savannah and dense tree savannah may be related to the close spectral signature of some vegetation classes (Bourdouxhe, 2017; Kpedenou *et al.*, 2017; Soro *et al.*, 2014). Despite these confusions, the mapping results was highly appreciable with regard to the Kappa indices obtained, as when the Kappa index is higher than 50% the mapping results are validated (Tankoano *et al.*, 2015).

Land covers dynamics of the DCF

The comparative method revealed regressive dynamics for all vegetation classes. The greatest loss was observed in the dense tree savannah with 362.38 ha of lost while fields or anthropised areas and bare soil of 777.21 ha inscreased. Similar findings were made by several authors (Cecchi *et al.*, 2009; Mama *et al.*, 2013; Soro *et al.*, 2014). This increase in anthropised areas can be explained by strong land pressure in the periphery of the forest due to its proximity with villages (Koti, Indeni, Poa) and farming hamlets around (Tankoano *et al.*, 2016). Agricultural clearing has already been identified as an important factor in the regressive dynamics of the woodlands (Tankoano *et al.*, 2015). In sub-Saharan Africa, the lack of new agricultural and fertile lands leads people to settle in protected areas (Ouedraogo, 2006; Kambiré *et al.*, 2015).

In addition to these agricultural activities, gold panning, bush fires and overgrazing are very damaging to the vegetation (Diallo *et al.*, 2011, N'Da *et al.*, 2008). The relatively low rate of regression of the gallery forest (0.08%) can be explained by the fact that this formation is less accessible than the savannah and is not subject to bush fires. The adverse effects of climate change could also explain the degradation of gallery forest. Some authors (Ozer *et al.*, 2010) have revealed that climate change has led to the loss of vegetation cover in the Sahelian zone.

Composition and configuration of the DCF landscape

The processes of landscape transformation are complementary scientific evidence of observed changes (Toyi *et al.*, 2018). The observed changes in the landscape are evidenced by the dissection process observed in gallery forest, wooded savannah, Open tree savannah and dense tree savannah.

This dissection process is attributable to the process of creating the anthropised areas class. This identification of processes in the landscape was possible due to the simplicity and speed of the decision tree (Ba *et al.*, 2004). According to Inoussa *et al.* (2011), these processes are mainly related to human activities and herbivores. These two processes reveal a form of degradation of the vegetation cover of the Dibon classified forest.

Floristic composition and horizontal structure of the DCF

DCF Floristic composition analysis of DCF revealed a relatively good floristic richness. However, this relatively good floristic richness should not hide the fact that the DCF is highly anthropised. Several studies showed that the DCF is undergoing unprecedented anthropisation (Sarr, 2008; Tankoano, 2017). The most dominant families, Fabaceae-Caesalpinioideae, Combretaceae and Fabaceae-mimosoideae are characteristic of regions with a generally dry climate (Aubreville, 1957).

For Gnoumou (2013) the dominance of these families is a characteristic of African savannas. The Rubiaceae are mainly found in the gallery forest; in fact, for Aubreville (1957) the tree and shrub Rubiaceae are rather species of dense humid forest and Traoré (2013) notes the presence of this family in the southern Sudanian sector of the eastern part of Burkina.

The analysis of the horizontal structure of the DCF shows an inverted J-shaped diameter class distribution with the shape parameter c=0.92. This structure is characteristic of plant formations in equilibrium (Traoré, 2013; Glélè *et al.*, 2016).

There are smaller diameter individuals than large diameter individuals. This distribution is typical of stable populations, likely to renew themselves through natural regeneration (Savadogo, 2013; Tindano *et al.*, 2018) in the sub-Saharan zone.

The dense tree savannah and the fields show a straight asymmetric distribution. Such a distribution reveals the predominance of a single species (Tindano *et al.*, 2018; Sanon *et al.*, 2015) and is characteristic of populations with low regeneration potential due to exogenous actions (Glélè *et al.*, 2016). There would be a problem of recruitment of young individuals into the older classes.

Conclusion

The main objective of this study was to improve knowledge of the anthropisation phenomenon in the Dibon Classified Forest in order to provide managers with useful information for decision-making in order to preserve this protected area. The methodology adopted consisted of processing Sentinel-2 images coupled with data collected on the vegetation during the field phase. The calculation of spatial structure indices was done in order to determine the transformation processes taking place in the said classified forest. The analysis of the spatial structure between 2016 and 2018 of the said forest revealed the beginnings of a degradation of the vegetation cover attributable to anthropic actions. As for the horizontal structure of the vegetation of the classified forest, we note a predominance of small-diameter individuals, which presages a good regeneration capacity.

In order to contribute to the conservation of the biodiversity of this protected area, it would be necessary, even fundamental, to reinforce the monitoring and awareness-raising of the local populations. In view of the regressive dynamics revealed by the Sentinel-2 images, strong political decisions will be needed to clear the illegal occupants of the Dibon Classified Forest; otherwise it will be totally invaded in the near future.

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