Original research article

Cocoa crops are destroying the forest reserves of the classified forest of Haut-Sassandra (Ivory Coast)

Yao Sadaiou Sabas Barima [a,*], Akoua Tamia Madeleine Kouakou [a], Issouf Bamba [a], Yao Charles Sangne [a], Michel Godron [b], Julien Andrieu [c], Jan Bogaert [d]

[a] Université Jean Lorougnon Guédé, UFR Environnement, BP 150 Daloa, Cote d'Ivoire
[b] La Graineterie, 18410 Brinon, France
[c] Université Nice Sophia Antipolis, UMR 7300 ESPACE, 98 boulevard Edouard Herriot - BP 3209 - 06204 Nice Cedex 3, France
[d] Université de Liège / Gembloux Agro-Bio Tech. Unité Biodiversité et Paysage, Passage des Déportés, 2 B-5030 Gembloux, Belgique

A R T I C L E   I N F O

A B S T R A C T

The aim of this study is to determine landscape dynamics in the classified forest of Haut-Sassandra (CFHS) during the periods of conflict in Ivory Coast (or Côte d'Ivoire). To achieve this, the land cover of this protected area was determined by classifying satellite images obtained before, during and after the conflicts, and via ground surveys. Metrics of landscape ecology were calculated. A ground campaign for observing the CFHS's flora and damages incurred was carried out using a sampling of eighteen 500 m-long transects. The results show that forest fragmentation intensified during and after the period of conflicts. Forests covered over 93% of the CFHS's area before conflicts and under 28% in 2015. The main cause of this deforestation is cacao growing. Anthropic activities caused the loss of 40% of plant species, including some which are endemic in Ivory Coast.

1. Introduction

The west-African region has been a source of conflicts in Africa for over two decades (Annan, 2014; Hall, 2015). These conflicts are generally not structured and involve multiple parties, each defending its own interests (Reno, 2001; Buhaug and Rod, 2006). Conflicts in Ivory Coast, or Côte d'Ivoire, went on for a decade after a failed coup in 2002. They led to the partition of the country in two: the North and the West fell under the control of rebel groups and the South remained under government control. In between, a buffer zone was controlled by UN forces and French soldiers (Fig. 1(A)). Despite the presence of these soldiers, military incursions were observed in both areas and reached their peak in 2011 as a result of the military conflict triggered by the presidential election.
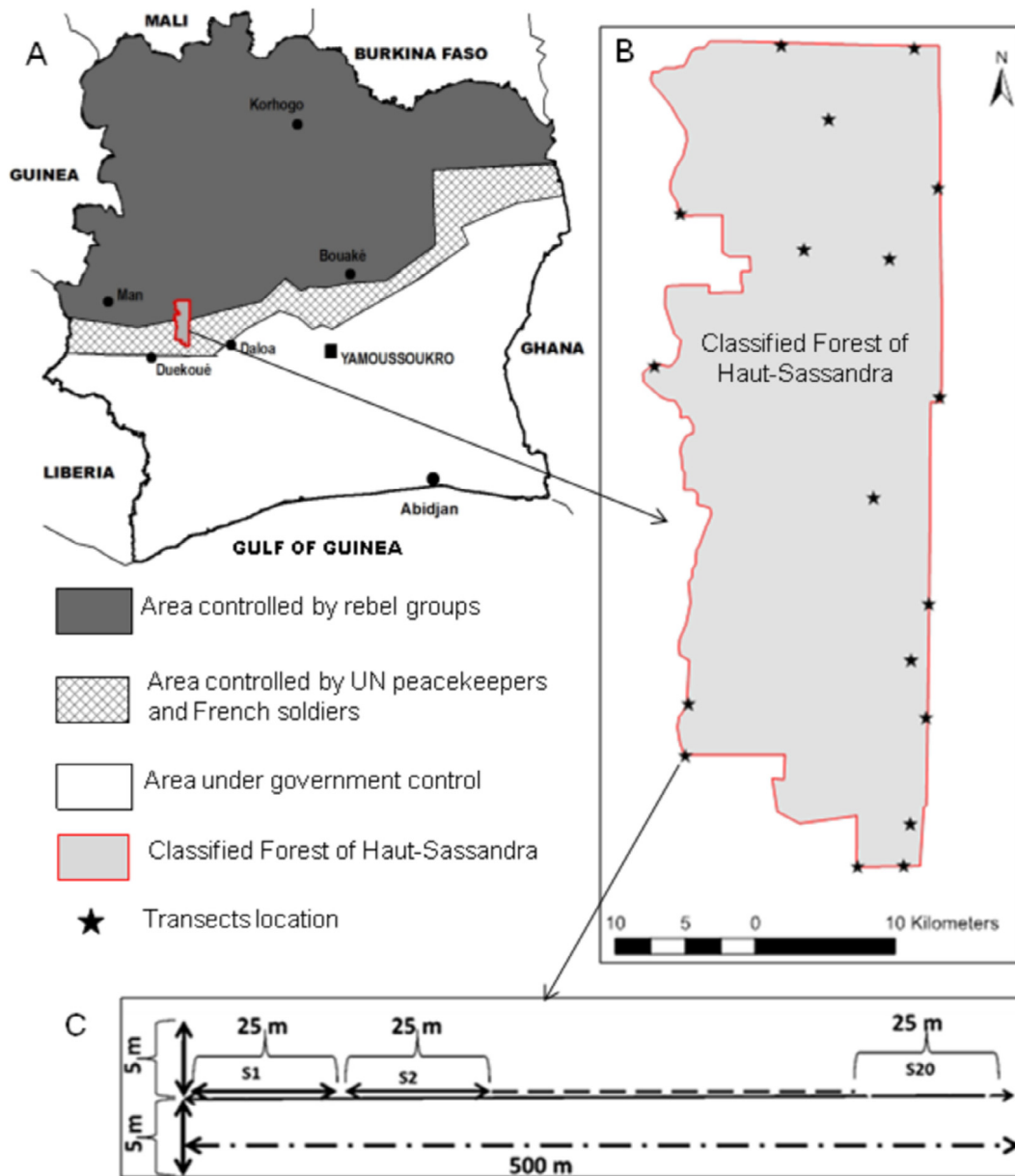
These various political and military crises affected the population's social balance (Chauveau and Richards, 2008; Dabalen and Paul, 2014) and the environment. Indeed, war-related activities have direct or indirect negative impacts on all levels of biodiversity from genes to ecosystems (Nackoney et al., 2014). Direct impacts can be hunting or destruction of the habitat by armies; indirect impacts can be caused by the activities of refugees or other displaced persons, or the withdrawal of those in charge of forest conservation (Draulans and Van Krunkelsven, 2002). The indirect effects of conflicts often have

Fig. 1. Location of classified forest of Haut-Sassandra in Ivory Coast (A), site of floristic data sampling (stars, B) and illustration of segments on a transect (C).

more extensive repercussions than direct destruction on battle fields. Finally, military spending could be incurred to the detriment of other government programs, including the management of natural resources (Hanson et al., 2009).

Ivory Coast's Center-West region is by far the area most affected by the conflicts (Dabalen and Paul, 2014): massive transfers of people, lower income, farming losses, loss of cattle, numerous victims etc. The conflict situation in the region also highlighted problems linked to land resources in the area. The numerous population movements exacerbated land conflicts which were already recurrent in the region. Yet, the people in the Center-West of Ivory Coast are heavily dependent on the forest and its functions, not only for farming but also for the non-timber forest products it provides (FAO, 2007). At national level, the Center-West region has the second highest production of cocoa and coffee (Adou, 2012; MINIGRA, 2012; Koffie-Bipko and Kra, 2013). These crops are Ivory Coast's main financial resource, accounting for over 20% of its gross domestic product. The Center-West region also has one of the most important protected forests in Ivory Coast, namely the classified forest of Haut-Sassandra (CFHS). This protected area was created in 1974 and was, before the conflicts, one of the best protected forest reserves in Ivory Coast (Oszwald, 2005). During the crises, the northern part of the CFHS was in the area controlled by rebel groups, and the southern part in the area controlled by UN forces and the French army. Due to its

Table 1
Characteristics of remote sensing imagery used in this study. TM = Thematic Mapper; ETM = Enhance Thematic Mapper; OLI = The Operational Land Imager; TIRS = Thermal Infrared Sensor.

