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RESEARCH ARTICLE

ANALYSIS OF THE SPATIAL AND TEMPORAL STRUCTURE OF LANDSCAPE OF DEUX BALÉ NATIONAL PARK, BURKINA FASO

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ABSTRACT

Burkina Faso's protected areas are under pressure from human activities, in particular agricultural expansion. In addition to the effects of climate change which are a major cause of land cover modifications. Together, these factors causes the loss of biodiversity in protected areas. The main objective of this study is to analyze changes in the spatial structure of the Deux Balé National Park, Burkina Faso. Land cover maps of the park for the years 1986 and 2016 were used for the calculation of the landscape indices and the transition matrix approach allowed to better quantifying the changes in the landscape of the park. The results reveal three processes of change, including i) the fragmentation of tree savannahs, ii) the creation of new shrub savannahs patches, anthropogenic zones, bare soils and water bodies and iii) the removal of gallery forests. The processes of fragmentation and suppression of classes comprising tree cover are mainly related to human activities. This is a danger to the conservation of biodiversity in this park if no corrective measures are taken to reverse the trend.

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INTRODUCTION

Forests play an important role in the balance of nature and climate (Kabulu *et al.*, 2008) and serve as shelters for most animal species. In addition, forests provide many ecosystem functions, such as the provision of food to local populations, carbon sequestration, biodiversity conservation, erosion control, water storage and interception, and redistribution of rains. Forests are an exhaustible resource (Kabulu *et al.*, 2008), therefore it is more than necessary to manage them for future generations. However, most of the forest landscapes worldwide are modified by human activities undertaken to supply the needs of populations (Fahrig 2003, Ouoba, 2006, Kabulu *et al.*, 2008; Inoussa *et al.*, 2011). In West Africa, especially in tropical zone, the general observation is a continuous regression of the forest cover (Toko *et al.*, 2012). Unfortunately, the protected areas, which today are reservoirs of biodiversity, are under unprecedented human pressure. According to the Direction of Forests (DIFOR) (2007), it is estimated that 60% of the protected areas in Burkina Faso are occupied by farms, and sometimes villages with socio-economic infrastructures (Schools, health centre, boreholes, markets, etc.). In West Africa, the major causes of deforestation and degradation of protected areas are uncontrolled bush fires, slash itinerant agriculture, overgrazing and irregular rainfall (Hien *et al.*, 2002, Grégroire and Simonetti, 2010, Diallo *et al.*, 2011, Inoussa *et al.*, 2011; Tankoano *et al.*, 2015). This process increases carbon emissions and add to the effects of global climate change (Ozer, 2004, Inoussa *et al.*, 2011, Tankoano *et al.*, 2016a). All of these anthropogenic pressures causes a forest ecosystem dysfunction and loss of biodiversity (Toko *et al.*, 2012). Thus, the combined effects of human activities and climate change has severe consequences in terms of fragmentation of forest

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ecosystems and reduction of wildlife habitats and flora (Clerici *et al.*, 2007, Touré 2010, Inoussa *et al.*, 2011, Mama *et al.*, 2013, Tankoano *et al.*, 2015). Remote sensing and geographic information system (GIS) approaches have been applied previously in Deux Balé National Park (PNDB) for analyzing changes in forest cover and floristic diversity (Coziadom, 2009, Tankoano *et al.*, 2016b, 2016c). However, research focusing on the dynamics in the spatial structure of the park is lacking. Such information is crucial to better characterize the processes that operate in the park. In addition, such information is necessary for the development of forest management plan for a rational exploitation of forest resources. This study aims to fill this gap. The general objective is to analyze dynamics of the spatial structure of landscape of the PNDB by satellite imagery and landscape ecology techniques. Specifically, the objective of the study is to (i) describe the land use changes between 1986 and 2016, and (ii) assess changes in the spatial pattern of vegetation classes between 1986 and 2016 using landscape metrics.

