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Impacts of land-use Dynamics on the periphery of state-owned areas: the case of the Haut-Sassandra classified forest (Central-western Côte d'Ivoire)

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ABSTRACT

In Côte d'Ivoire, state-owned areas and their periphery are subject to heavy anthropization, leading to changes in the landscape. The general objective of this study is to understand the impact of occupation dynamics at the periphery of the Haut-Sassandra classified forest on its forest cover between 1997 and 2018. To achieve this, remote sensing and landscape ecology methods were used. Consequently, satellite images from the Landsat sensor were processed and verified in the field to highlight the different types of land cover. In addition, transition matrix and decision trees were used to analyze changes in the landscape. At the end of this study, the results showed that the landscape of the Haut-Sassandra classified forest and its periphery are marked by the regression of forest surfaces in favor of anthropized surfaces (crop-fallow, perennial crop and bare soil-habitat) during the period from 1997 to 2018. Indeed, the surface area of the forest class within the Haut-Sassandra classified forest, which was estimated at 73.7% in 1997, has fallen to just 1.1% in 2018. As for the periphery, the forest class, which occupied 18.4% in 1997, fell to just 4% in 2018. Also, over the study period, the dominant transformation process in the Haut-Sassandra classified forest at forest class level is removal, followed by the creation of new patches of crop-fallow. In view of the extent of degradation, environmental management and preservation programs through agroforestry must be initiated within the Haut-Sassandra classified forest as well as on its periphery.

***Key words:** Forest covers degradation, Land use dynamics, Landscape ecology, Landscape transformation, Classified forest.*

Introduction

Covering around 7% of the earth's land surface, tropical forests are home to half of the planet's terrestrial biodiversity (Dupuy *et al.*, 1999). What's more, their capacity to store carbon makes them an important player in global climate regulation (Ciesla, 1997). However, these forests are being cleared mainly for agriculture (Oszwald, 2005), resulting in landscape modification and a significant loss of forest area (Nzigou, 2014). Landscape changes brought about by land use have an influence on climate change, biodiversity and soils (Foley *et al.*, 2005). Indeed, these modifications contribute to global climate change, which in turn controls them, whether on a global, regional or local scale

(Lambin *et al*., 2006). Analyses of changes in land cover and land use have thus become essential elements in studies of land cover change and the assessment of land cover degradation (Kuenzer *et al.*, 2015).

What's more, although global deforestation declined from 8.5 million hectares in 2000 to 6.6 million hectares in 2015, Africa alone saw an annual loss of 2.8 million hectares between 2010 and 2015 (FAO, 2015). This loss of forest cover is due to population growth, which results in the conversion of forests to agricultural land (Jahel, 2016). Indeed, West Africa has been marked over the last fifty years by rapid mutations in rural and state-owned spaces, which are mainly visible in the advance of the cultivated domain to the detriment of natural vegetation, rangeland and grazing areas (Jahel, 2016). Thus, among West African countries, Côte d'Ivoire's forest ecosystems are constantly subjected to various anthropogenic pressures, the most important of which are urbanization, logging and agriculture (Koné *et al.*, 2014), thus leading to the modification of its forest cover. Indeed, in Côte d'Ivoire, forest area fell from 16 million hectares in 1900 to almost 12 million hectares in 1960, then to around 6 million hectares in 1975 (Traoré, 2018) and to 2.97 million hectares (Pirad *et al.*, 2021). However, very early on, the colonial authorities took steps to safeguard natural resources. To this end, from the 1920s onwards, a major network of classified forests, parks and reserves was set up, designed to free many of the country's most representative ecosystems from exploitation by local communities (Ibo, 1993). Unfortunately, in Côte d'Ivoire, these so-called "protected" areas are today subject to strong anthropic pressures. For example, most of these protected areas have seen heavy infiltration by populations in search of arable land for cocoa plantations (Barima *et al*., 2016; Kouakou, 2019), leading to degradation. This was notably the case for the Haut-Sassandra classified forest (FCHS), which was one of the best protected forests in Côte d'Ivoire. Indeed, the degradation of the FCHS was accentuated during the decade of politico-military crisis that Côte d'Ivoire experienced, causing the loss of over 70% of its forest cover to cocoa farming (Barima *et al*., 2016). Furthermore, the work of Sangne *et al*. (2015) and Kouakou *et al.* (2017) showed that during this decade of crisis, the FCHS experienced massive population infiltration. In addition, studies carried out by Zanh *et al.* (2018), showed that the periphery of this classified forest was in a situation of land saturation.

In this context, the main question is whether the scarcity of land observed in rural areas has contributed to the modification of the FCHS landscape. To answer this question, the present study set itself the general objective of understanding the dynamics of change within the FCHS and its periphery between 1997 and 2018 in a context of land saturation. Specifically, the aim was to (1) map the land-use types of the FCHS and its periphery from 1997 to 2018, (2) analyze the spatio-temporal dynamics of the FCHS and its periphery over the same period, and (3) determine the spatial transformation processes operating in the land-use classes of the FCHS and its periphery at the different study dates. Knowledge of the changes observed in and around the Haut-Sassandra classified forest will enable decision-makers to take the necessary measures to protect the forest.

Materials and Methods

Study area

The study took place within the Haut-Sassandra classified forest (FCHS) and its periphery (Figure 1). For the purposes of this study, a 10 km radius around the FCHS was considered as the peripheral zone. Its western boundary is marked by the Sassandra River. The FCHS and its periphery belong to the semi-deciduous dense rainforest zone (Guillaumet and Adjanohoun, 1971). Today, this vegetation is dominated by cash crops, notably cocoa (*Theobroma cacao* L.) and coffee (*Coffea canephora* Pierre ex Froehner) plantations, as reported by

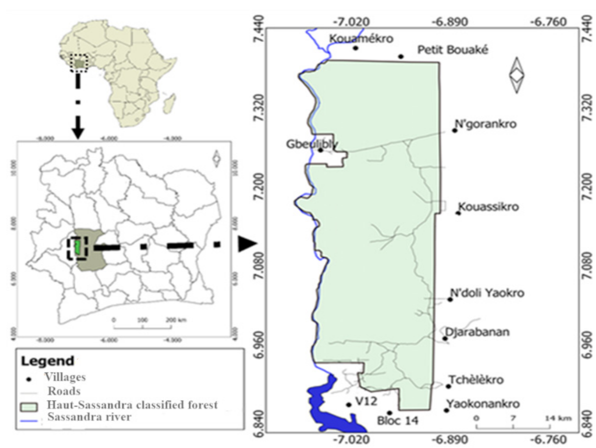

Fig. 1. Location of the Haut-Sassandra classified forest and its periphery

Kouakou *et al*. (2015).