N°	Dates	Scene ID	Sensor	Resolution (m)
1	02/06/1997	LT51980551997037MPS00	Landsat 5 TM	30
2	12/13/2002	LE71980552002347EDC00	Landsat 7 ETM	30
3	12/08/2006	L71198055_05520061208	Landsat 7 ETM+	30
4	12/19/2013	LC81980552013353LGN00	Landsat 8 OLI TIRS	30
5	01/07/2015	LC81980552015007LGN00	Landsat 8 OLI TIRS	30

situation, it was strongly subjected to significant infiltrations by local populations and by immigrants for logging and above all to grow cacao (Chauveau and Bobo, 2005; Gyau et al., 2014; Kouakou et al., 2015b).

The aim of this study was to determine the impact of these conflicts on the spatial and temporal landscape changes in the CFHS. It is based on the hypothesis that the transfer of people as a result of conflicts and also the lack of surveillance of forests due to the war caused damages to the CFHS and deforestation. The specific objectives are: (1) to determine the main types of damage occurred within the CFHS; (2) to identify the dynamics of forest areas and the dominant processes of spatial transformation of its landscapes; (3) to highlight the current state of floristic diversity. Finally, this study will help to better understand the impact of civil wars and political instability on the dynamics of Ivory Coast's national forests.

2. Methods

2.1. Study area

The Haut Sassandra classified forest lies in the Center-West of Ivory Coast, some 60 km west of the town of Daloa (Fig. 1(A)) between 6°51′–7°24′ of latitude north and 6°59′7°10′ of longitude west. It is one of the most extensive classified forests in Ivory Coast, covering an area of 102,400 ha when it was created in 1974. The CFHS is characterized by a humid climate with two rainy seasons; the long dry season lasts from November to March. The most part of this forest belonged to the mesophilic sector's dense moist semi-deciduous forest zone with *Celtis spp.* and *Triplochiton scleroxylon* (Guillaumet and Adjanohoun, 1971).

The population around the CFHS is made up of several cosmopolitan groups doing subsistence farming (yam, rice, maize, groundnuts etc.) but above all growing cash crops (cocoa, coffee, rubber and cashew).

2.2. Classification of satellite images and land cover maps

Five (5) remote sensing images with a 30 m resolution taken by Landsat sensor were used for this study. They date from 1997, 2002, 2006, 2013 and 2015 (Table 1) and were taken during the dry season to avoid the effect of haze or clouds on the quality of the classification. Images from 1997 to 2002 covered the period before the conflicts in Ivory Coast, those from 2002 to 2006 and from 2006 to 2013 covered respectively the beginning and the end of conflicts. Images taken in 2013 and 2015 cover the post-conflict period. The orthorectification of the older images (1997, 2002 and 2006) has been checked with the geographical coordinates of invariant points. The geometrical accuracy of registration between the various scenes is under 1 pixel, which is the minimum requested for analyzing changes (Mas, 2000). Subsequently, the images were processed under supervised classification after applying a false-color composition obtained with the following spectral bands: Blue (0.45–0.50 μm), Red (0.62–0.70 μm) and Near-infrared (0.70–1.30 μm), using the maximum likelihood algorithm. This algorithm uses the statistics of training sites to calculate the probability for each pixel of belonging to one of the classes (Mas, 2000) and has the advantage of providing, for each pixel, in addition to the class to which it has been allocated, a certainty index linked to that choice. Indeed, the Red and Near-infrared channels are the most widely used for studying vegetation because they help to discriminate vegetation at best (Bonn and Rochon, 1992). This classification was carried out according to the following classes: forest, bare soil and habitat (including inselbergs) and cultivation and fallow. The bare soil included inselbergs. By habitat, we refer to a set of geographic facts about the human residence (shacks, camps, villages).

The classification was first carried out on the most recent image on the base of 54 training zones determined via field visits. It was used for classifying images of the conflict and pre-conflict periods in Ivory Coast.

Reference data for checking the classification were obtained in 360 segments of 250 m² each from in situ observations. In these segments, the types of environment, activity, degree of damages were recorded. These observations will also help to interpret the cartographic results.

Evaluation of the classification's quality was carried out through the classification's overall accuracy and the kappa coefficient. Whereas the classification's overall accuracy gives the average percentage of correctly classified pixels, the kappa coefficient gives a more accurate evaluation of the quality of the classification. The 2015 land cover map, after being validated, was used for defining new reference areas (under ENVI 4.4) in order to evaluate the quality of the classification of pre-2015 images.

2.3. Composition and changes in the land cover

Transition matrices were created in order to identify how frequently a transition occurred between classes during each period of time under study. Indeed, the transition matrix is one of the main models for evaluating landscape changes (Barima et al., 2009; Godron, 2012). It is a chart presenting the transitions between classes in a given period, in other words, percentages of transition observed in a finite time. Therefore it constitutes an exact and highly condensed summary of the whole of changes occurred within a period of study. The matrices were made before, during and after the conflicts in order to understand how the composition of landscapes changed during these different periods.

An analysis of changes in terms of loss or gain of area was carried out. To do so, the period under study (1997–2015) was divided into four periods: before conflicts (1997–2002), at the beginning of conflits (2002–2006), at the end of conflicts (2006–2013) and post-conflicts (2013–2015).

2.4. Spatial transformation process

For each class of land cover, the landscape's spatial structure was characterized based on the number of patches (np), the area (A) and cumulative perimeter (P) of patches using a decision tree proposed by Bogaert et al. (2004). Thus, assuming that there is a limited number of spatial configurations (Collinge and Forman, 1998), the possible spatial transformations in the landscape are aggregation (merging of patches), suppression (disappearance of patches), creation (formation of new patches), distortion (change in the shape of patches), expansion (increase in the size of patches), perforation (formation of holes in patches), displacement (translocation of patches), contraction (reduction in the size of patches), fragmentation (break in the continuity of patches resulting in several loose patches) and dissection (subdivision of patches by small lines). The creation, dissection and fragmentation of forests are associated with an increase of np ($np_{t+1} > np_t$) whereas aggregation is associated with a decrease of np. The other processes do not induce an increase or decrease of np ($np_{t+1} = np_t$). Areas were compared in order to identify on the one hand the creation, aggregation and expansion processes ($A_{t+1} > A_t$, and on the other hand the fragmentation and dissection processes ($A_{t+1} < A_t$) (Bogaert et al., 2004), fragmentation being associated with a bigger loss of area than dissection (Jaeger, 2000). Thus, when $A_{t+1}/A_t > 0.5$, the process retained will be dissection and when $A_{t+1}/A_t < 0.5$, the process retained will be fragmentation (Barima et al., 2009).

2.5. Floristic and dendrometric inventory, and types of disruption

Floristic and dendrometric inventories, as well as the inventory of the types of disruption were carried out using linear transects of 500 m, subdivided into twenty segments of 25 m (Fig. 1(C)). Along the line that materializes each segment, all plant species were recorded as well as their height. At a distance of 5 m on each side of that line, species with a diameter at breast height >10 cm were counted and their height noted. In each area corresponding to segments (25 m × 10 m), the various types of disruption and their characteristics were determined. Artificialization can be one consequence of disruption. Overall, floristic and dendrometric inventories and those of the types of disruption were carried out in 360 segments of 250 m² each spread over 18 transects (Fig. 1(B)).

Processing the floristic inventory data consisted in generating the floristic diversity, dominant families, endemic species and special-status species. The floristic diversity or overall amount of species was determined based on the inventoried data. All plant families of which the number of species is superior or equal to 10 were considered as dominant families. Special-status species were determined according to the International Union for Conservation of Nature (IUCN 2015) Red List. Height measurements were used to classify the sample individuals into the following height classes (m): [0–1[; [1–4[; [4–8[; [8–16[; [16–32[and ≥32.

A list of the CFHS's flora species had been drawn up before the beginning of the conflicts in 1998 (Kouamé, 1998). To compare that list with the one obtained in 2015, it is necessary to compare the number of species which are common to those of each of both lists and look for the most adequate distance index.

