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Levers for the transformation of land use on the periphery of the Haut-Sassandra classified forest (Center-WEST of Ivory Coast)

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Abstract

The development of the agricultural sector in Côte d'Ivoire has led to profound changes in forest cover in general and around the protected areas of the State in particular. The aim of this work is to give an account of the process of mutation of the rural space of the classified forest of Haut-Sassandra for a better conservation of the latter. To achieve this objective, satellite images dating from 1997, 2002, 2006, 2013 and 2018 have been classified followed by observations and field surveys. The results show a reduction in forest cover in favour of agriculture. In fact, the forested areas that occupied 18.4% of the landscape in 1997 fell to 4% in 2018 with a conversion of more than 80% of the forested areas to crops. The latter are dominated by three perennial crops with associated food crops. Among these perennial crops, cocoa and coffee are the old ones and are essentially cultivated on a forest cultivation precedent, thus leading to a rarefaction of forest areas. While cashew trees, the third perennial crop, are more recent and were introduced into the area as a result of the increasing scarcity of forest areas. Thus, cashew trees are essentially cultivated on previous crops grown on fallow land and old plantations.

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Introduction

Agriculture plays a key role in the economic development of Sub-Saharan African countries. In these countries, it accounts on average for 70% of total employment, 40% of export goods and one-third of Gross Domestic Product (GDP) (Esso, 2009). Thus, among these sub-Saharan African countries, Ivory coast has focused its economic development on the agricultural sector since independence. This sector is the engine of Ivorian growth with the development of cash crops encouraged by the State. According to the economic statistic, agriculture provides about 40% of Ivory coast export earnings and contributes to 15% of Gross Domestic Product (GDP) (Assiri *et al.,* 2016).

However, agricultural pratices led a drastic reduction in forest cover (Koffi *et al*., 2018). Ivorian forest, which represented about 16 million hectares in 1960, has undergone a rapid reduction in area to less than 2.5 million hectares in 2007 (Chatelain *et al.,* 2004). Agricultural activities are pointed out in Ivory coast as the main driver of deforestation (Desdoigts and Kouadio, 2013 ; Cissé *et al.,* 2016). This is leading to the depletion of forest reserves (Kassin, 2009). Faced with this depletion of forest reserves, a displacement of populations from the pre-forest areas of the Center to forest areas including the Center-West of Ivory Coast in search of land suitable for cocoa production is observed. Furthermore, the displacement of populations in the Center-West of Ivory Coast has increased pressure on the land resources still available and the emergence of inter-community conflicts. Pressure on these resources has increased in both protected and rural areas (Ruf, 2018).

The rural area of the Haut-Sassandra classified forest (CFHS) has experienced a massive displacement of population mainly from central Ivory Coast and Burkina Faso, in search of land suitable for cocoa production (Kouakou *et al.,* 2015), increasing land and forest pressures. Once settled, these populations set up large camps (Oswald, 2005). In the face of these pressures on land and forest resources, monitoring and quantification of the dynamics of land use in the CFHS rural area is relevent in order to inform These natural resources management. Thus, the present study aims to determine the processes of transformation of the rural space of the classified forest of Haut-Sassandra for a better conservation of the latter. Indeed, the classified forest of Haut-Sassandra was declared a permanent domain of the Ivorian state in 1969 (Kouamé, 1998). This forest has been described as a dense semi-deciduous forest with *Celtis* spp. and *Triplochiton scleroxylon (*K. Schum*,* from the mesophilic sector within the Guinean domain (Guillaumet and Adjanohoun, 1971). The flora of the CFHS is highly diversified both at the generic and specific levels (Kouamé, 1998). In 1998, it contained 1047 species composed of several endemic species with special IUCN status. Thus, it accounted for 25% at the species level and 43% at the genus level of the general flora of Ivory Coast (Kouamé *et al.,* 1998). This state-owned area has experienced and continues to experience strong anthropogenic pressure (Kouakou *et al.,* 2018; Kouakou *et al.,* 2017). To date, forest area has decreased by more than 50%, with an annual loss of 17% to crops and housing (Barima *et al.,* 2016, Kouakou *et al.,* 2015; Sangne *et al.,* 2015). This degradation of the CFHS could be the result of the anthropization of its periphery. The identification and understanding of the drivers of the modification of the peripheral areas of the CFHS could allow a better understanding of the pressures exerted in the protected area and guide the manager's decision making.

Materials and methods

Study area

This study was carried out in the rural area of the CFHS in the Center-West of Ivory Coast located between 6°50-7°24 North latitude and 6°51-7°05 West longitude. Located in the second cocoa producing region of Ivory Coast, the vegetation belongs to the semi-deciduous humid dense forest domain characterized by *Celtis* spp and *Triplochiton scleroxylon (*K. Schum) (Guillaumet and Adjanohoun, 1971) with ferralitic soils suitable for agricultural activities. These natural conditions suitable for agriculture have resulted in a strong settlement of populations in this region practising perennial crops and food crops.

Land cover mapping

The mapping was carried out using five dry season Landsat-type satellite images (Table 1). These images have already undergone pre-processing (geometric corrections) before being put on line on the Earth explorer download site. Dry season images were used for two main reasons, firts, they present a large spectral difference between land cover classes and second, they allow a easy difference between anthropised areas (crop, fallow) from areas of natural vegetation (Barima *et al*., 2009; Oszwald *et al*., 2010). Thus, during the dry season the atmospheric effects on the images are reduced.

For the actual processing, it was a question of extracting the study area of the entire scene of the 1997, 2002, 2006, 2013 and 2018 images from the CFHS vector file. According to the CFHS boundaries, the study area was delimited at 10Km on both sides of this forest with the exception of the western boundary materialized by the Sassandra River.