Land-use mapping of the Haut-Sassandra classified forest and its periphery

Mapping was carried out using five Landsat 30m resolution satellite images taken during the dry season in 1997, 2002, 2006, 2013 and 2018. These images have already undergone pre-processing (geometric corrections) before being uploaded to the Earth explorer download site ((http:// earthexplorer.usgs.gov/). Dry season images were used for two main reasons: the large spectral difference between land use classes and the ease of differentiating anthropized areas (crops, fallow land) from areas of natural vegetation (Barima *et al*., 2009; Oszwald *et al*., 2010). Also, during the dry season, atmospheric effects on images are reduced.

The actual processing involved extracting the study area from the entire scene of the 1997, 2002, 2006, 2013 and 2018 images, using the FCHS vector file. According to the FCHS boundaries, a 10 km buffer zone was delimited on both sides of the study area, with the exception of the western boundary marked by the Sassandra River.

Using the most recent image of the study area, i.e. that dating from 2018, an unsupervised classification was carried out in order to select the classes representing the objects to be verified during the field visit. In addition, this field visit was carried out around 11 villages located within a 10 km radius of the FCHS in order to record coordinates and describe the land occupations present in the study area. A total of 75 points were grouped into 8 land use classes. In addition, the training points were used to perform a supervised classification of the 2018 image, a method that involves assigning a predefined class to each object in the image. This classification was performed using the maximum likelihood algorithm (Mather and Koch, 2011). Also, the spectral features of the land cover classes obtained following classification of the 2018 image were used as training areas to perform supervised classification of earlier images (Barima *et al*., 2016; Koua *et al*., 2020). Furthermore, in order to estimate the classification quality of images prior to 2018, the 2018 land use map, after validation was used to define new reference areas for images from 1997, 2002, 2006 and 2013 (Barima *et al.,* 2016). Subsequently, an image evaluation and validation was performed based on the confusion matrix using the Kappa coefficient and overall accuracy (Padonou *et al*., 2017). Following validation of the land-use maps, the proportions of the different land-use classes were determined.

Analysis of changes in the landscape of the Haut-Sassandra classified forest and its periphery

The various changes observed within the Haut-Sassandra classified forest and its periphery was detected on the basis of the transition matrix, rates of change in land-use class areas and landscape indices.

Indeed, transition matrices are developed to describe changes in land use over a given period (Schlaepfer, 2002). Thus, the transition matrices in this study made it possible to highlight the different forms of conversion that the land-use classes underwent between 1997 and 2018. Moreover, the number X of rows in the matrix indicates the land-use classes at time t_0 (1997), while the number Y of columns in the matrix corresponds to the converted land-use classes at time t_1 (2018), and the diagonal contains the areas of land-use classes that have remained unchanged. The transformations are therefore from rows to columns. In addition, the areas of these different land-use classes were calculated by cross-referencing land-use maps from 1997 to 2018 using QGIS 2.14 software. In addition, the rate of change (Tc) in land cover between two dates was calculated for each land cover class using the following mathematical formula:

In this formula, A_1 and A_2 are respectively the initial and final areas of the land use class.

A positive value for Tc indicates an increase in the land use class, while a negative value indicates a loss of land use within the class. Conversely, a value close to zero indicates that the class in question is relatively stable.

For the calculation of landscape indices, spatial structure indices at the level of land-use classes were calculated. These are the number of patches and the total area of the land-use classes. Thus, the total area (a_{tj}) occupied by any given land-use class, noted (j), is the total surface area occupied by all the patches making up this class. It is expressed in square kilometers (km²) and calculated according to the formula below:

$$Tc = \frac{A_2 - A_1}{A_1} \times 100 \quad (1)$$

In this formula, A_1 and A_2 are respectively the initial and final areas of the land use class.

A positive value for Tc indicates an increase in the land use class, while a negative value indicates a loss of land use within the class. Conversely, a value close to zero indicates that the class in question is relatively stable.

For the calculation of land scape indices, spatial structure indices at the level of land-use classes werecal culated. These are the number of patches and the total area of the land-use classes. Thus, the total area (a_{tj}) occupied by anygiven land-use class, noted (j), is the total surface area occupied by all the patches making up this class. It is expressed in square kilometers (km²) and calculated according to the formula below:

$$a_{tj} = \sum_{i=1}^{n_j} a_{ij} \quad (2)$$

In this formula, a_{ij}representsthe surface area of the i[ème] spot of class j.

The indices of patch number, total patch area and patch perimeter provide a complementary approach to analyzing the structural dynamics of land use through spatial transformation processes (Forman, 1997). These features are identified as the main elements for describing the landscape configuration through the use of the "Decision Tree" (Bogaert et *al.*, 2004). Indeed, this algorithm, which uses area, perimeter and number of patches to determine transformation processes, was adopted in the present study to better understand the spatial dynamics of the landscape between 1997 and 2018. Following this dichotomous approach, ten spatial transformation processes were proposed by Bogaert *et al.* (2004).

In addition, to differentiate between fragmentation and dissection processes, a threshold value (t = 0.5) is used to identify the spatial transformation process. This value (t) is compared with an observed t-value (tobs = a_1 /a_0). Thus, if tobs < t, the process dominating the landscape is fragmentation, and if not, it is dissection (Barima *et al.*, 2009).

Results and Discussion

Land use in and around the Haut-Sassandra classified forest

The land-use maps of the FCHS and its periphery show five (05) classes. These are forest, perennial crop, crop-fallow, bare soil-habitat and water (Figure 2). The perennial crop class concerns mature plantations, mainly composed of cocoa and coffee orchards aged 10 years or more. The fallow-crop class is made up of non-mature perennial crops (newly established cocoa, coffee, cashew and rubber plantations, and cocoa-coffee plantations undergoing renewal) combined with annual crops and fallow land.