The Sørensen similarity index (Sørensen, 1948) was calculated in order to determine the similarity between the lists of species drawn up in 1998 and 2015. This index is one of the most frequently used in literature for that purpose, and is obtained from the following formula:

$$Cs(s) = 100 \times {}^{2c}/_{(a+b)}$$

where Cs is the Sørensen similarity coefficient, a = the number of species in 1998, b = number of species in 2015, c = number of species common to both dates.

3. Results

3.1. Validation of land cover maps

Five (5) maps of the CFHS's land cover were obtained by classifying the images, covering the periods before, during and after conflicts (Fig. 2). The maps were checked from 360 observation points in areas of 250 m² each, and showed kappa coefficients and an overall classification accuracy superior to 80% (Table 2).
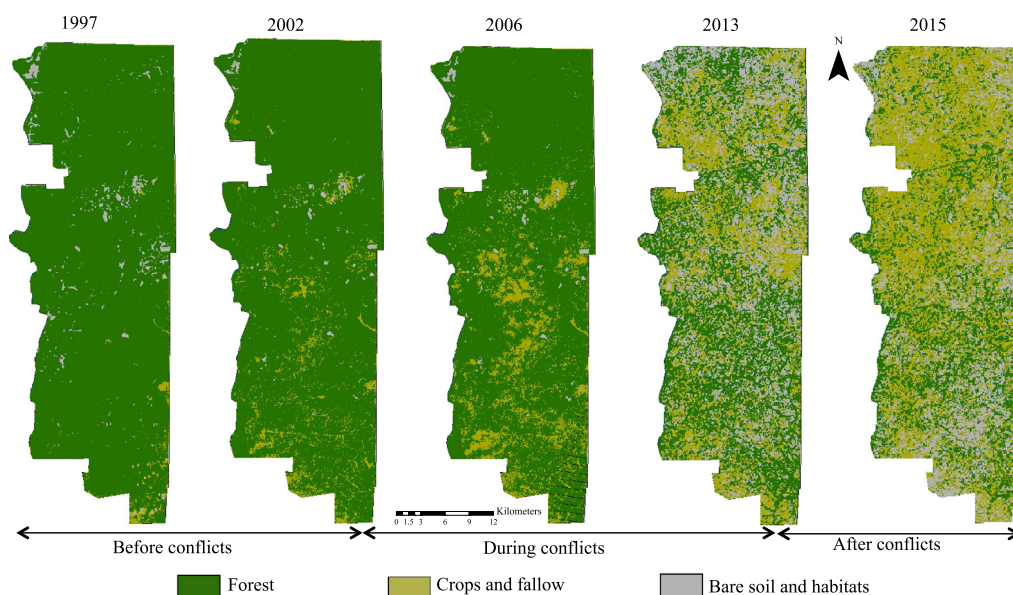
Fig. 2. Land cover maps of classified forest of Haut-Sassandra, before (1990–2002), during (2002–2013) and after the conflicts in Ivory Coast.

Table 2
Accuracy and precision of land cover maps.

	1997	2002	2006	2013	2015
Overall precision	93.68	92.98	90.87	91.79	81.33
Coefficient of Kappa	93.21	92.18	89.44	90.43	79.85

Table 3
Land cover class metrics percentage of classified forest of Haut-Sassandra.

	1997	2002	2006	2013	2015
Number of patches (%)					
Forest	1.96	1.61	2.98	19.34	33.35
Crops and fallow	45.19	86.43	87.03	38.65	25.56
Bare soil and habitat	52.84	11.96	9.99	42.01	41.10
Perimeter (%)					
Forest	11.08	2.22	48.95	20.64	36.63
Crops and fallow	33.23	83.62	46.63	34.59	25.04
Bare soil and habitat	55.69	14.16	4.42	44.77	38.33
Area (%)					
Forest	96.02	93.52	86.55	42.85	28.46
Crops and fallow	1.48	5.33	12.19	26.77	45.53
Bare soil and habitat	2.50	1.15	1.26	30.38	26.01

3.2. Landscape metrics

Regarding the area, with 96.02% of the overall area studied (95,935 ha) in 1997, i.e. around 92,117 ha, the area of study was almost entirely occupied by the dense forest class (Figs. 2 and 3) against 2.50% only (2398 ha) for the bare soil and habitat class and 1.48% (around 1420 ha) for cultivation and fallow. When conflicts broke out in 2002, 93.20% of the CFHS overall area was still occupied by dense forest against 86.55% during conflicts in 2006. Between 2006 and 2013, a regression of forest areas was observed, these areas covered 42.85% (41,108 ha) of the landscape of this protected area in 2013. This regression occurred to the benefit of the other classes which increased to 26.77% for cultivation and fallow and 30.38% for bare soil and habitat. That trend was maintained and became even more pronounced at the end of the conflicts, when forest occupied 28.46% (27,303 ha) of the space against 45.53% (43,679 ha) for cultivation and fallow and 26.01% (24,953 ha) for bare soil and habitat.

In 1997, patches of the bare soil and habitat class occupied 52.84% of the total 1529 patches present in the CFHS against 45.19% for the cultivation and fallow class (Table 2). Forest patches were the least numerous in 1997, with 1.96% of the total.
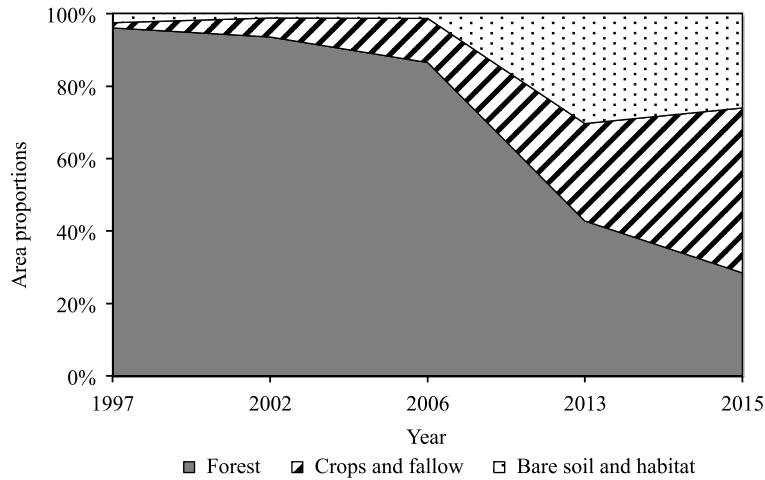
Fig. 3. Evolution land cover area proportion of classified forest of Haut-Sassandra from 1997 to 2015.

In 2002, cultivation and fallow increased to 86.43% (i.e. 3274 patches) thus constituting the highest number of patches in the landscape against 1.61% (i.e. 61 patches) for the forest class. In 2015, the most numerous patches were bare soil and habitat with 41.10% (5992 patches) and forest with 33.35% (4862 patches).

As for the perimeter of the patches, it was higher before conflicts for the cultivation and fallow class with 83.62% of the total perimeter of the patches. In 2015, this percentage dropped to 25.04% while bare soil and habitat accounted for 38.33% of the total perimeter. The perimeters of the forest class patches were those with the highest increase, from 2.22% in 2002 to 36.63% in 2015.

3.3. Periodic and annual variations

On the whole, the variations in area in the various periods studied show an overall regression of dense forest and an increase of the cultivation and fallow class before, during and after conflicts (Fig. 3). Contrasted trends were observed for the bare soil and habitat class. In more detail, a significant regression of dense forests (−50.49%) was observed during the 2006–2013 period (Fig. 4). In that period, the largest areas were covered by bare soil and habitat. The increase in area of the cultivation and fallow class (+260%) was at its top before the conflicts. With a regression of more than 17% per year, the highest annual deforestation rate was observed after the conflicts (Fig. 4). A strong annual variation of the cultivation and fallow areas was observed before the conflicts (+52%). The biggest increase in the bare soil and habitat class was recorded between 2006 and 2013 with an annual evolution of 33%.

3.4. Transfer of land cover

The transition matrix shows the dynamics of land cover during the periods studied (Table 4). It appears that 0.79% of the landscape which was occupied by the cultivation and fallow class in 1997 remained the same in 2002 while 0.08% was converted into the bare soil and habitat class. In those days, with 91.71% of the total, the dense forest class was the matrix of the CFHS. That class was still the matrix of the landscape during the conflicts despite a significant decrease in percentage, from 85.97% between 2002 and 2006 to 38.70% between 2006 and 2013.