MATERIAL AND METHODS

Study area

PNDB was created in 1988 by Zatu AN VII/FP/PRES/MET, following the merging of two protected forests (Deux Balé and Dibon), and covers an area of 80 600 ha (Kafando, 2003). The park is located between 11°25'-11°36' latitude N; 2°45' and 3°12' longitude W (Figure 1). PNDB extends on a peneplain with altitudes ranging between 240 m and 320 m (Coziadom, 2009). At ground level, the park is characterized by vertisols, hydromorphic soils and ferruginous tropical soils (Diawara, 2012). The climate is classified as Sudanian type with two distinct seasons, including a rainy season from May to October and a dry season from November to April (Fontès and Guinko, 1995) and an annual average temperature around 28°C with a thermal amplitude approximately 7°C (Coziadom, 2009). The PNDB is located in south-Sudanian district (Fontès and Guinko, 1995) where the landscape is characterized by tree savannahs, shrub savannahs and gallery forests.

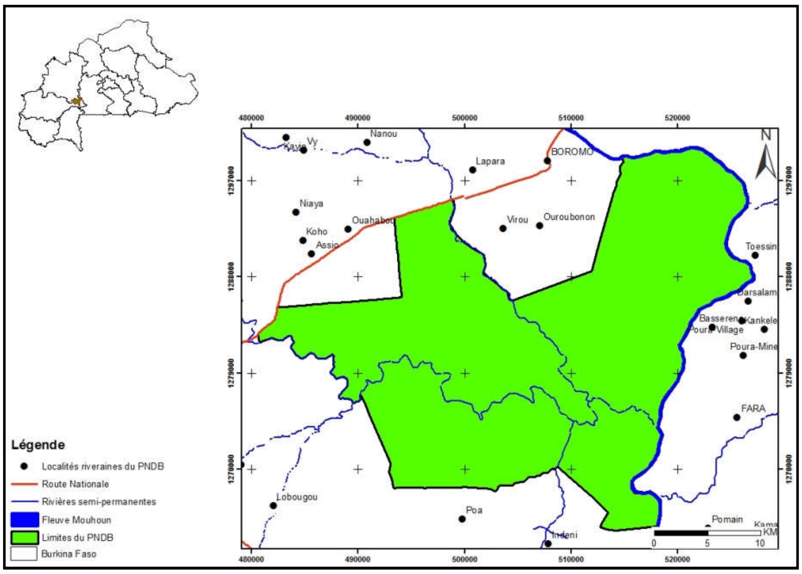

Figure 1. Location of Deux Balé National Park (PNDB)