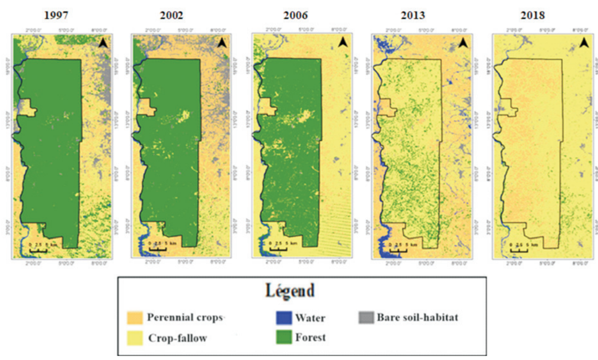

Fig. 2. Land use maps of the FCHS and its periphery from satellite images from 1997 to 2018

Landscape composition of the Haut-Sassandra classified forest and its periphery

The proportions of land-use classes in and around the FCHS vary over the years 1997, 2002, 2006, 2013 and 2018 (Figure 3).

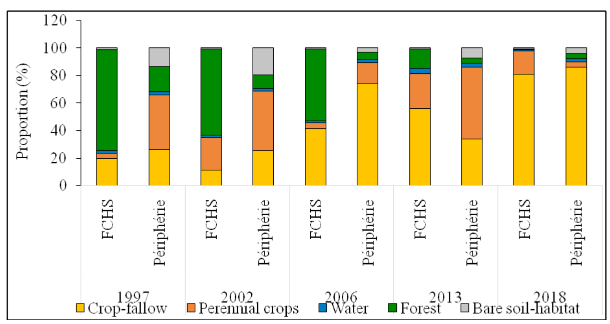

Fig. 3. Proportions of land-use classes in the FCHS and surrounding area from 1997 to 2018

In 1997, the peripheral landscape was dominated by the perennial crop class at around 40%. The crop-fallow, forest, bare soil-habitat and water classes occupied proportions of 26.4%, 18.4%, 13.4% and 2.2% respectively. On the other hand, the FCHS landscape was predominantly forest, with 73.7%, and the crop-fallow and perennial crop classes occupied 19.8% and 3.9% respectively, at the same period.

In 2002, the FCHS peripheral landscape was dominated by the perennial crop class at 43%. In addition, the crop-fallow, forest, bare soil-habitat and water classes respectively occupied 25.5%, 10%, 19.4% and 2.1% of the landscape at the forest periphery, while that of the FCHS was still dominated by forest with a rate of 62.6%.

In contrast to 2002, in 2006 the peripheral landscape was dominated by the crop-fallow class (74.2%). In addition, the perennial crop, forest, bare soil-habitat and water classes occupied only 15%, 5%, 3.2% and 2.6% of the landscape respectively. However, at the same time, the FCHS was still dominated by the forest class with a proportion of 52.7%. However, the crop-fallow class showed a significant increase, with a high proportion of 41.4%, against a low representation of the other land-use classes.

Thus, in 2013, the FCHS rural landscape was dominated mainly by the perennial crop class (52.3%), with a reduction in the area of the crop-fallow class from 74.2% in 2006 to 34% in 2013. However, the forest, bare soil-habitat and water classes occupied 3.7%, 7.3% and 2.7% of the landscape respectively. Yet within the FCHS, the forest class has declined drastically from 52.7% to just 14.7% in the space of 7 years. In addition, the crop-fallow class increased in proportion and even became the dominant class with a rate of 56%, followed by the perennial crop class with a proportion of 25.5%.

Finally, in 2018, the composition of the FCHS landscape was very different from that observed in previous years. Indeed, the FCHS periphery was dominated by the crop-fallow class, with a proportion of 86.2%, as was the interior with a rate of 81.1%. However, a slight increase in the area of forest class (4%) was noted in the FCHS periphery.

Land-use dynamics in the Haut-Sassandra classified forest and its periphery

Changes in land-use classes in the Haut-Sassandra classified forest and its periphery

Analysis of the rate of change in land use classes from 1997 to 2018 in the FCHS and its periphery highlights the changes made over this period (Figure 4).

Thus, from 1997 to 2002, there was a decline in the area of the forest and crop-fallow classes, with respective rates of 46.61% and 35.84%. On the other hand, this period was also marked by an increase in the bare soil-habitat and perennial crop classes, with respective rates of 45.13% and 62.3% on the periphery of the FCHS. Within the FCHS, however, the forest, crop-fallow and bare soil-habitat classes declined, with rates of 1.54%, 32.71% and 30.64% re-

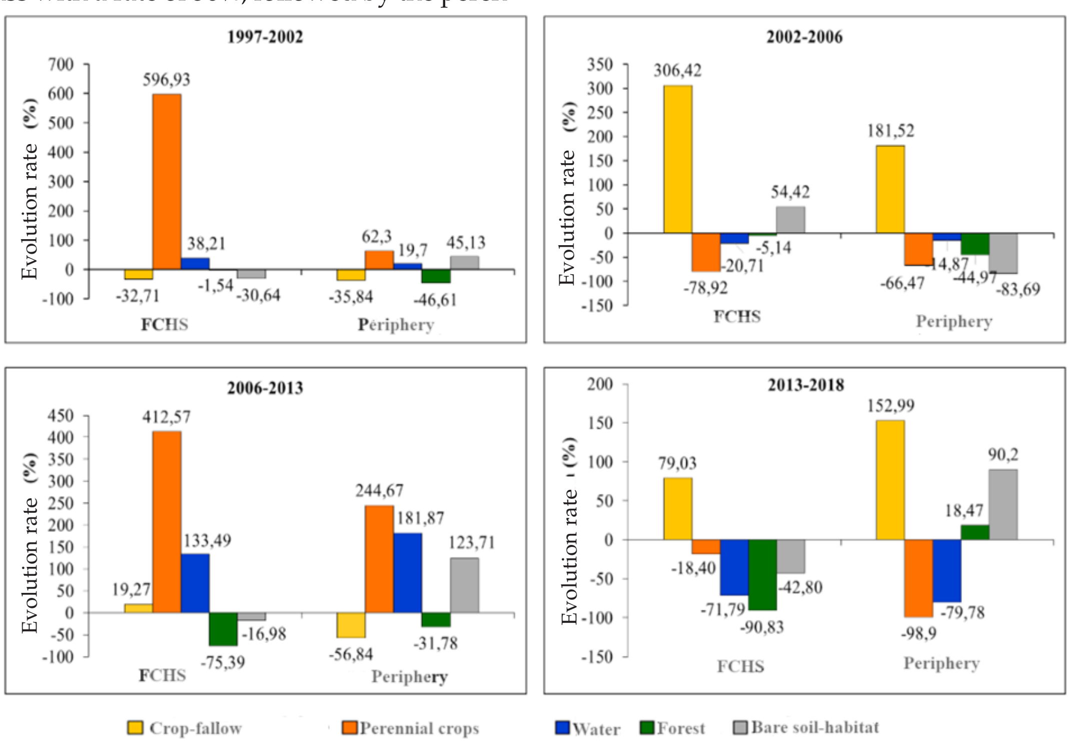

Fig. 4. Rate of change in land-use classes in the FCHS and surrounding area from 1997 to 2018

spectively. On the other hand, the perennial crop class showed a significant increase of 596.93%.