After the conflicts, in 2015, the matrix of the CFHS was no longer made up of dense forest but rather of cultivation and fallow accounting for 45.53% of the CFHS as a whole. Such proportions result from the conversion of the dense forest class (11.26%) and the bare soil and habitat class (13.18%) into cultivation and fallow.

The dense forest class is by far that of which most areas have been converted into other classes during the conflict period and mainly after the conflicts (Table 5). Indeed, although the dense forest's stability rate was over 90% before and at the beginning of the conflicts, 24.77% was converted into the cultivation and fallow class and 30.52% into bare soil and habitat between 2006 and 2013. 26.28% of the dense forest available at the end of the conflicts in 2013 (42.85% of the landscape in 2013) had been converted from that class to the cultivation and fallow class by 2015 (Table 5).

3.5. Structural dynamics of the classified forest of Haut-Sassandra

Comparing the parameters of the landscape configuration (np, A and P) for each of the periods studied made it possible to determine the spatial processes in landscape transformation (SPLT) before, during and after the conflicts (Table 6). For the dense forest class, from 1997 to 2015, $np_{t+1} > np_t$ and $a_{t+1} < a_t$, the SPLT is the fragmentation of dense forest. However, this fragmentation seems less significant and would be closer to the dissection of dense forest between 1997 and 2002. For
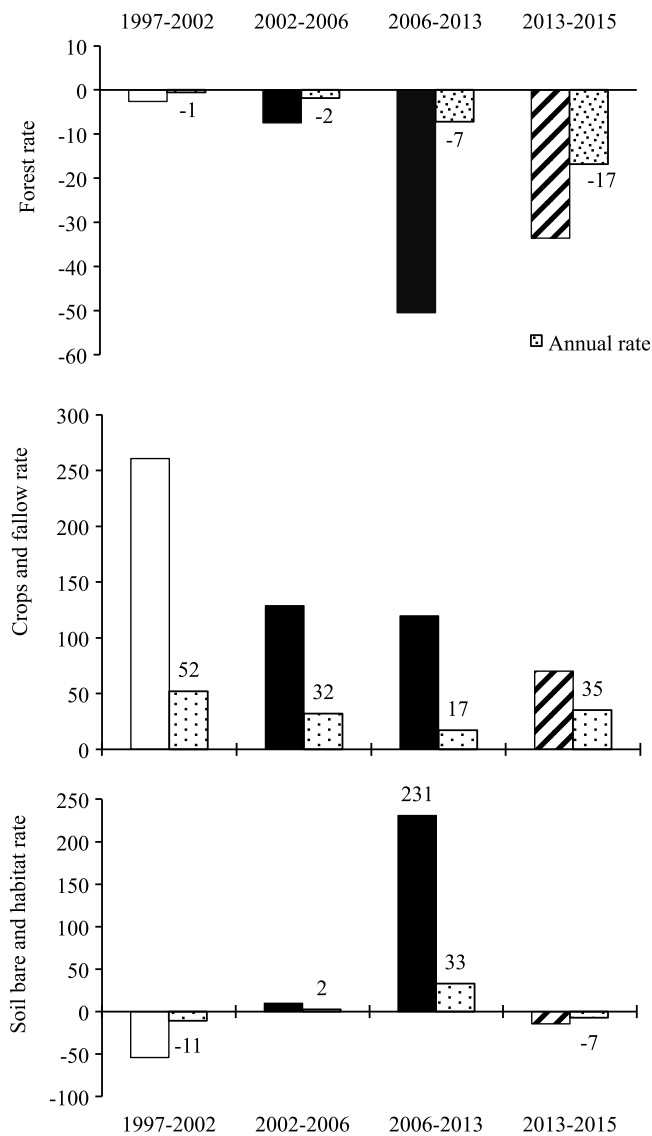
Fig. 4. Variation of land cover area rate of classified forest of Haut-Sassandra, before (white), during (black) and after (Hatched) conflict periods, and annual rate (dotted lines) in these periods.

the cultivation and fallow class, the pre-conflict SPLT was dissection. During the conflicts, cultivation and fallow patches were created. Between 2013 and 2015, the SPLT was aggregation. The bare soil and habitat class' SPLT was suppression of the patches until 2006, then creation between 2006 and 2013 and finally dissection between 2013 and 2015.

3.6. Disruptions in the classified forest of Haut-Sassandra

Twelve kinds of disruption were inventoried in the CFHS (Table 7). The most frequent disruptions are cacao plantations, with a frequency rate of 23.32%. These plantations are between a few months and under ten years old. Fallen trees after slash-and-burn and trees burnt at the base of the trunk occur with a frequency rate of respectively 21.06% and 18.84% of the overall disruptions of the environment. Mixed cultivations accounting for 15.97% of the disruptions consist in farms including several food species such as banana, chilli, okra, taro, eggplant etc. Uprooted trees are not frequent in the classified forest, they account for 4.79% of disruptions. They are essentially due to the wind or other natural causes.

To sum it up, the most frequent types of disruption are cacao plantations, fallen trees due to slash-and-burn, trees burnt at the base of the trunk and mixed cultivations. Around 95% of the disruptions recorded are of anthropic origin and 5% of natural origin.

Table 4
Transition matrix of land cover classes of classified forest of Haut-Sassandra.

	Forest	Crops and fallow	Bare soil and habitat	Total
1997–2002				
Forest	91.71	4.17	0.14	96.02
Crops and fallow	0.60	0.79	0.08	1.48
Bare soil and habitat	1.20	0.37	0.93	2.50
Total	93.52	5.33	1.15	100.00
2002–2006				
Forest	85.97	7.27	0.29	93.52
Crops and fallow	0.53	4.72	0.08	5.33
Bare soil and habitat	0.05	0.21	0.89	1.15
Total	86.55	12.19	1.26	100.00
2006–2013				
Forest	38.70	21.44	26.41	86.55
Crops and fallow	4.02	5.13	3.04	12.19
Bare soil and habitat	0.13	0.20	0.93	1.26
Total	42.85	26.77	30.38	100.00
2013–2015				
Forest	25.59	11.26	6.00	42.85
Crops and fallow	0.67	21.10	5.01	26.77
Bare soil and habitat	2.20	13.18	15.00	30.38
Total	28.46	45.53	26.01	100.00

Table 5
Conversion of forest in other land covers classes.

|		Forest	Crops and fallow	Bare soil and habitat	Total
Forest	1997–2002	95.51	4.34	0.15	100.00
	2002–2006	91.92	7.77	0.31	100.00
	2006–2013	44.71	24.77	30.52	100.00
	2013–2015	59.72	26.28	14.01	100.00

Table 6
Spatial processes in landscape transformation (SPLT) of classified forest of Haut-Sassandra, before (1997–2002), during (2002–2006; 2006–2013) and after the conflicts in Ivory Coast. np = number of patch, a = area, $peri$ = perimeter. $t_{obs} = a_{t+1}/a_t$).