Images were then processed on a pixel-by-pixel comparison basis with the Envi 4.7 software using a false-color composition to determine land cover units. This false-color composite combined the near-infrared, red and green bands by putting the near-infrared bands in the red, the red in the green and the green in the blue. Unsupervised classification was first used on the 2018 image (the most recent one). This was done on the basis of eight (08) land cover classes. Then, field visits were conducted around 11 villages based on stratified sampling. During the field visit, based on the unsupervised classification map of the 2018 image, different homogeneous plots were delineated using a GPS (Global Positioning System). This field visit made it possible to determine the final number the land cover classes. A total of 125 plots representing all types of land cover were delineated. The field visits made it possible to combine some classes obtained during the unsupervised classification.

These operations allowed to obtain five (05) classes of land cover, namely: forest, perennial crop, culture and fallow, water and bare soil-habitat. However, our various analyses will be done without the water class. The perennial crop class concerns mature plantations, mainly composed of cocoa orchards with an age of 10 years at minimum. The culture and fallow class is composed of non-mature perennial crops (recently cocoa plantation, coffee, cashew and rubber crops and cocoa-coffee renewal) associated with annual crops and fallows. After the field visit, each of the images underwent a supervised classification starting with the 2018 classification, of which 50 of the 125 plots delineated during the field visit were used as training plots. The spectral characteristics of the land cover types of the 2018 image made it possible to delineate training plots for the supervised classification of the 1997, 2002, 2006 and 2013 images. These supervised classifications were based on the maximum likelihood algorithm. After supervised classification, an image evaluation and validation were done. This evaluation was realised by calculating a confusion matrix (Godard, 2005) using the Kappa coefficient and overall precision, which are the most common index used (Foody, 2002; Padonou *et al.,* 2017). Indeed, the calculation of the confusion matrix establishment was consisted to define control plots.

These plots corresponded to the sites delimited during the field visit but not used during the classification. A total of 75 control plots were identified during the field visits for the 2018 image. Then, a correspondence between the training plots and the control plots for the evaluation of the accuracy of the land cover class classifications was established in order to calculate the Kappa coefficient and the overall accuracy.

Highlighting changes

In order to understand the changes, the transition matrix was first calculated to identify the transition frequencies between classes over the study period. This transition matrix was also used to calculate a stability index. This index represents the ratio of the sum of the diagonal and off-diagonal values of the transition matrix (Bogaert *et al.,* 2014). Next, spatial transformation processes were defined for each land cover class.

These processes are determined basing on the three main index considered as the essential elements for the description of the landscape configuration namely (i) the total area of patches (a), (ii) the perimeter of patches (p) and (iii) the number of patches (n). Indeed, the calculation of these landscape index makes it possible to validate or inform of changes in the landscape over a given period.

The decision tree proposed by Bogaert *et al.* (2004) was adopted for identify the spatial transformation processes (STP) dominating the study area landscape over the periods 1997-2002, 2002-2006, 2006-2013 and 2013-2018. Taken into account the decision tree of Bogaert *et al.* (2004) The different spatial transformation processes were counsidered : aggregation (merging of patches), attrition (disappearance of patches), creation (formation of new patches), deformation (change in patch shape, without patch size change), enlargement (expansion of patch size), perforation (formation of holes in patches), shift (translocation of patches), shrinkage (reduction in patch size), fragmentation (breaking continuity into several disjointed patches of different shapes and sizes) and dissection (subdivision of patches by small lines). These processes identification is done between times T_0 and T_1 by comparing the values of a_0, n_0 and p_0 with those of a_1, n_1 and p_1 respectively. This decision tree is based on the equality, increase or decrease of the value of these different index. In order to make a difference between the fragmentation and dissection processes, a threshold value (t = 0.5) was used. This value (t) is compared to an observed t-value ($t_{obs}= a_1/a_0$). If $t_{obs}< t$ the process dominating the landscape is fragmentation and if not, it is dissection (Bogaert *et al.,* 2004).

Analysis of the factors of deforestation and forest degradation

Using interview technics, a surveys were done considering local famers who are at least 18 years old and have a plantation in the localities on the periphery of the CFHS. A total of eleven localities were considered for this survey. In each village, a questionnaire about the different perennial crops grown, their age, their area, their precedent of crop and the associated food crops was administered to the farmers selected.

Result and discussion

Land use map and cartographic accuracy

The land cover maps obtained showed five (05) classes (Fig. 1) which forest, perennial crop, culture and fallow, bare soil-habitat and water. These different maps showed a significant reduction in forest cover and an increase of anthropised areas (crops, fallow land and bare soil). The confusion matrix obtained in this study showed a best images classification with Kappa coefficients greater than 0.81 (Table 2).

Kappa coefficients values for 1997, 2002, 2006, 2013 and 2018 were respectively 0.96; 0.84; 0.96; 0.98 and 0.98 with an overall precision of 95.8%; 87.6%; 97%; 98.51% and 97% respectively (Table 2).

Table 1. Satellite image characteristics.

Sensors	Date of acquisition	Identity of the scene	Resolution (m)
Landsat 5 TM	06/02/1997	LT51980551997037M PS00	30
Landsat 7 ETM	13/12/2002	LE71980552002347E DC00	30
Landsat 7 ETM+	08/12/2006	L7119805505520061 208	30
Landsat 8 Oli tirs	19/12/2013	LC81980552013353L GN00	30
Landsat 8 Oli tirs	07/04/2018	LC81980552018047L GN00	30

Table 2. Overall accuracy and Kappa coefficients of supervised classifications of Landsat imagery from 1997, 2002, 2006, 2013 and 2018 of the classified forest of Haut-Sassandra.