As for the period from 2002 to 2006, on the outskirts of the FCHS, we observed an increase in the area of the crop-fallow class, with a rate of 181.52%. However, the bare soil-habitat, forest and perennial crop classes showed a decline, with rates of 83.69%, 44.97% and 66.47% respectively. On the other hand, within the FCHS, the crop-fallow and bare soil-habitat classes progressed by 306.42% and 54.42% respectively. However, the perennial crop class suffered a significant loss of area. From an area of 596.93% between 1997 and 2002, it fell to 78.92% between 2002 and 2006. On the other hand, the forest class also experienced a smaller decline of 5.14%.

During the period from 2006 to 2013, on the periphery of the FCHS, the forest and crop-fallow classes experienced a regression in their areas, with rates of 31.78% and 56.84% respectively. In fact, the most remarkable changes were recorded in the perennial crop and bare soil-habitat classes, with increases of 244.67% and 123.71% over this period. On the other hand, the dynamics of deforestation in the FCHS increased. Indeed, the forest class experienced a 75.39% decline in area, corresponding to an annual deforestation rate of 10.77%. This loss of area was to the benefit of the perennial crop class, which recorded a rate of 412.57%. On the other hand, the area of the fallow-crop class declined by 306.42% from 2002 to 2006, compared with 19.27% from 2006 to 2013.

Over the period from 2013 to 2018, in the FCHS periphery, the forest class increased its area by 18.47%, representing an annual reforestation rate of 3.69%. As for the crop-fallow and bare soil-habitat classes, these also saw an increase in area, with rates of 152.99% and 90.2% respectively. In contrast, the perennial crop class saw its area decrease by 98.9% over the same period. However, within the FCHS, the forest class regressed by 90.83%. In fact, this regression in forest area within the FCHS corresponds to an annual deforestation rate of 18.16%. In addition, the perennial crop and bare soil-habitat classes also saw their respective surface areas decline by 18.40% and 42.80%. In contrast to these classes, the area of the crop-fallow class recorded a gain of 79.03% (Figure 4).

Transfer of land use to the periphery of the Haut-Sassandra classified forest

Table 1 shows the changes in the different land-use classes between 1997 and 2018 through the transition matrix at the periphery of the FCHS.

Thus, between 1997 and 2002, the transition matrix shows a 27.67% conversion of the forest class to the crop-fallow class. On the other hand, there was an increased conversion of the crop-fallow and bare soil-habitat classes into the perennial crop class, with rates of 41.85% and 24.33% respectively.

For the period from 2002 to 2006, the transition matrix also shows a more significant conversion of the forest, perennial crop and soil-nu-habitat classes into the crop-fallow class, with rates of 64.46%, 72.11% and 80.47% respectively. In addition, the greatest stability was achieved in the crop-fallow class (87.94%).

As in previous periods, the forest and fallow-crop classes underwent significant conversion to perennial crops, with respective rates of 34.89% and 51.53% between 2006 and 2013. In addition, the bare soil-habitat class also saw its area converted, but to crop-fallow (34.08%). With the exception of the water class, the greatest stability was observed in the perennial crop class (67.06%).

From 2013 to 2018, forest regressed to the benefit of other land use classes, notably crop-fallow with 82.81%. In contrast to the forest class, the perennial crop class saw a rate of change of 99.49% and has almost disappeared from the landscape on the periphery of the classified forest. Furthermore, the greatest conversion of the perennial crop class was to the crop-fallow class, with a proportion of 89.24%. However, the crop-fallow class remained intact, with an area of 87.04%. Only 10.95% was converted to the bare soil-habitat class and 0.81% to the forest class, compared with 0.77% in the perennial crop class. Finally, 61.51% of the bare soil-habitat class remained intact and 38.80% was converted to crop-fallow.

Transfer of land use within the Haut- Sassandra classified forest

The changes in the various FCHS land use types between 1997 and 2018 were highlighted by the transition matrix established between the different study dates (Table 2). Indeed, the change in the total area of a class is in favor of or to the detriment of one or more other classes. For example, between 1997 and 2002, the forest that was the FCHS matrix at that time remained stable at 98.27%. Furthermore, during the period 2002 to 2006, 95.8% of the area of the forest class remained stable, with only 4.2% converted to fallow crops (2.8%) and perennial crops (1.4%). On the other hand, the greatest transformation was observed in the fallow-crop class, with perennial crops accounting for 40.3%. On the other hand, during the same period, 33% of the crop-perennial class was also converted to crop-fallow. However, between 2002 and 2006, 66.1% of the bare soil-habitat class remained unchanged, while 32.7% of its area was converted to crop-fallow.

Over the period 2006 to 2013, the forest remained stable at 23.3%, with the largest proportion of forest converted to the crop-fallow class at 72.6%. Perennial crops accounted for 4% of converted forest. This period was also marked by the conversion of the perennial crop class, 61.1% of which was converted to fallow and 21.8% of which remained untouched (Table II). Analysis of land cover dynamics using the transition matrix between 2013 and 2018 reveals an almost total loss of forest. In fact, forest has been converted in favor of the crop-fallow (85.6%) and perennial crop (10.1%) classes. During the same study period, the perennial crop class underwent a significant conversion of 70.5% in favor of the crop-fallow class. In contrast, the bare soil-habitat class recorded a 7.3% increase in area.