		1997–2002	2002–2006	2006–2013	2013–2015
Forest	np	$np_{2002} > np_{1997}$	$np_{2006} > np_{2002}$	$np_{2013} > np_{2006}$	$np_{2015} > np_{2013}$
	Area	$a_{2002} < a_{1997}$	$A_{2006} < a_{2002}$	$a_{2013} < a_{2006}$	$a_{2015} < a_{2013}$
	Peri	$P_{2002} < p_{1997}$	$p_{2006} > p_{2002}$	$p_{2013} < p_{2006}$	$p_{2015} < p_{2013}$
	SPLT	Fragmentation ($t_{obs} = 0.4$)	Fragmentation ($t_{obs} = 0.35$)	Fragmentation ($t_{obs} = 0.03$)	Fragmentation ($t_{obs} = 0.33$)
Crops and fallow	np	$np_{2002} > np_{1997}$	$np_{2006} > np_{2002}$	$np_{2013} > np_{2006}$	$np_{2013} < np_{2013}$
	Area	$a_{2002} < a_{1997}$	$a_{2006} > a_{2002}$	$a_{2013} > a_{2006}$	$a_{2015} > a_{2013}$
	Peri	$p_{2002} > p_{1997}$	$p_{2006} > p_{2002}$	$p_{2013} > p_{2006}$	$p_{20135} > p_{2013}$
	SPLT	Dissection ($t_{obs} = 0.76$)	Creation	Creation	Aggregation
Bare soil and habitat	np	$np_{2002} < np_{1997}$	$np_{2006} < np_{2002}$	$np_{2013} > np_{2006}$	$np_{2015} > np_{2013}$
	Area	$a_{2002} < a_{1997}$	$a_{2006} < a_{2002}$	$a_{2013} > a_{2006}$	$a_{2015} > a_{2013}$
	Peri	$p_{2002} < p_{1997}$	$p_{2006} < p_{2002}$	$p_{2006} > p_{2006}$	$p_{t+1} < p_{2013}$
	SPLT	Suppression	Suppression	Creation	Dissection ($t_{obs} = 0.75$)

Table 7
Frequency of occurrence of disturbance types.

Disturbance types	Frequency of occurrence
Cocoa	23.32
Falling trees	21.06
Burned to the base of trees	18.84
Combination of crops	15.97
Chablis	4.79
Fallow	3.95
Logging	3.68
Track	3.16
Clearing undergrowth	2.77
Food crops	1.74
Bushfire	0.36
Habitat	0.36
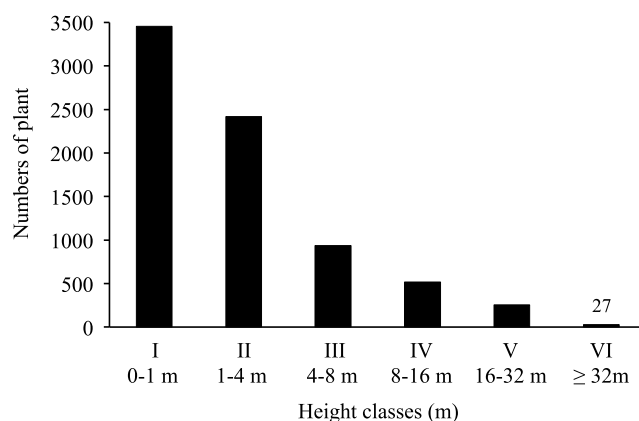
Fig. 5. Number of plants in height classes (m). I: [0–1[; II: [1–4[; III: [4–8[; IV: [8–16[; V: [16–32[; VI: ≥32.

3.7. Floristic composition of the classified forest of Haut-Sassandra

In 2015, after the conflits, records show that the CFHS was home to 622 species divided into 410 genera and 104 families, of which 18 present numbers higher or equal to 10 species. Among these families, Rubiaceae and Fabaceae are the most species-rich with 6.87% and 5.75% respectively. Floristic inventories carried out in the CFHS before the conflits by Kouamé (1998) and Kouamé et al. (2004) showed 1047 species against 622 in 2015. Which means that around 40% of species in this protected area should be disappeared during the decade of conflits. However, it is useful to note that these results should be tempered because the sampling methods are not the same. In 1998, the CFHS was home to 68 species endemic in West Africa and eight (8) species endemic in Ivory Coast (Kouamé, 1998). Today this forest has only 45 species endemic in West Africa and five (5) species endemic in Ivory Coast. These are *Baphia bancoensis, Chrysophyllum taïense, Cissus miegei, Geophila afzelii* and *Hibiscus comoensis*. According to the IUCN Red List (2015), the CFHS' post-conflict flora includes 16 rare or endangered species among which *Milicia excelsa* and *Hugonia rufipilis*, with a proportion of 0.2% each of the total individuals recorded, are the most numerous, followed by *Diospyros vignei* (0.16%). The CFHS has 26 vulnerable species including *Guibourtia ehie,* which is the most abundant vulnerable species with 1.13% of the overall number of individuals.

The Sørensen similarity index calculated between the 1996 and 2013 floristic lists showed a similarity of around 48% between the two lists.

Height measurements revealed the types of strata found in the CFHS. So, now 45% of the CFHS is dominated by individuals between 0 and 1 m high. Individuals higher than or equal to 32 m are rare and account for 0.35% of the total of individuals recorded (Fig. 5).

4. Discussion

4.1. Accuracy of the land cover maps of the classified forest of Haut-Sassandra

The map accuracy rates obtained for this study are mostly over 80% (Table 2), proof that images were classified correctly. Indeed, according to accuracy standards defined by Landis and Koch (1977) and Streiner and Norman (1989), a kappa coefficient higher than 74% reflects a very good (Landis and Koch, 1977) to excellent (Streiner and Norman, 1989) classification result.

Classification accuracy drops as the environment becomes more and more heterogeneous. Indeed, in such an environment, classification accuracy is low due to the fact that details are impossible to observe when cartographic units are smaller than a pixel. For example, in our case study, it is technically impossible to distinguish two classes of land cover on an area smaller than a pixel (900 m^2). Higher accuracy before the conflits would therefore be due to the relative homogeneousness of the CFHS compared to its post-conflits condition.

4.2. Forest landscape composition and land cover dynamics in the classified forest of Haut-Sassandra

Analyzing the CFHS' landscape composition showed that before the conflits, forest was the matrix of the landscape although it represented less than 2% of the total patches in that protected area. (Table 3). Which means that it was a large compact forest block. However, 1.48% of the CFHS was occupied by farms and 2.50% by bare soil and habitat. Therefore, the infiltration of people in the CFHS for farming started before conflits broke out in Ivory Coast in 2002 and has already been the subject of several studies, including those of N'guessan et al. (2003) and Oszwald (2005). According to Kouakou et al. (2015a,b), these cultivations were usually located in the periphery of the classified forest, adjoining the rural area. Farms within the forest were very few. It could then be suggested that part of the people infiltrations in these days was due to their

ignorance of the boundaries of the classified forest. By extending their farmlands, these people would have encroached on the classified forest.

But with the passing years, the matrix's large forest blocks have been dissected and replaced by more numerous fragments but with lower areas. The increase in the dense forest perimeter with the passing time shows that these forest blocks are progressively breaking apart. The near absence of forest surveillance as a result, among others, of the mobilization of wardens for the various war fronts, may have facilitated the infiltration of this protected area, as already shown by Kouakou et al. (2015a) and Assalé et al. (2016).

However, before 2006, the regression of the forest area was in phase with the spatial dynamics of forests worldwide, and notably in Africa. Indeed, the net annual loss of forest area is estimated at 5.3 million hectares for the whole of Africa, i.e. 0.78% of the overall forest area (FAO, 2001). In West African countries, where the curse is the worst, the loss of forest cover is usually due to farming. Indeed, forests are considered by farmers as the environment with the most fertile soil hence the most favorable for farming. In addition to fertile soils, forests prevent the proliferation of weeds and insects (Moran et al., 2000), are a humidity factor, limit the effects of wind and erosion (Brou, 2009) etc. For local populations, for example, a cacao plantation can be set up only on freshly cleared land (Assalé et al., 2016). In this kind of process, and with a view to increasing their yield or renewing old plantations, farmers are constantly moving their clearing front forward thus encroaching on protected areas.

A striking feature in the land cover class dynamics is the shrinking by more than 50% of the area occupied by dense forest between 2006 and 2013, followed by the multiplication by 20 of areas occupied by the bare soil and habitat class (Figs. 2 and 3). This period seems to be a turning point in the CFHS anthropization. It coincides with the resumption of fighting in the area studied and the arrival of new warlords in that part of the country run by rebel groups.

As a result, the end of the conflicts did not materialize in the end or slowdown of the CFHS deforestation. Quite the opposite, two to three years after the end of hostilities, infiltrations into the CFHS went on and got worse to the point of modifying the new matrix of this protected area in 2015 from dense forest before and during conflicts to cultivation and fallow after the war. Indeed, in 2015, dense forest occupied only 28.46% of the CFHS area against 45.53% for the cultivation and fallow class. To sum it up, the CFHS dynamics' dominant feature is a continuous replacement of dense forest by farming.