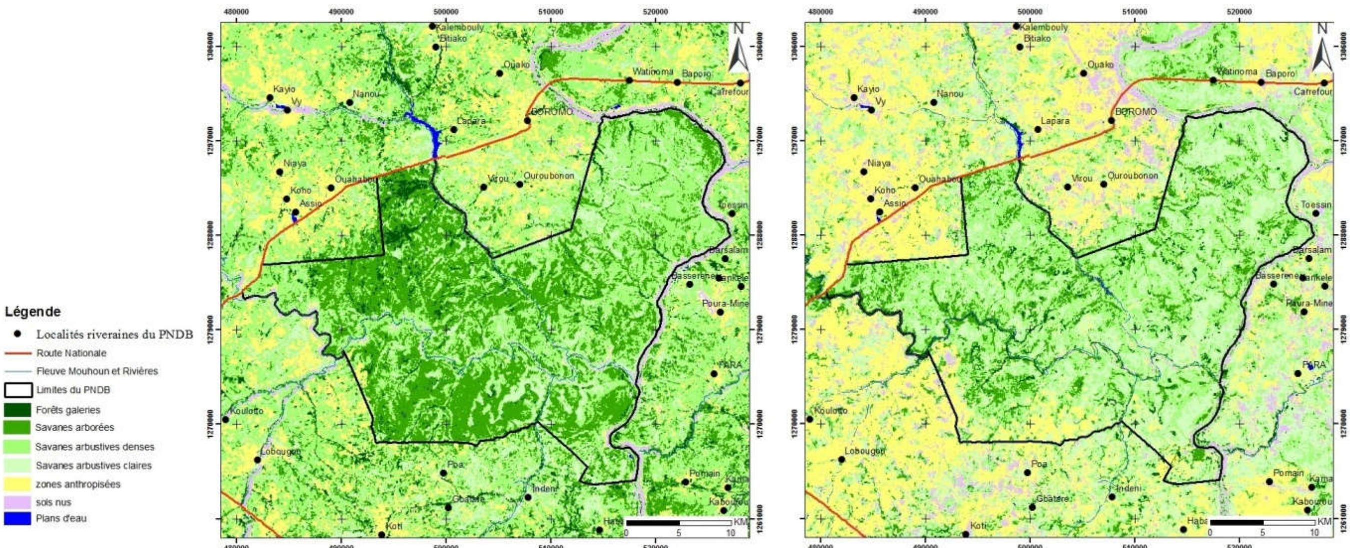

Figure 2. Land cover maps of Deux Balé National Park in 1986 and 2016 (Tankoano *et al.*, 2016b)

The river Mouhoun runs through the area and receives water from temporary watercourses (smaller streams and creeks). Traditional agriculture is the main livelihood strategy of the populations in and around the park. In recent years cotton-growing has been stimulating the clearing of new lands (Sawadogo, 1996).

Material

Land use maps of 1986 and 2016 (Figure 2) were used in this study. Fragstats 4.2 software was used to generate the various landscape indices. ArcGis 10.2 software was used to overlay the two land use maps as well.

Methods

PNDB Land Use Changes: transition matrix

The transition matrix method was used to characterize the changes that have occurred in the Deux Balé National Park between 1986 and 2016. This technique has already been used successfully by several authors (Schlaepfer, 2002; Bamba *et al.*, 2008; Inoussa *et al.*, 2011). The transition matrix was obtained from statistical of the two land cover map, representing two dates (t_0 and t_1). The transition matrix values come from the overlay of the two land cover maps using ArcGis 10.2 software. This technique allowed to detecting of landscape changes in the park between 1986 and 2016. It is a square matrix describing condensed state changes of land cover classes during the period under review (Schlaepfer, 2002, Bamba *et al.*, 2008; Inoussa *et al.*, 2011). The matrix cells contain the value of a variable that has passed from an initial class i to a final class j for the period t_0 to t_1. The values of columns and rows represent proportions of the areas occupied by each class at the corresponding time. Thus, the columns of the matrix indicate the states of land use in 2016 and the lines correspond to the states of land use in 1986. To achieve this crossing, a codification of the vegetation classes was necessary. Thereafter, a comparison of the codes between the two maps was made. This was an approach to identifying changes from code changes for vectors of identical class.. Thus, it was possible to identify the stability, the progression and regression of land use classes.

Calculation of landscape indices

The calculation of the landscape indices allowed to analyze changes in the spatial structure of the land cover classes between 1986 and 2016. The landscape indices were calculated using the Fragstats 4.2 software. The main output from Fragstats include the number of patches (n_j) of each class ($_j$), total area (a_j), perimeter (P_j), dominance (D_j), mean area (□□) and the fractional dimension index (Df_j). The number of patches (n_j) provides information about the fragmentation of a class between two times. Indeed, the increase of the number of patches of a class may be due to the fragmentation of this class (Davidson, 1998).The total area (a_j) occupied by the class j (ha) reflects the degree of fragmentation of the individual classes and was calculated according to Equation 1,where a_{ij} is the area of the i-th patch of the class j.

$$a_j = \sum_{i=1}^{n_j} a_{ij} \qquad \text{………Equation 1.}$$

If the area of a class is large, its fragmentation is expected to be low, and if it is small, the fragmentation of the class is important (Kabulu *et al.*, 2008). The total perimeter (P_j) of class j (expressed in kilometer) is the sum of the contours of each of the patches (P_{ij}) of this class and was calculated using Equation 2, where

$$P_j = \sum_{i=1}^{nj} Pij \qquad \text{……….Equation 2}$$

Dominance (D_j) indicate the proportion of areas occupied by the dominant patch in the class j, and was calculated according to Equation 3. Dj varies from $0 \leq$ □□ ≤ 100 whereaclass is less fragmented when the value of dominance is higher.

