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Forest Dynamics in the North of the Classified Forest of Haut-Sassandra During the Period of Armed Conflicts in Ivory Coast

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Abstract: Ivory Coast (or Côte d'Ivoire) has experienced a succession of political and military crises from 2002 to 2011. This has resulted in a general degradation of the environment. In rural areas, the natural formations such classified forest of Haut-Sassandra (CFHS) in the West Central, underwent severe human pressure. This study, which took place in the northern part of the CFHS, aimed to determine the spatial and temporal evolution of the forest and its floristic composition during this time of conflicts. Two satellite images dated from 2001 and 2013 were the subject of a supervised classification from the maximum likelihood algorithm. Floristic surveys were used to determine the current state floristic diversity of CFHS compared to the situation prior to the conflicts. The results show that forest areas, representing 94 % of the area in 2001, increased to 34 % in 2013, representing an annual rate of 5 % of deforestation. About 13 % of species recorded before the conflict had disappeared in 2013. However, with 239 inventoried northern of CFHS remains a refuge area of the Ivorian plant diversity.

Keywords: Armed Conflicts, Human Pressure, Spatial Transformations, Flora, Endemic Plant Species

1. Introduction

The biodiversity of forest ecosystems is a wealth for local population and the rest of humanity. The deforestation in tropical areas is hence at the center of international debate on the conservation of natural resources [1]. Yet the majority of developing countries, especially in tropical areas are familiar with high rates of deforestation and forest degradation [2]. Countries that have the most difficulty in maintaining their forest patrimony are those where poverty is highest and / or who are affected by armed conflicts [3]. These countries constitute a fertile ground for the development of inequality and corruption leading to illegal exploitation of natural resources, particularly forest. Ivory Coast or Côte d'Ivoire has experienced since 2002 a series of political and military crises. Several actions were taken in order to achieve peace and social balance but have not always incorporated the protection of protected areas. During these conflicts, pressures on these environments have increased, affecting the functioning of these ecosystems; however, no studies have been conducted to date in order to assess the impact on forest ecosystems.

The classified forest of Haut-Sassandra (CFHS), located in the West Central, is one of the most important biodiversity areas in the country and is a suitable site to conduct such an assessment. Before the outbreak of conflicts, CFHS housed 25.4 % of plant species present in Ivory Coast [4] including 68 West African endemic plant species and 8 Ivorian endemic plant species (*Chrysophyllum taiense, Eugenia tabouensis, Geophila afzelii, Gymnostemon zaizou, Hibiscus comoensis, Piptostigma fugax, Psychotria abouabouensis* et *Sapium aubrevillei*) [5]. These species represent 10.8 % of the Ivorian endemic species.

The Ivorian crisis gave rise to a partition of the country with

roughly, the North, Centre and West under occupation of rebel groups, and other parts in government administration. CFHS was under the legal authority but was also the border between rebel areas and the part under government control during the conflicts. Near rebel areas, CFHS remained without legal forest authority and therefore experienced a disruption of conservation activities. Thus, illegal installations have occurred in this forest, favorable to its degradation. Large movements of population fleeing the fight zones have also been observed in this region.

Our research hypothesis was that in the west, the absence of forest authority during the period of political and military crises has encouraged deforestation of protected areas in the region, leading to disappearance of plant species.

The objective of this study was to determine the dynamics of the northern part of the CFHS, transitional space between government and the area under rebel control. This was to evaluate the evolution of the area and the floristic composition of the forest at the end of ten years of armed conflicts.

2. Material and Method

2.1. Location of Classified Forest of Haut-Sassandra

CFHS located in the West Central (Fig. 1), since 1974 belongs to the permanent forest domain of the Ivorian state. It is located between 6° 52' and 7° 24' north latitude and 6° 59' and 7 ° 10' west longitude. It covers an area of 102,400 hectares and belongs to the administrative departments of Vavoua and Daloa. The climate is bimodal Guinean forest. The temperature minima average monthly between 2002 and 2013 was 22° C; maximum temperatures oscillate between 28 and 35° C. This forest belongs to the mesophilic sector of Guinean domain, characterized by dense semi-deciduous forest at *Celtis* spp and *Triplochiton scleroxylon* [6].