4.3. Structural dynamics of the classified forest of Haut-Sassandra

The decision tree proposed by Bogaert et al. (2004) and used for determining the landscape's structural transformation processes offers numerous advantages such as being simple and quick to implement. Regarding the dense forest, it confirmed that fragmentation began much before the conflicts broke out. Thus, between 1997 and 2002, the a2002/a1997 ratio = 0.4 therefore close to 0.5 which is the threshold between fragmentation and dissection (Bogaert et al., 2004; Barima et al., 2009). Indeed, both the fragmentation and dissection processes are characterized by an increase of the number of patches and a decrease of their area. But fragmentation is materialized by a bigger gap between patches hence a lower area of patches compared to dissection. Thus, the a_{t+1}/a_t ratio will be higher in the case of dissection compared to fragmentation. With t_{obs} = 0.4; 0.35; 0.03 and 0.33 between 1997–2002, 2006–2002, 2013–2006 and 2015–2013 respectively, it could be concluded that fragmentation was less pronounced until 2006 and could be similar to dissection, i.e. the subdivision of forest blocks by small lines (Saura and Martinez-Mlian, 2001). But from 2006 onwards, forest fragmentation is a reality in the CFHS (t_{obs} = 0.03 and an increase of the number of patches of over 500%). If nothing is done to stop that trend, it will inexorably lead to the process of suppression of patches. In other words, the residual forest patches will be converted into cultivation and fallow and then $n_{t+1} < n_t$ and $a_{t+1} < a_t$ (Bogaert et al., 2004; Barima et al., 2009).

4.4. Damages to the classified forest of Haut-Sassandra

Results of damages in the CFHS revealed that 95% of the types of disruption occurred in the CFHS have an anthropic origin and only 5% a natural origin. These types of disruption are mostly cacao trees, fallen trees, slash-and-burn at the foot of trees and mixed cultivations (Table 7). In fact, in most African countries, the method of cacao-growing is the same: slash-and-burn farming, traditional logging and stump removal by burning (Monnerat and Tchatchou, 2014). Therefore, the prevalence of these types of disruption (cacao trees, fallen trees, slash-and-burn at the foot of trees and mixed cultivations) could be explained by the fact that all are related to the same activity, namely cacao-growing. So this activity is by far the main cause of disruption of the CFHS' forest cover. Also, the significant presence of food crops combined with cacao trees suggests that although the primary objective of the infiltrations is cacao-growing, it is combined with food crops not only to ensure food sufficiency but also to produce a marketable surplus providing a regular income. The association of food crops with cacao trees is also due to the shortage of land for subsistence farming. However, self-consumption crops are associated with cacao only during the first years of creation of a cacao plantation; after that, all the space is devoted to cacao growing (Jagoret et al., 2009). Moreover, a significant number of cacao plantations are under ten years old, hence posterior to the beginning of the conflicts (2002), thus showing that damages to the CFHS occurred during the 2000 decade of politico-military crises experienced by the country.

Rather similar processes of agricultural infiltration into a classified forest have been studied in Casamance (Sidibé, 2005), but in other regions of the African tropical zone, the causes of damage to forests seem to differ from those observed in

the CFHS. For example in Benin, uncontrolled wood-cutting, mostly for charcoal-making, is the main cause of damage to protected areas (Adjonou et al., 2009). In Madagascar, the main causes of damage to the Tapia forest are bush fires, illicit production of firewood, excessive gathering of non-timber forest products and invasion by exotic reforestation species (Rakotondrasoa et al., 2012). In the Democratic Republic of the Congo, the causes are logging and the extraction of wood fuel (Tchatchou et al., 2015).

Owing to crises in Ivory Coast, all areas of the CFHS have been damaged at the same time without distinction. The forest seems to have suffered from lack of control and follow-up not only in the northern part run by rebel groups but also in the southerner zones run by impartial forces. The latter observation is worrying because it shows that despite the presence of international forces, infiltrations went on and gathered momentum in the CFHS. It also highlights the passivity of such international forces in front of the damages and deforestation of protected areas as observed in the east of Congo and many countries in conflict (Smouts, 2000).

Cacao-related disruptions consist in clearing the undergrowth prior to planting cacao trees. The tall trees are left and, seeing the canopy from above, one can think that the forest is healthy (Fig. 6). The wood and leaves cleared from the undergrowth are piled up around the big trees. Then cacao is sowed in the cleared areas. The following step consists in burning the heaps of wood and leaves around the big trees and these die standing. After two to three years, the original vegetation has been replaced by a cacao plantation (Fig. 6).

However, outside the cocoa farming, wormy loggers have also taken advantage of this situation in Ivory Coast crisis to plunder the CFHS its contents of timber (Kouakou et al., 2015a). Although the volume of timber removed from the CFHS has not been quantified, we can imagine its magnitude when we know this forest was one of the rare forest reserves in the Central west of Côte d'Ivoire

Disruptions with a natural origin that account for 5% of the types of disruption observed in the CFHS are broken tree branches or trunks, or partially or completely uprooted trees (Foster, 1988; Everham and Brokaw, 1996). These are beneficial to the forest because they contribute to the regeneration of tree species (Ulanova, 2000). Normally, they do not occur very often and their occurrence is limited in time. However, it could indirectly be due to anthropic activities. In the case of the CFHS, fallen dead trees are the result of slash-and-burn at the base of the trunk. The infiltration of clandestine populations coming from various horizons is another agent of anthropic origin. But most of these populations come from the hinterland and mainly from Burkina Faso (Barima et al., 2015). Such infiltrations are often organized in channels and have probably been made possible because of the absence of wardens, but have also benefited from the complicity of local people and the corruption of some administrative and military authorities (Barima et al., 2015).

4.5. Dynamics of the classified forest of Haut-Sassandra floristic composition

The consequence of the fragmentation and modification of habitats in the CFHS, essentially of anthropic origin, is, among others, the disappearance of numerous animal and vegetal species as stipulated by Kouakou et al. (2015b). Indeed, the larger the patch, the more possibilities of micro-habitat it offers and the more likely it is to be home to a significant population (Jaeger, 2000). Fragmentation is also a threat to the specific diversity of forests (Collinge, 1996; Benítez-Malvido and Martínez-Ramos, 2003; Bamba et al., 2010), notably that of the CFHS.

Floristic inventories carried out in 2015 have indicated the presence of 622 species. Therefore it seems that the CFHS is still floristically rich. However, around 40% of this protected area's species seem to have disappeared during the conflict period, including some West African and Ivorian endemic species. The fact that these species are no longer observed could be due to anthropic activities in the CFHS. Yet the particularity of Ivorian flora is linked to the existence of endemic species which have never been observed outside Ivory Coast.

At structural level, the CFHS, which has been classified since 1974 (over 40 years) nowadays has a higher proportion of small individuals and young plants, thus confirming the damaging of forests by agriculture as shown by Fig. 6.

4.6. Armed conflicts and preservation of natural resources

Illicit exploitation of natural resources during armed conflicts has increased strongly (McNeely, 2003). This is very often more pronounced in protected areas due to their great biological diversity and the absence of conservation authorities. The arrival of refugees in an area is often a cause of the shrinking of natural resources. People fleeing combat zones to settle in protected areas exert a strong pressure on these areas' natural resources (Dudley et al., 2002). In addition to refugees, both rebel groups and governments are instrumental to the loss of natural resources during conflicts. These groups exploit natural resources to finance their military operations and keep them going. Forest resources are then submitted to excessive exploitation leading to a significant reduction of the forest cover. Unfortunately, the end of conflicts is not synonymous with the end of pressure. Indeed, after a war, both governments and international organizations are too concerned about health and economic issues and national reconciliation to focus on the preservation of natural resources, notably in protected areas. Therefore, illegal activities such as farming, logging and mining continue to proliferate in these areas.