	1997	2002	2006	2013	2018
Overall accuracy	95.80	87.60	97.00	98.51	97.00
Kappa Coefficient	0.96	0.84	0.96	0.98	0.97

Composition of land cover on the periphery of the classified forest of Haut-Sassandra

The analysis of landscape composition showed, a dominance of cultivated areas compared to the forest areas during the period of the study (Fig. 2). Taken into account the statistics, the forest class, which represent 18.4% of the landscape in 1997, descrease to 10% in 2002, 5% in 2006 and 3.6% in 2013. However, forest class knowed an augmentation to 4% of the landscape in 2018. Considering 1997-2002 and 2006 -2013 periods, the culture and fallow class experienced a regression in its area. While over the periods 2002-2006 and 2013-2018, this class experienced an increase with a landscape occupancy of 86.2% in 2018.

The perennial crop class also experienced a variation in its area, from 39.7% of the landscape in 1997, this class increased to 43% in 2002 then to 15% in 2006 and to 3.7% of the landscape in 2018. However, this class experienced an increase in its area from 2006 (15%) to 2013 (52.3%).

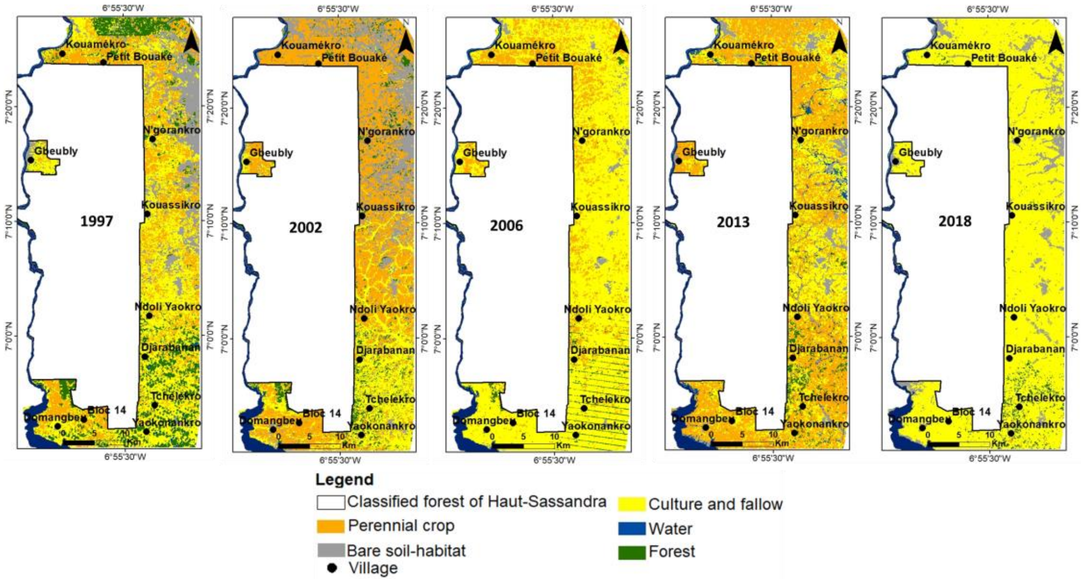

Fig. 1. Maps of land cover at the periphery of the classified forest of Haut-Sassandra in 1997, 2002, 2006, 2013 and 2018.

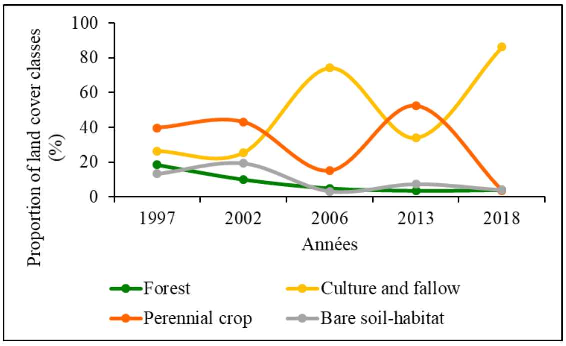

Fig. 2. Evolution of the proportions of land cover classes from 1997 to 2018 at the periphery of the classified forest of Haut-Sassandra.

Temporal variation in land cover class areas from 1997 to 2018

Different change rates in land cover classes over the periods 1997 - 2002, 2002 - 2006, 2006 - 2013 and 2013 - 2018 are presented by Fig. 3. This Fig. showed that during 1997-2002 period, the forest and culture and fallow classes cover are knowed a dimunition of 46.61% and 35.84% respectively. On the other hand, the perennial crop and bare soil-habitat classes cover increased by 62.3% and 45.13% respectively.

The period from 2002 to 2006 is marked by the forest, perennial crop and bare soil-habitat classes regression estimated at 44.97%, 66.47% and 83.69%. Regression of previous classe covers (perennial crop and bare soil-habitat classes) led augmentation of culture and fallow class eestimated at 181.52%.

During 2006-2013 period, forest and culture and fall classes covers were deascresed while perennial crop and bare soil-habitat classes increased, which experienced a significant rate of increase of 244.67% and 123.71% respectively. From 2013 to 2018 a regression of perennial crop class was oberved and estimated at 98.9%. On the other hand, there is an increase in of forest classes, culture and fallow and bare soil-habitat for 18.47%, 152.99% and 90.2% respectively.

Considering changes between 1997 and 2018, only culture and fallow class experienced an augmentation estimated at 120.21% (Fig. 4). However, forest, bare soil-habitat and perennial crop classes regressed with respective rates of 78.3%, 69.84% and 85.66%.