$$D_j = \frac{a_{max,j}}{a_{tj}} \times 100 \qquad \text{………Equation 3}$$

The mean area □□describes the average value of the area of the patches of class j and was calculated according to Equation 4. This index will be higher when the average land cover blocks are large, signaling a low degree of fragmentation (Kabulu *et al.*, 2008). So, we can expects that the landscape will be more intact when the index is high.

$$\bar{a}_j = \frac{a_{tj}}{n_j} \qquad \text{………..Equation 4}$$

The fractal dimension (Df_j)was proposed by Mandelbrot (1994) and essentially uses of the ratio between perimeter and area. According to Iorgulescu and Schlaepfer (2000), the purpose of Df_j is to quantify the shape of complex objects. Df_j is considered to be a measure of the degree of anthropization of the patches of a landscape class (Krummel *et al.*, 1987) and is derived by Equation 5,

$$p_{tj} = k \times a_{tj}^{Dfj/2} \qquad \text{...…….Equation 5}$$

where P_{tj} is the sum total of the contour of each of the patches of a class and Df_j the fractal dimension of class j. To obtain Df_j, a logarithmic transformation was made (Equation 6),

$$\log p_{tj} = \log k + \left(\frac{Df_j}{2}\right) \times \log a_{tj} \qquad \text{……….Equation 6}$$

where Dfj is the fractal dimension of class j and k is a constant. The fractal dimension of the class j is obtained from linear regression between the areas ($\log a_{ij}$) and the perimeters ($\log p_{ij}$) of all the patches of this class. The graph log-log gives the slope of the regression line that is equal to $Df_j/2$. The value of the fractal dimension is thus twice the value of the slope of the regression line obtained and varies from 1 to 2. When Df_j tends toward 2, the patches have complex shapes (i.e., less anthropized natural environment) and when Df_j tends toward1, patches have simple or regular shapes (e.g., square, rectangle) most often related to human activities (Krummel *et al.*, 1987; Iorgulescu and Schlaepfer, 2000; Diallo *et al.*, 2011; Mama *et al.*, 2013). In landscape ecology, in order to describeof the landscape dynamics, the decision tree proposed by Bogaert *et al.* (2004) has often been used (Barima *et al.*, 2009; Diallo *et al.*, 2011; Inoussa *et al.*, 2011; Mama *et al.*, 2013). The decision tree approach can identify the following ten spatial transformation processes:

- Suppression or deletion: disappearance of one or several patches;
- Creation: formation of new patches;
- Distortion: change in shape of the patches without change of area;

Table 1. Transition matrix in percentage of land cover in PNDB

1986 / 2016	GF	TS	DSS	SSS	AA	BS	WB
GF	10.63	2.07	3.34	3.73	0.85	3.88	11.02
TS	32.42	16.2	13.77	8.7	11.16	5.76	0
DSS	36.75	42.53	41.88	41.37	21.23	7.11	0
SSS	15.49	31.4	36.01	38.26	22.53	8.22	0
AA	4.2	7.25	4.08	6.14	27.08	23.74	0
BS	0.41	0.47	0.89	1.75	17.14	50.83	0.79
WB	0.1	0.07	0.035	0.04	0.01	0.46	88.19
Change	89.37	83.8	58.12	61.74	72.92	49.17	11.81

Caption : GF : Gallery Forests; TS : tree Savannahs; DSS : dense shrub savannahs; SSS : sparse shrub savannahs; AA: Agricultural area; BS : Bare soils; WB : water bodies