5. Conclusion

Significant changes have occurred in the classified forest of Haut-Sassandra land cover between 1997 and 2015. Before conflicts broke out, the rate of forest cover was above 93%. At the end of the conflicts, only 28.46% of the space was occupied
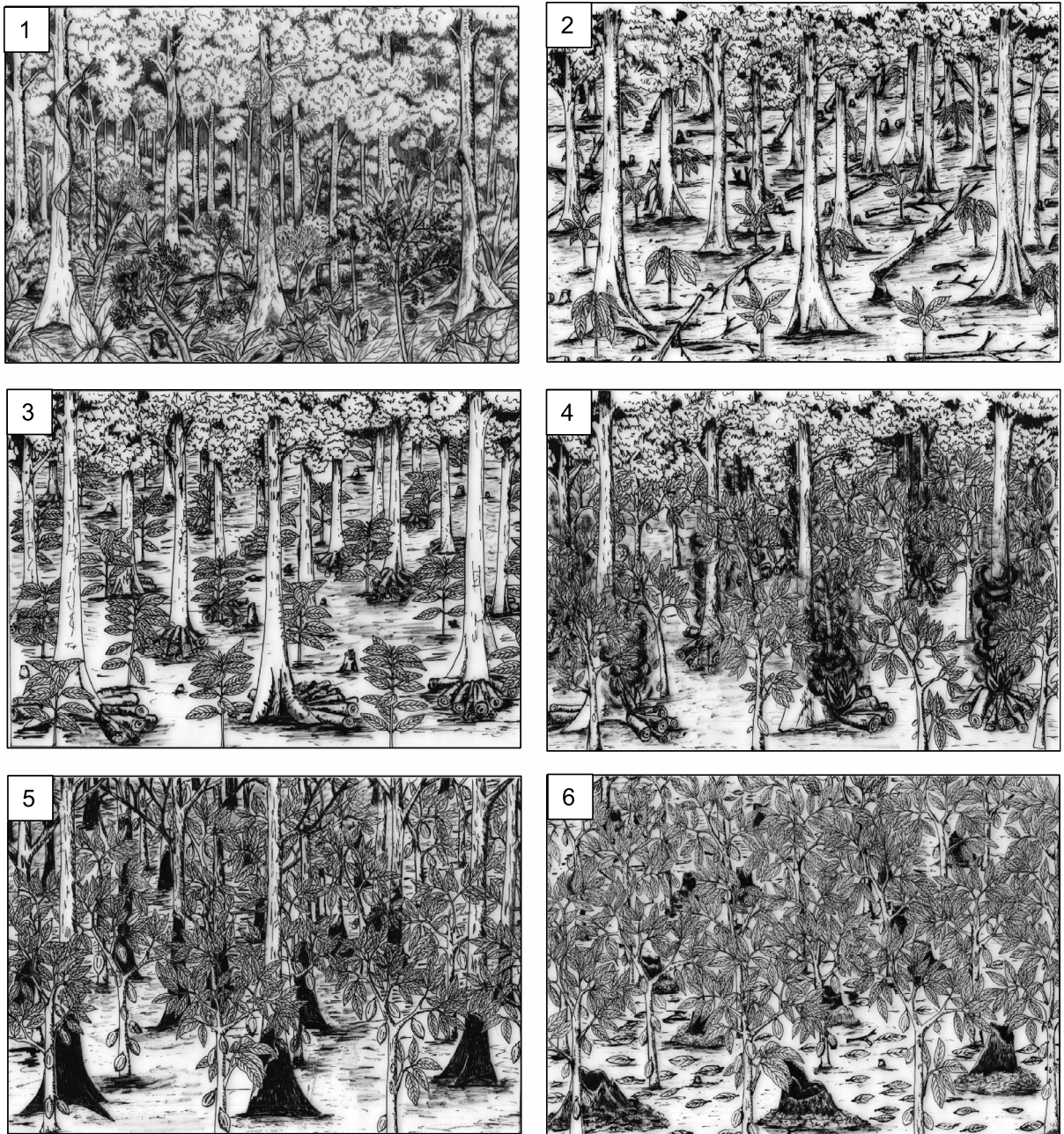
Fig. 6. Process of creation of cocoa plantation in the classified forest of Haut-Sassandra. (1) Forest at baseline with big trees. Crown is contiguous and presence of many lianas. (2) Clearing of undergrowth and cocoa planting. (3) Grouping of dead wood around big trees. (4) Burned of wood and leaves around big trees. (5) Cocoa plantation with the presence of dead trees. (6) Drop of dead timber. Cocoa with little or no wood.

by dense forest. 95% of the deforestation of the CFHS is due to anthropic causes. Most of these human activities are related to the setting up of cacao plantations inside the CFHS to the detriment of forest areas. Such agricultural practices contribute not only to modifying its landscapes but also its floristic composition, including with the disappearance of species. During the period of conflicts, over 40% of plant species may have disappeared from the CFHS, including some important special-status species. The impacts of conflicts in Ivory Coast resulted in the regression of the forest cover, fragmentation and loss of biological diversity.

In the end, the CFHS, which only 15 years ago was a vestige of the Ivorian semi-deciduous moist dense forest, is nowadays a vast cacao plantation scattered with standing dead trees and with a dense network of footpaths and habitat, reflecting the condition of the whole of the protected areas left in tatters after a decade of political and military conflicts. Therefore, it is a matter of urgency to adopt a consequent policy of protected areas supported by vigorous measures with a view to reversing

the trend towards total deforestation of the CFHS. Such measures could include expelling clandestine populations from the CFHS and resettling them in the periphery. Also, the number of wardens should be increased and their capabilities reinforced to face the new threats to protected areas. Finally, local populations living close to the CFHS' outer boundaries should be involved in an efficient participative management of the forest.

Acknowledgments

Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2016.08.009.

References

Adjonou, K., Bellefontaine, R., Kokou, K., 2009. Les forêts claires du Parc national Oti-Kéran au Nord-Togo: structure, dynamique et impacts des modifications climatiques récentes. Secheresse 20, 394–396.

Adou, D.L., 2012. L'économie de plantation et la dynamique de peuplement dans la région du Haut-Sassandra. Université Félix Houphouët-Boigny, Abidjan-Cocody, Côte d'Ivoire.

Annan, N., 2014. Violent conflicts and civil strife in west Africa: Causes, challenges and prospects. Stab.: Int. J. Sec. Dev. 3, 1–16.

Assalé, A.A.Y., Barima, Y.S.S., Kouakou, K.A., Kouakou, A.T.M., Bogaert, J., 2016. Agents de dégradation d'une aire protégée après une décennie de conflits en Côte d'Ivoire: cas de la forêt classée du Haut-Sassandra. Int. J. Innov. Sci. Res. 2, 123–133.

Bamba, I., Barima, Y.S.S., Bogaert, J., 2010. Influence de la densité de la population sur la structure spatiale d'un paysage forestier dans le bassin du Congo en R. D. Congo. Trop. Conserv. Sci. 3, 31–44.

Barima, Y.S.S., Bamba, I., Sangne, Y.C., Ndoumé, C., 2015. GRIEPE,. Les enjeux de la gestion participative sur la préservation des aires protégées après les conflits en Côte d'Ivoire: cas de la forêt classée du Haut-Sassandra. Groupe de Recherche Interdisciplinaire en Écologie du Paysage et en Environnement, Université Jean Lorougnon Guédé, UFR Environnement, Daloa, Côte d'Ivoire.

Barima, Y.S.S., Barbier, N., Bamba, I., Traore, D., Lejoly, J., Bogaert, J., 2009. Dynamique paysagère en milieu de transition forêt-savane ivoirienne. Bois For. Trop. 299, 15–25.

Benítez-Malvido, J., Martínez-Ramos, M., 2003. Impact of forest fragmentation on understory plant species richness in Amazonia. Conserv. Biol. 17, 389–400.

Bogaert, J., Ceulemans, R., Salvador-Van Eysenrode, D., 2004. Decision tree algorithm for detection of spatial processes in landscape transformation. Environ. Manage. 33, 62–73.

Bonn, F., Rochon, G., 1992. Précis de télédétection - Principes et méthodes. Presses universitaires du Québec, Canada.

Brou, Y.T., 2009. Impacts des modifications bioclimatiques et de l'amenuisement des terres forestières dans les paysanneries ivoiriennes: quelles solutions pour une agriculture durable en Côte d'Ivoire. Cuad. Geogr. 45, 13–29.

Buhaug, H., Rod, J., 2006. Local determinants of African civil wars, 1970–2001. Politcal Geogr. 25, 315–335.