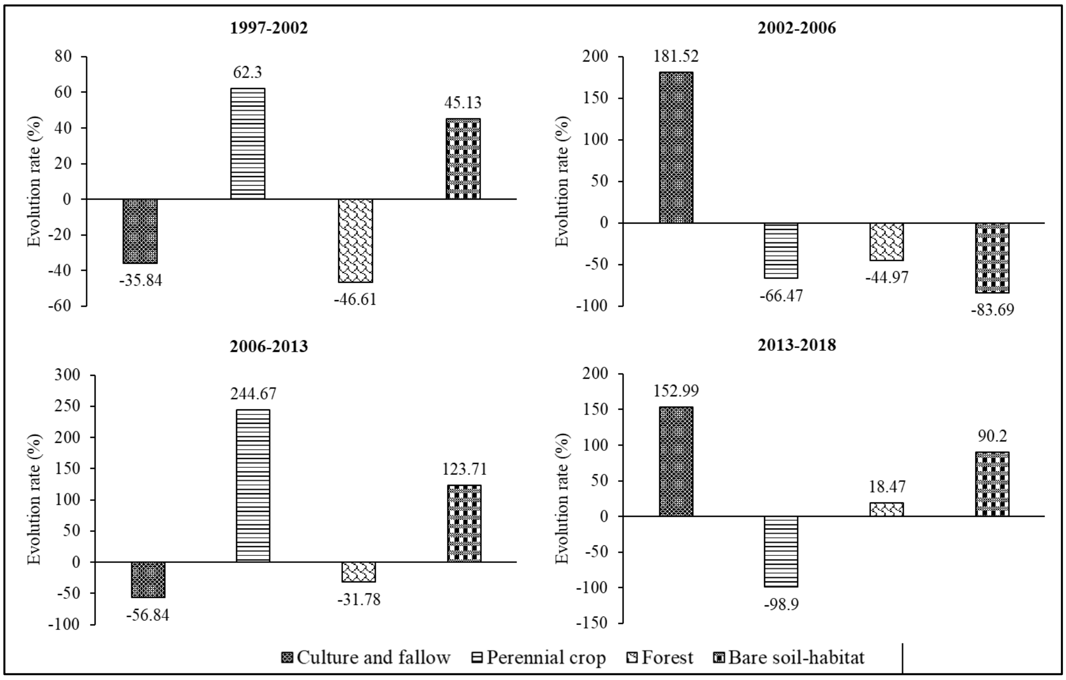

Fig. 3. Rate of evolution of the surface areas of the land cover classes of the periphery of the classified forest of Haut-Sassandra over the periods 1997-2002, 2002-2006, 2006-2013 and 2013-2018.

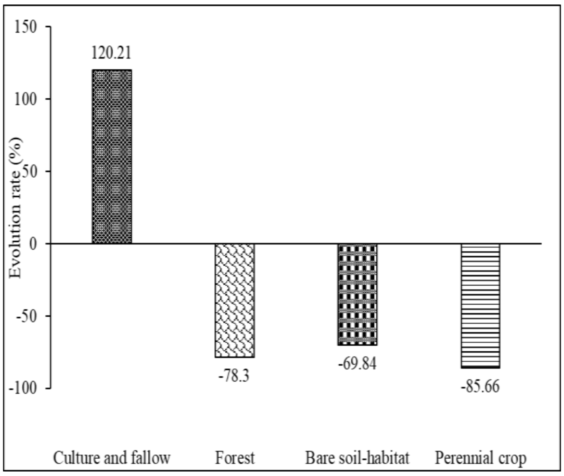

Fig. 4. Rate of evolution of the surface areas of the land cover classes at the periphery of the classified forest of Haut-Sassandra from 1997 to 2018.

Transfer of land cover from 1997 to 2018

The different transfers between land use classes over the 1997-2002, 2002-2006, 2006-2013 and 2013-2018 periods are presented in Table 3.

This Table analysis showed that from 1997 to 2002, forest areas were converted into other classes, with high conversion rate for culture and fallow class estimated at 27.67%. During the same period, more than 41% of culture and fallow class was converted into perennial crop class. considering bare soil-habitat class, 63.18% remained intact while 36.82% were converted into other classes. Overall, perennial crop class knowed the more importang of cover conversion with a rate of 24.33%. During 2002 to 2006 period, the most important changes were observed for the forest, perennial crop and bare soil-habitat classes. These classes underwent an important conversion to the culture and fallow class estimated at rates of 64.46%, 72.11% and 80.47% respectively.

Observing 2006-2013 period changes, forest class knowed an important conversion into other classes. Perennial and culture and fallow classes are the most converted with a conversion rate estimated at 57.89% and 27.96% respectively analyzing transformation process, about 1.21% and 0.66% of culture and fallow class were respectively converted into to bare soil-habitat. Also, the culture and fallow class experienced a significant conversion of its area during this same period to the perennial class of 51.53%.

As for the bare soil-habitat class, 53.59% of the area remained unchanged and 46.41% was converted in the other classes with the highest conversion to the fallow class (34.08%).

Table 3. Transition matrix of land cover classes and landscape stability index of the periphery of the classified forest of Haut-Sassandra from 1997-2002, 2002-2006, 2006-2013, 2013-2018 and 1997 to 2018. The values in bold in the diagonal of the transition matrix express the percentage of stability of the classes.