Table 2. Landscape indices of the land cover classes in1986 and 2016 of the PNDB

	GF	TS	DSS	SSS	AA	BS	WB
1986							
n_j	1690	2328	2458	3354	706	308	8
a_j (ha)	3079.8	33577.2	31906.72	9447.72	1331.19	228.51	11.43
$\bar{a}_j$	1.82	14.42	12.98	2.82	1.89	0.74	1.43
p_j (km)	1014.3	5262.66	6930.06	2831.88	502.68	119.76	4.44
D_j (%)	9.75	44.29	36.17	5.04	10.57	2.32	21.26
Df_j	1.04	1.06	1.06	1.05	1.05	1.04	1.05
2016							
n_j	1362	3499	2578	3654	1852	605	20
a_j (ha)	2462.31	11802.87	32995.08	26468.28	4847.85	964.89	41.13
$\bar{a}_j$	1.81	3.37	12.80	7.24	2.62	1.59	2.06
p_j (km)	873.06	3515.94	7723.92	5476.74	1295.46	356.04	16.8
D_j (%)	6.63	3.62	66.2	7.38	19.82	8.41	90.59
Df_j	1.04	1.06	1.05	1.06	1.06	1.04	1.06
t_{obs}	0.8	0.35	1.03	2.8	3.64	4.22	3.6

Caption : GF : Gallery Forests; TS : tree Savannahs; DSS : dense shrub savannahs; SSS : sparse shrub savannahs; AA: Agricultural area; BS : Bare soils; WB : water bodies

- Dissection: subdivision of patches by lines of uniform width and small dimension;
- Expansion: increase in size of the patches;
- Fragmentation: break of continuity in several patches Disjointed, different shapes and sizes;
- Perforation: formation of holes in the patches;
- Displacement: translocation of one or several patches;
- Aggregation: merging patches
- Shrinkage: reduction in size of the patches.

The input parameters to the decision tree are the number of patches (n_j), the area (a_j), and the perimeter (p_j) of the class j, at the start and end of the study period. These three elements are considered as the main elements of the description of the landscape configuration (Barima *et al.*, 2009; Diallo *et al.*, 2011). The change in each of the three elements was used to characterize a representative process of the observed dynamics. Input for these three elements was derived from for the land cover maps of 1986 (a_{1986}, p_{1986} and n_{1986}) and 2016 (a_{2016}, p_{2016}, n_{2016}). The decision-making process was based on a comparison of their values. Thus, according to the decision tree, there is creation, for example, when $n_{2016} > n_{1986}$ and $a_{2016} > a_{1986}$. In the case where $n_{2016} > n_{1986}$ and $a_{2016} < a_{1986}$, two processes can be identified : fragmentation and dissection. To differentiate the processes of fragmentation and dissection, it is necessary to make a comparison between t and t_{obs}. The choice of t is subjective (with $0 < t \leq 1$) but tobs was calculated (Bogaert *et al.*, 2004; Barima *et al.*, 2009). We adopted the threshold of t=0.5 proposed by Barima (2009). Thus, when t_{obs} 0.5 there is dissection and when $t_{obs}<0.5$ there is fragmentation (Equation 7).

$$t_{obs} = \frac{a_{2016}}{a_{1986}} \quad \text{........Equation 7}$$

The others processes of transformation are the aggregation ($n_{2016}<n_{1986}$, $a_{2016}> a_{1986}$) and deletion ($n_{2016}<n_{1986}$, $a_{2016}<a_{1986}$). When the number of patches for both dates is the same as $n_{2016} = n_{1986}$, there is either an enlargement ($a_{2016}> a_{1986}$), or a perforation ($a_{2016}<a_{1986}$ and $p_{2016}> p_{1986}$), or a shrinkage ($a_{2016}<a_{1986}$ and $p_{2016}<p_{1986}$), or a deformation ($a_{2016}<a_{1986}$ and $p_{2016} \neq p_{1986}$), or a displacement ($a_{2016}<a_{1986}$ and $p_{2016} = p_{1986}$).