Chauveau, J.-P., Bobo, S.K., 2005. Crise foncière, crise de la ruralité et relations entre autochtones et migrants sahéliens en Côte d'Ivoire forestieère. Outre-Terre 2, 247–264.

Chauveau, J.-P., Richards, P., 2008. West African insurgencies in Agrarian perspective. Côte d'Ivoire and Sierra Leone compared. J. Agrar. Change. 8, 515–552.

Collinge, S.K., 1996. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. Landsc. Urban Plan. 36, 9–77.

Collinge, S.K., Forman, R.T.T., 1998. A conceptual model of land conversion processes: prediction and evidence from a microlandscape experiment with grassland insect. Oikos 82, 66–84.

Dabalen, A.L., Paul, S., 2014. Effect of conflict on dietary diversity: Evidence from Côte d'Ivoire. World Dev. 58, 143–158.

Draulans, D., Van Krunkelsven, E., 2002. The impact of war on forest areas in the Democratic Republic of the Congo. Oryx 36, 35–40.

Dudley, J.P., Ginsberg, J.R., Plumtre, A.J., Hart, J.A., Campos, L.C., 2002. Effets of war and civil strife on wildlife and wildlife habitats. Conserv. Biol. 16, 319–329.

Everham, E.M., Brokaw, N.V.L., 1996. Forest damage and recovery from catastrophic wind. Bot. Rev. 62, 113–185.

FAO, 2001. Situation des forêts du Monde: L'état des ressources forestières dans le monde. Organisation des Nations Unies pour l'Alimentation et l'Agriculture.

FAO, 2007. State of the World's Forests, 2007. Food and Agriculture Organization of the United Nations Rome, Italy.

Foster, D.R., 1988. Species and stand response to catastrophic wind in central New England, USA. J. Ecol. 76, 135–151.

Godron, M., 2012. Écologie et Évolution du Monde Vivant. Harmattan, Paris.

Guillaumet, J.-L., Adjanohoun, E., 1971. La végétation de la Côte d'Ivoire. In: Avenard, J.-M., Edlin, M., Girard, G., Sircoulon, J., Touvhebeuf, P., Guillaumet, J.L., Adjanohoun, E., Perreaud, A. (Eds.), Le Milieu Naturel de la Côte d'Ivoire. In: Coll. Mémoires de l'Orstom, Orstom, Paris, France, pp. 157–263.

Gyau, A., Smoot, K., Kouame, C., Diby, L., Kahia, J., Ofori, D., 2014. Farmer attitudes and intentions towards trees in cocoa (Theobroma cacao L.) farms in Côte d'Ivoire. Agrofor. Syst..

Hall, J., 2015. Africa's perpetual troublemakers and hot spots: Africa-wide - continental overview. Afr. Confl. Monit. Feb, 4–9.

Hanson, T., Brooks, T.M., Da Fonseca, G.A.B., Hoffmann, M., Lamoreux, J.F., Machlis, G., Mittermeier, C.G., Mittermeier, R.A., Pilgrim, J.D., 2009. Warfare in biodiversity hotspots. Conserv. Biol. 23, 578–587.

Jaeger, J.A.G., 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landsc. Ecol. 15, 115–130.

Jagoret, P., Bouambi, E., Ngogue, H.T., Battini, J.L., Nyassé, S., 2009. Diversification des exploitations agricoles à base de cacaoyer au Centre Cameroun: mythe ou réalité? Biotechnol. Agron. Soc. Environ. 13, 271–280.

Koffie-Bipko, C.Y., Kra, K.S., 2013. La région du Haut-Sassandra dans la distribution des produits vivriers agricoles en Côte d'Ivoire. Rev. Geo. Trop. Environ. 2, 96–103.

Kouakou, A.T.M., Barima, Y.S.S., Kouakou, K.A., Kouamé, N.F., Bogaert, J., Kouadio, J.Y., 2015a. Forest dynamics in the North of the classified forest of Haut-Sassandra during the period of armed conflicts in Ivory Coast. Am. J. Life Sci. 3, 375–382.

Kouakou, K.A., Barima, Y.S.S., Kouakou, A.T.M., Sangne, Y.C., Bamba, I., Kouamé, N.F., 2015b. Diversité végétale post-conflits armés de la Fôret Classée du Haut-Sassandra (Centre-Ouest de la Côte d'Ivoire). J. Anim. Plant Sci. 26, 4058–4071.

Kouamé, N.F., 1998. Influence de l'exploitation forestière sur la végétation et la flore de la forêt classée du Haut-Sassandra (Centre-Ouest de la Côte d'Ivoire). Université de Cocody-Abidjan, Côte d'Ivoire.

Kouamé, N.F., Bongers, F., Poorter, L., Traoré, D., 2004. Climbers and logging in the Forêt Classée du Haut-Sassandra, Côte-d'Ivoire. For. Ecol. Manag. 194, 259–268.

Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33, 159–174.

Mas, J.F., 2000. Une revue des méthodes et des techniques de télédétection du changement. Can. J. Remote Sens. 26, 349–362.

McNeely, J.A., 2003. Conserving forest biodiversity in times of violent conflict. Oryx 37, 142–152.

MINIGRA, 2012. Directory of agricultural statistics, Abidjan. Direction of statistics, documentation and informatics. Ivory Coast.

Monnerat, M., Tchatchou, B., 2014. Foresterie urbaine et agroforesterie pour l'adaptation et l'atténuation à Lukolela. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Moran, E.F., Brondizio, E.S., Tucker, J.M., da Silva-Forsberg, M.C., McCrackena, S., Falesid, I., 2000. Effects of soil fertility and land-use on forest succession in Amazônia. For. Ecol. Manag. 139, 93–108.

Nackoney, J., Molinario, G., Potapov, P., Turubanova, S., Hansen, M.C., Furuichi, T., 2014. Impacts of civil conflict on primary forest habitat in northern Democratic Republic of the Congo, 1990–2010. Biol. Cons. 170, 321–328.

N'guessan, E., Bellan, M.-F., Blasco, F., 2003. Suivi par télédétection spatiale d'une forêt tropicale humide protégée soumise à des pressions anthropiques. Télédétection 3, 443–456.

Oszwald, J., 2005. Dynamique des formations agroforestières en Côte d'Ivoire (des années 1980 aux années 2000) - Suivi par télédétection et développement d'une approche cartographique. Université des Sciences et Technologies de Lille, Lille, France.

Rakotondrasoa, O.L., Malaisse, F., Rajoelison, G.L., Razafimanantsoa, T.M., Rabearisoa, M.R., Ramamonjisoa, B.S., Raminosoa, N., Verheggen, F.J., Poncelet, M., Haubruge, E., Bogaert, J., 2012. La Forêt de Tapia, écosystème endémique de Madagascar: écologie, fonctions, causes de dégradation et de transformation. Biotechnol. Agron. Soc. Environ. 16, 541–552.

Reno, W., 2001. The failure of peacekeeping in Sierra Leone. Curr. Hist. 100, 219–225.

Saura, S., Martinez-Mlian, J., 2001. Sensitivity of landscape pattern metrics to map spatial exten. Photogramm. Eng. Remote Sens. 67, 1027–1036.

Sidibé, M., 2005. Migrants de l'arachide: la conquête de la forêt classée de Pata, Casamance, Sénégal. IRD, Paris.

Smouts, M.C., 2000. Un monde sans bois ni lois. La déforestation des pays tropicaux. Crit. Int. 9, 131–146.

Sørensen, T., 1948. A method of establishing groups of equal amplitude in plant sociology based on similitary of species content. Det kongelige danske videnskabernes selskab. Biol. Skr. 5, 1–34.

Streiner, D.L., Norman, G.R., 1989. Health Measurement Scales: A Practical Guide to their Development and Use. Oxford University Press, UK.

Tchatchou, B., Sonwa, D.J., Ifo, S., Tiani, A.M., 2015. Déforestation et dégradation des forêts dans le Bassin du Congo: État des lieux, causes actuelles et perspectives. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

UICN, 2015. The IUCN Red List of Threatened Species. Union International pour la Conservation de la Nature.

Ulanova, N.G., 2000. The effects of windthrow on forests at different spatial scales: a review. For. Ecol. Manag. 135, 155–167.