1997-2002	Forest	Perennial crop	culture and fallow	bare soil-habitat	Water	Grand Total
Forest	35.78	19.93	27.67	14.31	2.31	100
Perennial crop	2.84	72.93	20.04	4.18	0.01	100
culture and fallow	5.30	41.85	34.09	17.92	0.84	100
bare soil-habitat	2.41	24.33	9.38	63.18	0.70	100
Water	3.29	1.88	11.72	3.24	79.87	100
Stability index: 1.33						
2002-2006	**Forest**	**Perennial crop**	**culture and fallow**	**bare soil-habitat**	**Water**	**Grand Total**
Forest	29.95	4.29	64.46	0.56	0.75	100
Perennial crop	1.04	26.73	72.11	0.12	0	100
culture and fallow	4.6	6.72	87.94	0.65	0.09	100
bare soil-habitat	0.8	3.76	80.47	14.52	0.45	100
Water	17.91	0	1.01	1.66	79.43	100
Stability index: 0.91						
2006-2013	**Forest**	**Perennial crop**	**culture and fallow**	**bare soil-habitat**	**Water**	**Grand Total**
Forest	12.22	57.89	27.96	1.21	0.66	100
Perennial crop	4.19	67.06	26.99	0.46	1.3	100
culture and fallow	3.04	51.53	34.34	6.78	4.21	100
bare soil-habitat	0	5.45	34.08	53.59	6.87	100
Water	0.01	0.05	0.74	0.04	98.95	100
Stability index: 1.14						
2013-2018	**Forest**	**Perennial crop**	**culture and fallow**	**bare soil-habitat**	**Water**	**Grand Total**
Forest	13.51	1.11	82.81	2.08	0	100
Perennial crop	2.51	0.51	89.14	7.24	0	100
culture and fallow	0.81	0.77	87.04	10.95	0	100
bare soil-habitat	0	0.08	38.1	61.2	0	100
Water	0.1	0.02	52.59	26.53	20.2	100
Stability index: 0.58						
1997-2018	**Forest**	**Perennial crop**	**culture and fallow**	**bare soil-habitat**	**Water**	**Grand Total**
Forest	7.55	6.02	84.47	1.64	0.32	100
Perennial crop	3.56	5.47	90.51	0.46	0	100
culture and fallow	3.67	2.8	90.13	3.4	0	100
bare soil-habitat	0.27	0.33	82.8	16.6	0	100
Water	7.5	0.8	29.98	0.62	61.1	100

From 2013 to 2018, the forest and perennial crop classes were mainly converted into culture and fallow class by 82.81% and 89% respectively. At the level of the culture and fallow class, 87.04% of the area remained unchanged against 10.95% converted to bare soil-habitat, 0.77% to perennial crop class, and 0.81% to forest class. Considering the bare soil-habitat class, 61.51% remained intact and 38.10% were converted to the culture and fallow class.

Taken into account overall evolution, the period from 2013 to 2018 have been characterized by the most transformation landscarp changes, with the lowest stability index value of 0.58. Analysis of the transition matrix from 1997 to 2018 indicated an important conversion of forest class into culture and fallow with a rate of 84.47%. Conversion rate observed was also higher in the period from 1997 to 2018 compared to other periods. Perennial crops also experienced a significant conversion to the culture and fallow class with a rate estimated at 90.51%. Considering culture and fallow class for this period, it was stable at over 90%.

Structural dynamics and spatial transformation processes

The spatial structure index calculated for the years 1997, 2002, 2006, 2013 and 2018 to characterize changes in spatial structure are presented by Table 4.

From 1997 to 2002 and from 2006 to 2013, the number of patches increased at the forest level respectively from 2839 to 3713 and 1326 to 1520. However, there was a decrease in its total area reflecting dissection (t_{obs}=0.53) as a transformation process at the level of this class during these two periods (Table 5). From both 2002 to 2006, and 2013 to 2018 period, this class was under strong pressure leading to a process of patch removal, marked by a decrease in the number, area and perimeter of patches (Tables 4 and 5).

Table 4. Spatial structure index calculated in 1997, 2002, 2006, 2013 and 2018 for each land cover class at the periphery of the classified forest of Haut-Sassandra. n: total number of patches, a : total area of the patches, p: perimeter of the patches, LCC: land cover class, FO: forest, PC: perennial crop, CF: culture and fallow, BSH: bare soil-habitat.

		Periods				
Index	LCC	1997	2002	2006	2013	2018
Number of patches (n)	FO	2839	3713	1326	1520	719
	PC	2978	2270	2620	1994	381
	CF	2858	1892	743	4212	137
	BSH	1383	3095	792	2173	1218
Total area of patches (a, km^2)	FO	202	108.1	55	38.5	22
	PC	288.4	467.66	165	546	6,05
	CF	433.2	277.68	814	355	902
	BSH	145.6	211.26	34.6	77	147
Patch perimeter (p, km)	FO	2973	2357.28	1226	1021	594
	PC	4546	5232.72	2946	6473	207
	CF	6774	4034.88	4380	6636	2640
	BSH	1811	3532.14	642	1658	1892

Table 5. Spatial transformation process of the land cover classes of the periphery of the classified forest of Haut-Sassandra over the periods 1997 - 2002; 2002 - 2006; 2006 - 2013 and 2013 – 2018. LCC: land cover class, FO: forest, PC: perennial crop, CF: culture and fallow, BSH: bare soil-habitat, n: total number of patches, a : total area of the patches, p: perimeter of the patches, STP: spatial transformation process.