RESULTS

Analysis of changes in the composition of the PNDB landscape: transition matrix

The analysis of the transition matrix (Table 1) reveals changes between the land use classes from 1986 to 2016 in PNDB. For example, the classes gallery forests, tree savannahs and agricultural area experienced high rates of changes between 1986 and 2016. The rates of change for the gallery forests, tree savannahs and agricultural area are respectively 89.37%; 83.8% and 72.92%. Dense and sparse shrub savannahs classes, bare soils and water bodies remained more stable than the other classes between 1986 and 2016. Thus, stability rates for the classes dense shrub savannah, sparse shrub savannah, bare soil and water bodies are 41.88%, 38.26%, 50.83% and 88.19%, respectively. In general, there is a progression of dense and sparse shrub savannahs. This increase was at the expense of other vegetation classes, such as gallery forests and tree savannahs. The synthetic analysis of the land cover changes in the landscape of PNDB between 1986 and 2016 helped to highlight the extension of agricultural area, reduction of the tree savannahs and the gallery forests, and the progressive installation of the shrub savannahs (sparse and dense).

Analysis of the dynamics of the spatial structure of landscape PNDB

To better assess the structural dynamics of PNDB, landscape indices was calculated for each land cover class in 1986 and of 2016 (Table 2). These indices allowed to detecting the changes in the landscape of PNDB between 1986 and 2016. Except for the gallery forest class, the number of patches has increased between 1986 and 2016. For tree savannahs class, the number of patches increased from 2328 in 1986to 3499 in 2016. For dense shrub savannahs, the number of patches increased slightly from 2458 in 1986 to 2578 in 2016. In addition, for the classes agricultural area, bare soils and water bodies, the number of patches nearly doubled between 1986 and 2016. Thus, by comparing the areas and the number of patches of the land cover classes in PNDB, three main transformation processes can be identified, including fragmentation, suppression and creation. For the shrub savannahs class, agricultural area, bare soils and water bodies, it was noted that $n_{2016} > n_{1986}$ and $a_{2016} > a_{1986}$, thus creating new patches. For the tree savannahs class, it was noted that $n_{2016} > n_{1986}$ and $a_{2016} < a_{1986}$. Under these conditions, both fragmentation and dissection processes can be considered. However, it can be seen that $t_{obs} < 0.5$, which means that this class of wooded savannahs was fragmented between 1986 and 2016. However, concerning the gallery forests class, $n_{2016} < n_{1986}$, $a_{2016} < a_{1986}$, which indicates that the deletion process occurred in this class. It should be noted that aggregation, enlargement, deformation, dissection, displacement, perforation, and shrinkage processes have not been observed in the PNDB landscape. The values of fractal dimension tend to 1 for all land cover classes between 1986 and 2016. This shows a transformation of the complex forms into more or less regular simple forms. These values of fractal dimension close to 1 show the anthropogenic influence in the PNDB landscape and also a suppression of certain fragmented patches. The values of D_j dominance also revealed the anthropization process of the PNDB landscape: the maximum and minimum D_j values varied between 2.32% and 44.29% in 1986 and between 3.2% and 90.59% in 2016. The D_j values for shrub savannahs, agricultural area, bare soil and water bodies increased significantly between 1986 and 2016. However, the values of tree savannahs class and gallery forests decreased between the two dates, indicating the level of the anthropization process and a degradation of the PNBD. The tendency to anthropization is confirmed by the dramatic decrease in the average area ($\bar{a}_j$) of the tree savannahs patches between 1986 and 2016. The value of the mean area $\bar{a}_j$ of the class has decreased considerably, from 14.42 ha in 1986 to 3.37 ha in 2016. During the same period, the average area $\bar{a}_j$of the shrub savannahs class, agricultural area, bare soils and water bodies has increased.

DISCUSSION

Choice of indices of spatial structure

The landscape indices used in this analysis was selected based on their successful application in previous research where satellite data has been used to assess spatial dynamics in land cover (Bamba *et al.*, 2008, Kabulu *et al.*, 2008, Barima, 2009, Inoussa *et al.*, 2011, Diallo *et al.*, 2011, Toko *et al.*, 2012).The existence of correlation between these indices, even though it indicates a redundancy of information (Bogaert and Mahamane, 2005), constitutes an argument to highlight the fact that the observations are not due to a hazard.