Structural dynamics and spatial transformation processes of the Haut-Sassandra classified forest and its periphery

Analysis of the spatial transformation process

Table 1. Land use class transition matrices and landscapestability indices for the FCHS peripheryfrom 1997 to 2018

19972002	Forest	Perennialcrops	Crop-fallow	Baresoil-habitat	Water
Forest	**35.78**	2.84	5.30	2.41	3.29
Perennialcrops	19.93	**72.93**	41.85	24.33	1.88
Crop-fallow	27.67	20.04	**34.09**	9.38	11.72
Baresoil-habitat	14.31	4.18	17.92	**63.18**	3.24
Water	2.31	0.01	0.84	0.70	**79.87**
Grand total	100	100	100	100	100
		Stabilityindex: 1.33			
20022006	Forest	Perennialcrops	Crop-fallow	Baresoil-habitat	Water
Forest	**29.95**	1.04	4.60	0.80	17.91
Perennialcrops	4.29	**26.73**	6.72	3.76	0.00
Crop-fallow	64.46	72.11	**87.94**	80.47	1.01
Baresoil-habitat	0.56	0.12	0.65	**14.52**	1.66
Water	0.75	0.00	0.09	0.45	**79.43**
Grand total	100	100	100	100	100
		Stabilityindex: 0.91			
20062013	Forest	Perennialcrops	Crop-fallow	Baresoil-habitat	Water
Forest	**12.22**	4.19	3.04	0.00	0.01
Perennialcrops	34.89	**67.06**	51.53	5.45	0.05
Crop-fallow	27.96	26.99	**34.34**	34.08	0.74
Baresoil-habitat	1.21	0.46	6.78	**53.59**	0.04
Water	23.66	1.30	4.21	6.87	**98.95**
Grand total	100	100	100	100	100
		Stabilityindex: 1.14			
20132018	Forest	Perennialcrops	Crop-fallow	Baresoil-habitat	Water
Forest	**13.51**	2.51	0.81	0.00	0.10
Perennialcrops	1.11	**0.51**	0.77	0.08	0.02
Crop-fallow	82.81	89.14	**87.04**	38.10	52.59
Baresoil-habitat	2.08	7.24	10.95	**61.20**	26.53
Water	0.00	0.00	0.00	0.00	**20.20**
Grand total	100	100	100	100	100
		Stabilityindex: 0.58			

Values in bold on the diagonal of the transition matrix express the percentage of class stability.

within the FCHS and its periphery over the period from 1997 to 2018 has shown a transformation of each of the land use classes. Indeed, during this period, the forest class on the periphery of the FCHS saw an increase in the number of its patches from 2839 to 3713, followed by a decrease in their total area from 202.03 km² to 108.10 km². These parameters reflect a process of dissection over the period 1997 to 2002. In contrast to the periphery, the forest class within the FCHS saw a decrease in the number of patches from 5 to 4 and in the total area of its patches from 941.7 km² to 930 km², giving rise to a process of forest patch suppression (Figure 5).

During the period from 2002 to 2006, there was a process of suppression of forest-class patches on the outskirts of the FCHS. Indeed, this process is indicated by the reduction in both the number and total area of patches, from 3713 to 1326 and 108.10 km² to 54.98 km² respectively. However, within the FCHS, the forest class was marked by dissection (tobs = 0.96), which resulted in an increase in the number of patches from 4 to 29 and a reduction in the total area of patches from 929.84 km² to 892.23 km².

As for the period 2006 to 2013, it was marked by a significant loss of forest-class area at FCHS level. In fact, the number of forest patches increased more than 90-fold, from 29 to 2,739, while the total area of patches declined from 892.23 km² in 2002 to 216.51 km² in 2013. Indeed, the evolution of these indices gives rise to a process of fragmentation of the forest

Table 2. FCHS land-use class transition matrices and landscapestabilityindices from 1997 to 2018

1997–2002	Forest	Perennial crops	Crop-fallow	Baresoil-habitat	Water
Forest	**98.27**	27.15	36.07	21.14	16.46
Perennialcrops	0.05	**55.00**	8.85	0.07	0.00
Crop-fallow	1.59	16.45	**46.56**	19.55	0.53
Baresoil-habitat	0.07	1.40	8.42	**59.20**	0.07
Water	0.02	0.00	0.10	0.03	**82.94**
Grand total	100	100	100	100	100
Stability index: 2.16					
2002–2006	Forest	Perennial crops	Crop-fallow	Baresoil-habitat	Water
Forest	**95.8**	9.1	6.1	0.5	13.3
Perennialcrops	1.4	**57.7**	40.3	0.8	0.0
Crop-fallow	2.8	33.00	**53.2**	32.7	0.6
Baresoil-habitat	0.0	0.2	0.4	**66.1**	0.4
Water	0.0	0.0	0.0	0.0	**85.7**
Grand total	100	100	100	100	100
Stability index: 2.53					
2006–2013	Forest	Perennial crops	Crop-fallow	Baresoil-habitat	Water
Forest	**23.3**	15.6	13.5	0.1	0.2
Perennialcrops	4.0	**21.8**	17.6	0.3	0.2
Crop-fallow	72.6	61.1	**67.3**	43.5	1.7
Baresoil-habitat	0.1	1.1	1.3	**55.9**	0.0
Water	0.1	0.2	0.3	0.2	**97.9**
Grand total	100	100	100	100	100
Stability index: 1.14					
2013–2018	Forest	Perennial crops	Crop-fallow	Baresoil-habitat	Water
Forest	**1.2**	0.4	0.2	0.0	1.9
Perennialcrops	2.3	**24.7**	10.1	0.0	0.8
Crop-fallow	85.6	70.5	**84.5**	36.8	53.3
Baresoil-habitat	10.9	4.4	5.2	**63.2**	7.8
Water	0.0	0.0	0.0	0.0	**37.0**
Grand total	100	100	100	100	100
Stability index: 0.72					

Values in bold on the diagonal of the transition matrix express the percentage of class stability.

patches (tobs = 0.24) (Figure 5). On the other hand, the process that took place at the level of the forest class at the periphery of the FCHS is a dissection (tobs = 0.7). Moreover, this dissection process is confirmed by an increase in the number of patches from 1326 in 2006 to 1520 in 2013 followed by a decrease in the total area from 54.98 km² to 38.53 km². However, at the periphery of the FCHS from 2013 to 2018, the forest class experienced a regression of more than half its number of patches as well as a decrease in total area from 1520 to 719 and 38.53 km² to 22 km² respectively, leading to a process of suppression.