		Periods			
LCC	Index	1997-2002	2002-2006	2006-2013	2013-2018
FO	n	$n_{2002}>n_{1997}$	$n_{2006}<n_{2002}$	$n_{2013}>n_{2006}$	$n_{2018}<n_{2013}$
	a	$a_{2002}<a_{1997}$	$a_{2006}<a_{2002}$	$a_{2013}<a_{2006}$	$a2018<a_{2013}$
	p	$p_{2002}<p_{1997}$	$p_{2006}<p_{2002}$	$p_{2013}>p_{2006}$	$p_{2018}<p_{2013}$
	STP	Dissection (t_{obs} = 0.54)	Attrition	Dissection (t_{obs} = 0.7)	Attrition
PC	n	$n_{2002}<n_{1997}$	$n_{2006}>n_{2002}$	$n_{2013}<n_{2006}$	$n_{2018}<n_{2013}$
	a	$a_{2002}>a_{1997}$	$a_{2006}<a_{2002}$	$a_{2013}>a_{2006}$	$a_{2018}<a_{2013}$
	p	$p_{2002}>p_{1997}$	$p_{2006}<p_{2002}$	$p_{2013}>p_{2006}$	$p_{2018}<p_{2013}$
	STP	Aggregation	Fragmentation (t_{obs} = 0.35)	Aggregation	Attrition
CF	n	$n_{2002}<n_{1997}$	$n_{2006}<n_{2002}$	$n_{2013}>n_{2006}$	$n_{2018}<n_{2013}$
	a	$a_{2002}<a_{1997}$	$a_{2006}>a_{2002}$	$a_{2013}>a_{2006}$	$a_{2018}>a_{2013}$
	p	$p_{2002}<p_{1997}$	$p_{2006}>p_{2002}$	$p_{2013}>p_{2006}$	$p_{2018}>p_{2013}$
	STP	Attrition	Aggregation	Creation	Aggregation
BSH	n	$n_{2002}>n_{1997}$	$n_{2006}<n_{2002}$	$n_{2013}>n_{2006}$	$n_{2018}<n_{2013}$
	a	$a_{2002}>a_{1997}$	$a_{2006}<a_{2002}$	$a_{2013}>a_{2006}$	$a_{2018}>a_{2013}$
	p	$p_{2002}>p_{1997}$	$p_{2006}<p_{2002}$	$p_{2013}>p_{2006}$	$p_{2018}>p_{2013}$
	STP	Creation	Attrition	Creation	Aggregation

The perennial crop class has undergone three processes of transformation: aggregation over the periods 1997-2002 and 2006-2013, fragmentation between 2002 and 2006 and attrition between 2013 and 2018. The aggregation process is confirmed by the increase in the total area of the patches and the decrease of their number. However, from 2013 to 2018, as the forest class, the perennial crop class was the least favoured of all the other classes considered. Indeed, this class experienced a suppression of its patches between 2013 and 2018 marked by a reduction in the number and total area of patches (Tables 4 and 5). The culture and fallow class has undergone three spatial transformation processes, namely attrition, aggregation and fragmentation. The attrition took place between 1997 and 2002. During this period, the culture and fallow class experienced a decrease in the number and area of its patches. The second process is aggregation, which took place between 2002 and 2006 and between 2013 and 2018, characterized by a decrease in the number and an increase in the total area of its patches.

The third process is fragmentation, which took place between 2006 and 2013 characterized by an increase in the number and total area of its patches (Tables 4 and 5). As for the bare soil-habitat classes, it has also undergone three processes. The first process is the creation that took place between 1997 and 2002 and 2006 and 2013. This process of creation is marked by the increase in the number and total area of patches. The second process is the attrition that took place between 2002 and 2006 characterized by the decrease in the number and total area of the patches (Tables 4 and 5). The third process observed for this class between 2013 and 2018 is an aggregation. Indeed, this process is indicated by a decrease in the number of patches and an increase in their total area (Tables 4 and 5).

Main perennial crops and associated food crops

Four main perennial crops are observed on the periphery of the CFHS. These are cocoa, coffee, cashew tree and rubber tree (Fig. 5). The most cultivated in terms of farm unit is cocoa with a rate of 37%. This is followed by coffee and cashew tree with 31% and 27% respectively. Hevea is less represented in the zone, with a proportion of 5%.

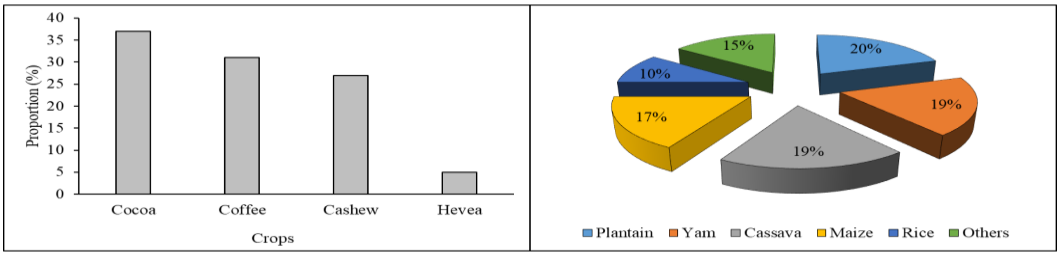

Fig. 5. Distribution of perennial crops grown on the periphery of the classified forest of Haut-Sassandra and associated food crops. Other food crops: millet, beans, okra, pepper, eggplant, taro, groundnut.

Five main food crops are associated with these perennial crops throughout the study area (Fig. 5). In descending order, these are plantain (20%), cassava (19%), yam (19%), maize (17%) and rice (10%).

Age of the main perennial crops

Perennial crop ages varies from 1 to 52 years and can be divided into four classes. These classes are plantations with an age inferior or equal at 5 years, ages between 6 and 15 years, ages between 16 and 30 years, and ages superior at 30 years (Fig. 6). Plantations older than 30 years are dominated by cocoa (39%) and coffee (35.1%). On the other hand, those under 5 years of age are dominated by cashew tree plantations (88%) and also include cocoa (10.2%) and coffee (11.7%).

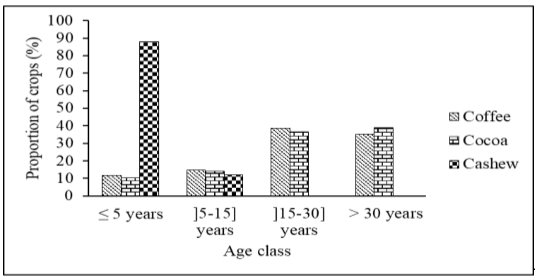

Fig. 6. Distribution of perennial crops according to their age at the periphery of the classified forest of Haut-Sassandra.