Transformations observed in the landscape of the PNDB

The analysis of the transition matrix shows a degradation of gallery forests and tree savannahs. In addition, an anthropization of these classes is illustrated by an increase in the total area of the agricultural area, and finally an increase in shrub savannahs (dense and sparse). Indeed, complacency in the protection of PNDB would have favored the installation of an area of agricultural settlement in the southern part of PNDB. In this part of the park, there is a strong presence of cotton producers and breeders from the locality of Koti and others villages (Fafo, Indeni, Poa). This colonization of the PNDB has contributed significantly to its degradation. This observation is in agreement with Ba *et al.* (2004) who also concluded that in sub-Saharan Africa, population growth and the land crisis encourage people to deforestation in protected areas.

Structural dynamics of the landscape of PNDB

The indices of spatial configuration of the patches of the different land cover classes allowed to highlighting the spatio-temporal dynamics of PNDB. This analysis has highlighted the processes of fragmentation and deletion, respectively, for the classes tree savannahs and gallery forests. The recurring intrusions of the riparian populations through agricultural activities, grazing and firewood collection could explain this phenomenon of degradation of the park. Anthropogenic activities have already been shown as an important factor in the regressive dynamics of plant formations (Bamba *et al.*, 2008; Faye *et al.*, 2008; Kabulu *et al.*, 2008; Inoussa *et al.*, 2011; Toko *et al.*, 2012). Arouna (2012) suggested that the major causes of the fragmentation of forests are agriculture, exploitation of trees and charcoal production by local populations. In this study we found farming and almost daily exploitation of wood within the PNDB. According to Bogaert and Mahamane (2005), the anthropization in a natural environment is generally characterized by fragmentation, a change in the geometry of the patches and an evolution of the anthropized classes at the expense of the natural land cover classes. This was confirmed in this study by the indices of fractal dimension. The fragmentation of tree savannahs may has seriously impacted the biodiversity of PNDB. Indeed, fragmentation results in the transformation of a continuous habitat of large size into smaller habitats isolated from each other (Tabarelli *et al.*, 2008). The reduction of habitat fragment size and the increased isolation causes in long term reduction of the viability of populations of plant and animal species that live there because of the limitation, or even the disappearance of the exchanges between these populations due to lack of connectivity (Cristofoli and Mahy, 2010). Fragmentation is a threat to the conservation of biodiversity, because homogenization of landscapes takes place through the expansion of agricultural areas (Sabatier *et al.*, 2010). Analysis of the spatio-temporal dynamics has shown also a process of creating new patches of shrub savannahs (dense and sparse) causing an increase in their area between 1986 and 2016. This increase could be explained by protection efforts in the northern part of the park initiated since 2009 by the National Office of protected areas.

Conclusion

The main objective of this study was to analyze the structural dynamics of land cover in the PNDB using satellite imagery and landscape indices. Thus, we used the landscape ecology techniques coupled with remote sensing and GIS. The study revealed significant changes in the landscape of the PNDB between 1986 and 2016. The transition matrix combined with calculations of landscape indices allowed to quantify changes in the landscape of PNDB. Indeed, three transformation processes have been identified, namely i) fragmentation of tree savannahs, ii) creation of new shrub savannahs patches, anthropogenic zones, bare soils and water bodies, and iii) suppression at gallery forests. One of the major causes of the fragmentation of tree savannahs and the creation of new patches of agricultural area would be agricultural clearing for cotton cultivation. The spatial configuration of the landscape has changed dramatically in 30 years. These changes in the landscape may have negative impacts on the conservation of biodiversity of flora and fauna. In short, we can say that spatial imagery coupled with indices of spatial structure has allowed identifying and analyzing relevant indicators that could help in the decision-making process for the sustainable management of PNDB.

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Conflicts of Interest

The authors declare no conflict of interest.

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