As for the perennial crop class, it underwent a process of creation that took place during the periods 1997 to 2002 and 2002 to 2006 within the FCHS. This process was marked by an increase in the number of spots from 91 to 134, then from 134 to 1509. Moreover, this increase is observed at the level of the total area going from 1.05 km² to 1.58 km² then from 1.58 km² to 21.99 km² over the periods 1997 to 2002 and 2002 to 2006 respectively. On the other hand, at the periphery, the perennial crop class saw a process of aggregation of patches over the period 1997 to 2002, resulting in a reduction in the number of patches from 2978 to 2270, with an increase in total area from 288.38 to 467.7 km². In addition, from 2002 to 2006, there was a process of fragmentation (tobs = 0.35) of the perennial crop class, always on the periphery of the FCHS. This fragmentation process is marked by an increase in the number of patches from 2270 in 2002 to 2620 in 2006, and a decrease in the total area of patches from 467.7 to 165.26 km².

Over the periods 2006 to 2013 and 2013 to 2018, within the FCHS, the perennial crop class saw a decrease in the number of its patches from 1509 to 1398 and 1398 to 943 respectively, followed by an increase in their total area from 22 to 47.12 km² and 47.12 to 86.5 km² respectively, giving rise to a process of patch aggregation. Similarly, the perennial crop class at the periphery of the FCHS, experienced a process of aggregation of these patches from 2006 to 2013. This process is determined by a reduction in the number of patches, from 2620 in 2006 to 1994 in 2013, and an increase in the total area of patches. However, over the period 2013 to 2018, the spots in the perennial crop class experienced a regression in both their number and area, resulting in a process of deletion (Figure 5).

On the other hand, in the crop-fallow class, over the periods 1997 to 2002, 2002 to 2006 and 2013 to 2018, the number of patches in the FCHS increased from 358 to 537, then from 537 to 1628 and 100 to 193 respectively, while the total area of patches increased from 5.87 to 19.7 km², then from 19.7 to 38.6 km² and 689.11 to 803 km², confirming the creation of new forest patches over these different periods (Figure 5). On the other hand, on the periphery of the FCHS, there was a process of suppression from 1997 to 2002, marked by a reduction in the number of patches (from 2858 to 1892) and their area (from 433.22 km² to 277.68 km²). Then, over the periods from 2002 to 2006 and from 2013 to 2018, an aggregation process is recorded at the periphery of the FCHS. This process is confirmed by a regression in the number of patches from 1892 to 743 between 2002 and 2006 and 4212 to 137 from 2013 to 2018, followed by an increase in the total area of patches from 277.7 km² to 814.26 km² and from 355.1 km² to 902 km² over these two periods. Between 2006 and 2013, we witnessed the aggregation of crop-fallow class patches within the FCHS. Indeed, this process of aggregation is confirmed by the sharp decline in the number of patches from 1628 in 2006 to 100 in 2013, with also a significant increase in the total area of patches from 38.64 km² to 689.10 km². On the other hand, at the periphery, we observe a fragmentation (tobs = 0.43) of the crop-fallow class, marked by an impressive increase in the number of patches from 743 in 2006 to 4212 in 2013. This process is also confirmed by a decrease in the total area of patches by more than half, from 814.26 km² to 355.11 km² between 2006 and 2013.

In short, at the level of the culture-jachery class, the transformation processes recorded were creation, suppression, fragmentation and aggregation.

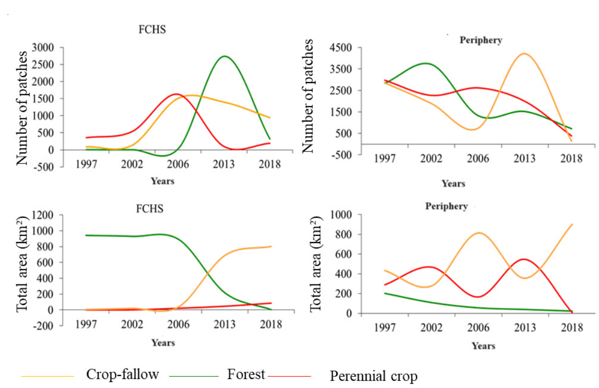

Fig. 5. Spatial structure indices of the FCHS and its periphery from 1997 to 2018

Discussion

Landscape composition of the Haut-Sassandra classified forest and periphery

The land-use mapping approach, based on a series of classifications of five Landsat TM (1997), ETM (2002), ETM+ (2006) and two Landsat OLI TIRS (2013 and 2018) satellite images, each with 30-meter resolution, coupled with ground truthing, has enabled us to draw up land-use maps and analyze the landscape dynamics of the Haut-Sassandra classified forest and its rural area.

Furthermore, using Landsat images, the present study has demonstrated the importance of remote sensing and landscape ecology in understanding the landscape structure of the FCHS classified forest and its surroundings. In landscape ecology, fragmentation, especially forest fragmentation, has become a very important research theme for conservation (Mouhamadou *et al*., 2012). It is specific to natural environments, notably forests (Bogaert *et al*., 2011). Fragmentation leads to a reduction in total area and an increase in the number of patches (Davidson, 1998). In addition, the transition matrix and stability index were used to highlight the evolution of vegetation cover in each zone. The transition matrix is used to analyze changes in landscape composition, while the stability index is used to assess the permanence of the initial landscape (Bogaert *et al*., 2014). Furthermore, the spatial processes involved in the transformation of vegetation cover have enabled us to understand that anthropogenic activities are the main factor potentially responsible for this change.

Land use dynamics in the Haut-Sassandra classified forest and its periphery

Analysis of the spatio-temporal dynamics of the land-use units of the FCHS and its periphery shows a regression in forest area in favor of anthropized formations. Indeed, the results obtained indicate the extent and rate of evolution of cultivated classes on the forest between 1997 and 2018. This loss of vegetation cover could be explained by population infiltration within the FCHS due to the scarcity of land observed on the periphery of the FCHS by Zanh *et al.* (2018). These authors showed in their work that over 80% of rural space was occupied by crops. Consequently, FCHS riparian populations, seeking to colonize new arable land for their agricultural activities, infiltrated the FCHS to install vast plantations (Barima *et al*. 2016). Indeed, the work of Barima *et al.* (2016) has shown that the main cause of deforestation in the FCHS is cocoa cultivation. Furthermore, Wood *et al.* (2004) concluded that agriculture remains the main factor inducing changes in vegetation cover in sub-Saharan Africa. However, this land pressure was also highlighted by mapping, which shows an increase in the agricultural front between 1997 and 2018. These results are in line with several works carried out in Côte d'Ivoire, including those of Barima *et al.* (2009) in the forest-savanna transition zone and Kouassi *et al.* (2012) in the N'zi Bandama watershed. According to these authors, the loss of forest cover is mainly caused by agricultural clearings linked to demographic pressure.