Cultivation history of perennial crops

Three precedents of crops of the main perennial crops were identified in the study area (Fig. 7). These are forests, fallow and old plantations. Cocoa and coffee plantations were established at 83% and 82% respectively after forest clearing. In contrast, cashew plantations were mainly established in old plantations (71%) and fallow (26%).

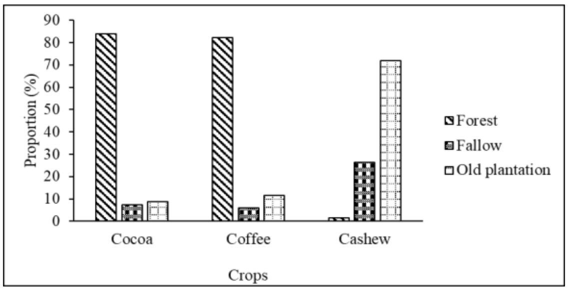

Fig. 7. Distribution of the main perennial crops according to precedents of crops at the periphery of the classified forest of Haut-Sassandra.

Surface area of the main perennial crops

The average areas occupied by cocoa, coffee and cashews were estimated at 3.7 ha, 2 ha and 1.2 ha respectively.

However, four classes of areas for these main crops have been defined. These are plantations of less than 1 ha, 1 to 3 ha, 3 to 5 ha and those larger than 5 ha (Fig. 8). Thus, 77.4% of cashew tree plantations have an area of less than 1 ha. This class also has the largest proportion of coffee (47%). Farms over 5 ha are dominated by cocoa with 16.8%.

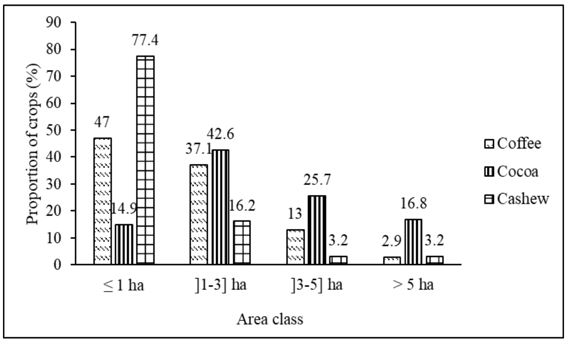

Fig. 8. Distribution of perennial crops as a function of the areas sown in the peripheral zone of the classified forest of Haut-Sassandra.

Methodological approach

The cartographic approach of land cover mapping associted to remote sensing technic were adopted. Five images : Landsat TM (1997), ETM (2002), ETM+ (2006) and two Landsat OLI TIRS (2013 and 2018) satellite images of 30 meters resolution were downloded for data treatment. Each image coupled with a ground truth allowed to establish the land cover maps and to analyze the landscape dynamics for the rural space of the Haut-Sassandra classified forest. These classifications by the maximum likelihood algorithm allowed to obtain overall precision values highly appreciable for all the images according of the consideration of Pontius (2000); Kabba and Li (2011).

The different Kappa coefficients obtained in this study are between 0.84 and 0.98 and justify the best images classification (Pontius, 2000). These high Kappa coefficient values obtained could be explained by the best knowledge of the study environment allowing a low confusion between different classes considered (Trepanier *et al.,* 2002; Kouakou *et al.,* 2017; Toyi *et al.*, 2018). However, the high mapping accuracy may also be due to the small number of classes considered in this study (Caloz and Collet, 2001; Mama *et al.,* 2014).

The characterization of the landscape structure allowed to determine different processes of landscape transformation. About this characterisation, numerous structure index have been proposed (Burel and Baudry., 2003; Bogaert and Mahamane, 2005; Mama *et al., 2013).* In this study, index directly resulting from the determination of the transformation processes of a landscape were used. Apart from these index, the stability index was used to better judge the magnitude of the changes that have taken place in the landscape.

Landscape dynamics

This study on the dynamics of land cover in the periphery areas of the CFHS allowed to analyze the changes in this area between 1997 and 2018. Results showed that 1997 to 2002 period was marked by a decline in the area under forest and culture and fallow classes in favour of areas under perennial crops and bare soil-habitat. This dynamic is due to the installation and expansion of vast farms and camps on the periphery of the CFHS during this period. From 1967 onwards, the populations gradually colonized the periphery of the CFHS by setting up farms occasioning the dusturbance of forest areas (Oszwald, 2005). These populations praticed perennial crops, especially cocoa and coffee, which led the degradation of important part of forest area in the study area. 2002-2006 period, was characterized by establishement of cocoa, coffee, cashew and rubber tree crops and cocoa-coffee in renewal on the periphery of the CFHS. This resumption of culture and fallow areas could be explained by the fact that the orchards being old and not very productive, the populations have proceeded to replant.

It could also be explained by the appearance of the swollen shoot virus disease in 2003 in this region (Kébé and N'Guessan, 2003) which led to the culling of the orchards. Indeed, several cocoa plantations were affected by this disease, transforming several plots into fallow crops. Furthermore, it should be noted that this period was marked by the intensification of violence and insecurity caused by the politico-military crisis in Ivory Coast.

This insecurity situation led the moving of the population from the study area, causing the abandonment of fields to other more peaceful localities, thus increasing the area of fallow land. From 2006 to 2013, a regression in culture and fallow areas was observed in favor of the perennial crop and bare soil-habitat classes. This regression in culture and fallow could be justified by the return of farmers who have abandoned their plantations. Indeed, these farmers who returned after the political-military crisis have maintained and rehabilitated the old plantations abandoned during the conflicts.