Spatial transformation of the Haut-Sassandra classified forest and its periphery

The calculation of structure indices reveals the spatial configuration of class patches in the landscape (Bamba, 2010). Indeed, the results revealed that the forest has been suppressed in favor of the creation and aggregation of anthropogenic classes. Various anthropogenic pressures and high space and resource requirements are thought to be the main causes of this forest formation degradation. Indeed, the multiple and repeated intrusions of man into the natural environment constituted by the FCHS, as well as the lack of fertile land on periphery for various agricultural activities, would explain this process of spatial transformation. On the other hand, on the outskirts of the FCHS, we are witnessing a process of suppression of the perennial crop class, which can be explained by the fact that farmers are abandoning former cocoa and coffee fallow fields to conquer other, even more fertile areas. Indeed, suppression is the most prevalent process in African forest regions (Bamba, 2010; Kouakou, 2019). Furthermore, according to Mama *et al.* (2014), current human pressures on forest resources are at odds with the regeneration capacities of natural plant formations, which are seriously threatened with extinction.

Conclusion

The techniques of remote sensing, cartography and landscape ecology were used to quantify the processes of landscape degradation in the FCHS and its periphery between 1997 and 2018. The thematic maps produced revealed a vegetation cover dynamic that reflects a transformation of the landscape. Over a 21-year period (1997 to 2018), land use types in and around the FCHS underwent significant disturbance. This area, whose landscape matrix was once dominated by forest, is now dominated by crops. In addition, the transition matrix shows the decline of natural formations, which is the occupation class most affected by degradation, while the perennial crop and fallow-crop classes are progressing. Over the study period, this matrix showed a 98.8% decline in forest area within the FCHS and 86.49% on its periphery.

From 1997 to 2018, in the natural class (forest), the value of the total area fell, confirming the almost definitive suppression of this class in the landscape composition of the FCHS and its periphery. On the other hand, in the crop-fallow class, the creation of new patches in the FCHS and the aggregation of patches on the periphery of this forest. In the perennial crop class, the processes of aggregation in the FCHS and suppression at the periphery were observed. These transformation processes revealed a change in the spatial structure of the landscape throughout the study area. Ultimately, this study suggests that the landscape dynamics observed at the periphery have made a significant contribution to the modification of the FCHS landscape. It is therefore important to be able to reconcile these results of landscape anthropization with the country's agricultural policy with a view to sustainable development. Environmental management and conservation programs through plantation reforestation (agroforestry) need to be initiated within the FCHS as well as on its periphery, especially in the localities closest to the FCHS.

Conflict of Interest: None

References

Bamba, I. 2010. Anthropization and spatio-temporal dynamics of forest landscapes in the Democratic Republic of Congo. Doctoral thesis, University of Brussels, Belgium, 189 p.

Barima, Y.S.S. 2009. *Dynamic fragmentation and plant diversity of forest landscapes in forest-savanna transition environments in the Department of Tanda (Côte d'Ivoire).* PhD thesis, University of Brussels, Belgium, 180 p.

Barima, YSS., Barbier, N., Bamba, I., Traoré, D., Lejoly, J. and Bogaert, J. 2009. Landscape dynamics in the Ivorian forest-savanna transition. *Bois et Forêts des Tropiques*. 299(1): 15-25.

Barima, Y.S.S., Kouakou, A.T.M., Bamba, I., Sangne, Y.C., Godron, M., Andrieu, J. and Bogaert, J. 2016. Cocoa crops are destroying the forest reserves of the classified forest of Haut-Sassandra (Côte d'Ivoire). *Global Ecology and Conservation.* 8: 85-98.

Bogaert, J., Ceulemans, R. and Van Eysenrode, S.D. 2004. A decision tree algorithm for detection of spatial processes in landscape transformation. *Environmental Management.* 33: 62-73.

Bogaert, J., Barima, Y.S.S., Ji, J., Jiang, H., Bamba, I., Lyongo, W.W.L., Mama, A., Nyssen, E., Dahdouh-Guebas, F. and Koedam, N. (Eds) 2011. A methodological framework to quantify anthropogenic effects on landscape pattern. *In*: *Landscape Ecology In Asian Cultures*. Edition Springer, New York, Verlag: 141-167.

Bogaert, J., Vranken, I. and Andre, M. (Eds.) 2014. Anthropogenic effects in landscapes: historical context and spatial pattern. *In: Biocultural Landscapes Diversity Functions and Values*. Edition Springer Science + Business Media Dordrescht, pp 89-112.

Ciesla, W.M. 1997. Climate change, forests and forest management: general aspects. *FAO*. 126: 152 p.

Davidson, C. 1998. Issues in measuring landscape fragmentation. *Wildlife Society Bulletin*, 26: 32-37.

Dupuy, B., Maitre, HF. and Amsallem, I. 1999. Tropical forest management techniques: a review of the sustainability of forest management practices in tropical countries. Working paper: FAO/FPIRS/04 prepared for the World Bank Forest Policy Implementation Review and Strategy, 50 p.

FAO. 2015. Global Forest Resources Assessment 2015. Data directory from France, Rome, 253 p.

Foley, JA., Defries, R., Asner, GP., Barford, C., Bonan, G., Carpenter, SR., Chapin, SF., Coe, MT., Daily, GC., Gibbs, HK., Helkowski, JH., Holloway, T., Howard, EA., Kucharik, CJ., Monfreda, C., Patz, JA., Prentice, CI., Ramankutty, N. and Snyder, PK. 2005. "Global Consequences of Land Use". *Science.* 309(5734): 570-574.

Forman, R.T.T. 1997. Land mosaics: the ecology of landscapes and regions. Cambridge, University Press, Cambridge, 632 p.