In addition, from 2013 to 2018, a regression of the perennial crop class was observed while as classes as culture and fallow, bare soil-habitat and forest are increased. This regression of the perennial crop class could be explained first by the old age of these perennial crops and second by the decline in soil fertility (Mollard, 1993; Léonard and Vimard, 2005). However, finding of authors such as Léonard (1997) pointed out the rainfall descreasing in the whole West African region as one of the causes of the reduction of the perennial crop class. Additionnaly replanting difficulties are imposed on farmers, hence the abandonment of old orchards for the creation of new fields increasing the area under fallow cultivation (Assiri, 2007; Tano, 2012). Thus, from an area formerly colonized by perennial crops in 1997, there has been a shift to fallow cropping as the dominant land cover in 2018. Furthermore, the surface areas occupied by anthropized spaces, which are perennial crops, bare soil-habitat and culture and fallow estimated at of 67.53% in 1997, increased to 91.9% in 2018. This high rate of land use could imply that the forest reserves on the periphery of the CFHS are exhausted and this zone would be subject to land saturation as Zanh *et al.* Have shown (2018).

These observations are confirmed by the spatial transformation process observed for the forest class. In fact, a comparison of the number of patches and the area of the forest class between 1997 and 2018 revealed a process of attrition of patches from this class which would lead to land saturation.

This saturation would be due to the unsupatchable practice of an archaic agrarian system, the increase in the number of farmers and the growing demand for food production (Kangah *et al.,* 2016). According to finding of Ouattara (1997) in southern of Ivory Coast, Arouna *et al.* (2010) in the Sudano-Guinean region of Benin and Djohy *et al.* (2016) in northern Benin, land saturation is characterized by very high anthropogenic pressure and especially by the intensification of agricultural activities. This land saturation on the periphery of the CFHS led the infiltration in the forest by non-indigenous populations seeking arable land for cocoa production (Kouakou *et al.,* 2015; Barima *et al.,* 2016; Kouakou, 2019. As most other protected forests in Ivory Coast, this intrusion of foreign populations into the CFHS has accentuated its degradation for the benefit of cocoa production (Kouakou *et al.,* 2015; Barima *et al.,* 2016; Kouakou, 2019).

Drivers of land saturation at the periphery of the classified forest of Haut-Sassandra

In the periphery of the classified forest of Haut-Sassandra, farms are dominated by perennial crops, including cocoa, coffee and cashew trees. This dominance of perennial crops is caused by the high demand from international markets (Ruf and Scroth, 1995). Also, these products perennial crops ensures a best financial income for farmers (Koulibaly, 2008). Food crops (yam, cassava, maize, etc.) are generally grown in association with cocoa, coffee or cashew trees, contributing to household food security. This finding is an amphasis with Lawali (2011) study that pointed out food crops help diversify agricultural production and improve yields of perennial crops.

Plantations of cocoa and coffee have the highest age (25 years) compared to other crops. The average age confirms that culture of both cocoa and coffee was praticed in the the study area since several decades. Indeed, this age is a reflection of the significant booms in cocoa expansion between 1970 and 1990 in Ivory Coast, especially in the Center-West of Ivory Coast (Assiri *et al.,* 2012). However, the northern and eastern sectors of the CFHS are mainly dominated by old cocoa and coffee plantations.

This dominance of cocoa and coffee plantations in these regions is explained by the fact that the first settlements of people for cocoa production took place mainly in these zones from the 1980s onwards. These populations of non-native origin coming from the first cocoa loop were encouraged by the availability of land in the central-western region, particularly around the CFHS to practice cocoa farming there. In addition, more than 50% of the heads of households own plantations of less than 2 ha. There are two main reasons for these small areas. The first reason would be the sharing of the family plantation between family members after the death of the father (Siapo *et al.,* 2018). The second reason would be due to the diversification of crops by farmers (Ruf and schroth, 2013) and the slowing down of the dynamics of plantation extension in the face of land depletion (Ruf, 2000). In Ivory Coast, the study of Assiri *et al.* (2009) showed that more than 80% of producers own farms of less than 10 ha. According to these authors, the decrease in the size of orchards would be linked to the slowing down of the dynamics of cocoa extension in the face of the increasing scarcity of forest land.

This study also showed that more than 40% of the cocoa and coffee plantations are located on a forest clearing. Indeed, forests are the privileged environment for the good development of cocoa trees. This observation has been also noted other authors (Ruf, 1995; Assiri *et al.,* 2009; Kpangui, 2015; Cissé *et al.,* 2016) in Ivory Coast. However, with the current scarcity of forests, farmers are trying to reclaim fallow land and old farms for the creation of new crop plantations less dependent on forest rent.

Conclusion

This study allowed us to highlight the dynamics of land cover in the periphery of the CFHS from 1997 to 2018. Analyses of the land cover maps from 1997 to 2018 showed a high reduction in forest area in favour of crops. Analysis of the transition matrix from 1997 to 2018 revealed a significant conversion of more than 80% of forest area to cropland. In addition, the analysis of the spatial transformation process by configuration index showed an attrition of forest patches by agricultural activities leading to a merging of agricultural patches. On the other hand, the culture and fallow class has seen the creation of new patches followed by their aggregation.

In addition, the analysis of the spatio-temporal dynamics and of the factors of forest degradation and deforestation has been carried out. From this analysis, a dominance of three (03) perennial crops, cocoa, coffee and cashew trees emerged. Of these three crops, cocoa and coffee are the oldest and occupy the largest areas. These speculations are cultivated on a previous forest crop. The largest proportion of farms belongs to those with less than 2 ha, this relatively small area is mainly due to a slowdown in the dynamic of plantation extension in the face of depletion of forest land. In the face of this rarefaction, the population is turning to new speculations such as cashew trees whose previous crop is essentially made up of old plantations and fallow land.

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