Guillaumet, J.L. and Adjanohoun, E. 1971. The vegetation of the Ivory Coast. *In: Le milieu naturel de la Côte d'Ivoire*. Avenard JM, Eldin M, Girard G, Sircoulon J, Touchebeuf P Guilaumet J-L, Adjanohoun E & Pernaud A (eds). Mémoires ORSTOM n°50, Paris (France), pp 161-263.

Ibo, J. 1993. Colonial nature protection policy in Côte d'Ivoire from 1900 to 1958. French Review of Overseas History. *Tome LXXX.* (298): 83-104.

Jahel, C. 2016. *Analysis of agroecosystem dynamics by spatialized modeling and use of satellite images Case study of western Burkina Faso.* PhD thesis. Institut des

Sciences et Industries du Vivant et de l'Environnement (AgroParisTech), Paris (France), 220 p.

Koné, M., Kouadio, Y.L., Neuba, D.F.R., Malan, D.F. and Coulibaly, L. 2014. Evolution of forest cover in Côte d'Ivoire from the 1960s to the early 21st century. *International Journal of Innovation and Applied Studies.* 7(2): 782-794.

Koua, K.A.N., Barima, Y.S.S., Kpangui, K.B. and Bamba, I. 2020. Impact of cocoa farming on the landscape in rural and state-owned areas of West Côte d'Ivoire. *International Journal of Innovation and Scientific Research.* 50(2): 128-137

Kouakou, A.T.M.., Barima, YSS., Konaté, S., Bamba, I., Kouadio, J.Y. and Bogaert, J. 2017. Management of state forests in times of conflict: the case of the Haut-Sassandra classified forest, Centre-West Côte d'Ivoire. *International Journal of Biological and Chemical Sciences.* 11(1): 333-349.

Kouakou, A.T.M. 2019. *Spatio-temporal dynamics of vegetation cover and floristic diversity in some national parks and classified forests of Côte d'Ivoire in a context of politico-military crises*. PhD, University Jean Lorougnon Guédé, Daloa, Côte d'Ivoire, 209 p.

Kouakou, K.A., Barima, Y.S.S., Kouakou, A.T.M., Sangne, Y.C., Bamba, I. and Kouamé, N.F. 2015. Armed post-conflict plant diversity of the classified forest of Haut-Sassandra (Centre-West Côte d'Ivoire). *Journal Animals Plant Sciences.* 26(2): 4058-4071.

Kouassi, A.M., Kouamé, K.F., Ahoussi, K.E., Oularé, S. and Biemi, J. 2012. Combined impacts of climate change and anthropogenic pressures on changes in vegetation cover in the N'Zi-Bandama watershed (Côte d'Ivoire). *Revue Ivoirienne des Sciences et Technologie.* 20: 124 -146.

Kuenzer, C., Dech, S. and Wagner, W. 2015. Remote sensing time series revealing land surface dynamics: status quo and the way forward. *In Remote Sensing Time Series.* Springer Cham, pp 1-24.

Lambin, EF., Geist, H. and Rindfuss, RR. 2006. Introduction: Local Processes with Global Impacts. In: *Land-Use and Land-Cover Change*. Global Change - The IGBP Series. Edition Lambin E. F. & Geist H., Springer, Berlin, Heidelberg, pp 1-8.

Mama, A., Bamba, I., Sinsin, B., Bogaert, J. and De Cannière C. 2014. Deforestation, savanization and agricultural development of savanna-forest landscapes in the Sudano-Guinean zone of Benin. *Bois & forets des Tropiques*. 322(4): 65-75.

Mather, P. and Koch, M. 2011. *Computer Processing of Remotely-Sensed Images: An Introduction*. John Wiley & Sons, 460 p.

Mouhamadou, T.I., Imorou, T.I., Sinsin, B. and Touré, F. 2012. Spatial structure indices of dense forest patches in the Monts Kouffé region. *[VertigO], La revue électronique en sciences de l'environnement*. 12(3): 1-17.

Nzigou, B.F. 2014. Land use dynamics and land cover types in the villages of Scierie Massaha and Nzé-Vatican in the Makokou region of Gabon. Department of Geography and Planning, Université Rennes 2, Renne, France, 36 p.

Oszwald, J. 2005. *Dynamics of agroforestry formations in Côte d'Ivoire (1980 to 2000) monitored by remote sensing and development of a cartographic approach.* PhD thesis, Géographie and aménagment, University of Sciences and Technologies of Lille, (Lille, France), 304 p.

Oszwald, J., Antoine, L., Arnauld, X., Marcello, T. and Gond, V. 2010. Analysis of directions of change in vegetation surface states to inform the dynamics of the Maçaranduba pioneer front (Brazil) between 1997 and 2006. *Remote Sensing.* 9(2): 97-111.

Padonou, E.A., Lykke, A.M., Bachmann, Y., Idohou, R. and Sinsin, B. 2017. Mapping changes in land use/land cover and prediction of future extension of bowé in Benin, West Africa. *Land Use Policy.* 69: 85-92.

Pirard, R., Cuny, P., Plancheron, F., Moynot, G., Rageade, M. and Leclercq, PE. 2021. Forest and fauna inventory of Côte d'Ivoire. ONF International, Nogent-sur-Marne, France, 8p.

Sangne, Y.C., Barima, Y.S.S., Bamba, I. and N'Doumé, C.T.A. 2015. Post-armed conflict forest dynamics of the Haut-Sassandra Classified Forest (Côte d'Ivoire). *Vertigo*, 15(3): 1-18.

Schlaepfer, R. 2002. Landscape dynamics analysis. Education sheet 4.2. Lausanne. Ecosystem Management Laboratory (GECOS), Federal Institute of Technology Lausanne, 11 p.

Traoré, K. 2018. Forest cover in Côte d'Ivoire: a critical analysis of the forest management situation (classified, parks and reserves). *The International Journal of Social Sciences and Humanities Invention.* 5(2): 4387-4397.

Wood, E.C., Tappan, G.G. and Hadj A. 2004. Understanding the drivers of agricultural land use change in south-central Senegal. *Journal Arid Environment.* 59: 565-582.

Zanh, G.G., Koua, K.A.N., Kouakou, K.A. and Barima, Y.S.S. 2018. Land saturation on the periphery of the classified forest of Haut-Sassandra (Central-Western Côte d'Ivoire) during the period 1990-2016. *Tropicultura.* 36(2): 171-182.