2.2. Data Collection

2.2.1. Satellite Data and Classifications

Two multi-spectral satellite imagery from SPOT sensor, dating from December 2001 (SPOT 4, 20 m resolution) and December 2013 (SPOT 5, 10 m resolution) covering the northern part of the CFHS were used. The spectral data have been corrected before distribution by the supplier, avoiding the geometric and radiometric corrections before their exploitation. However, to facilitate comparison, the images will not have the same resolution; we conducted resampling of the image of 2001 to 10 m resolution by the nearest neighbor method. Then a color combination in false colors on the images obtained from the combination of bands XS3 / XS2 / XS1 was performed. These bands correspond to the spectral bands of the near infrared, red and green. Training plots of 600 to 900 m^2 have been delimited on this combination for different classes selected for the classification. The choice of classes results of field observations and documentation such as the work of [7]. These are the classes «dense semi-deciduous forest on land», «forest on hydromorphic soils», «crop» and «degraded forest». A supervised classification from the maximum likelihood algorithm was carried out. After classification, confusion matrix and Kappa coefficient was calculated to verify the performance of our classification. These operations were made for the 2013 image from 30 control plots of 400 m^2 each, delimited during field missions. The control plots for 2001 image have been delimited on the basis of work already carried out in the study area [7]; [1]. Image processing was done using ENVI 4.4 software.

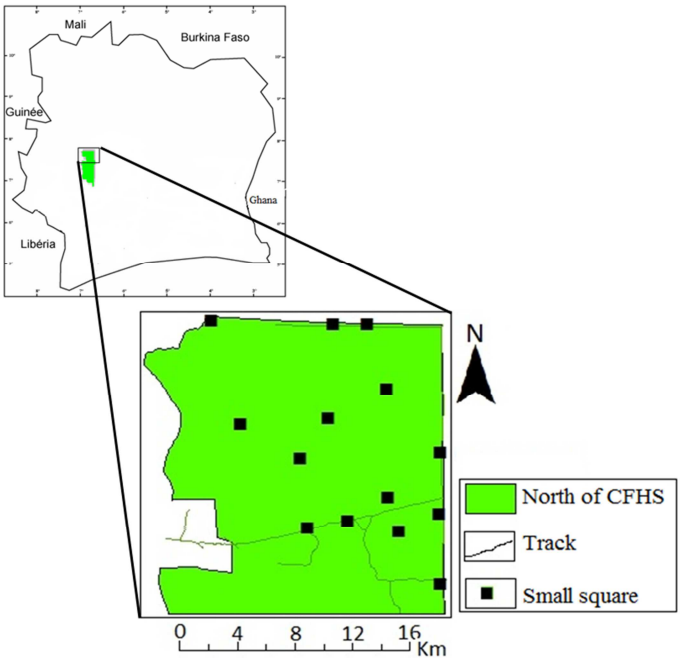

Figure 1. *Presentation of the study area and floristic survey sites.*

2.2.2. Phytosociological Inventories

Sampling sites were chosen after analysis of the land use map of CFHS taking into account the types of forest classes and accessibility. After analysis, 14 sites were chosen on each of which a small square of 20 m x 20 m was materialized (Fig. 1). Flora inventories were conducted in plots by collecting samples of all species encountered. Species lists were supplemented by species obtained from surveys conducted between plots. The different samples were used in the making herbarium before identification at the National Floristic Center of Felix Houphouet Boigny University in Abidjan. The scientific work treat of the floristic composition of the study area before the starting of crises in Ivory Coast have been exploited [5]; [4]; [7]. These data were compared to ours in order to analyze the change in the floristic composition of the CFHS during the conflict.

2.3. Data Analysis

2.3.1. Satellite Data

Many indices have been designed for the vegetation study from satellite data. They were classified into families according clues of whether they take into account external factors to plant cover such as the influence of atmosphere, the soil spectral contribution, the water content of plants. The NDVI (Normalized Difference Vegetation Index) calculated from red and near infrared bands permit to measure the greenness of forests in a given area, and indicates the vegetation mass present in it. However, errors resulting from the atmospheric correction can affect this index [8]. Other indices such as the EVI (Enhanced Vegetation Index) are less affected by this problem. Calculated using near infrared and blue bands, the EVI corrects the combined effects of soil and the atmosphere. Compared to NDVI, EVI does not saturate in areas with high biomass and should be adapted in our study area under humid tropical climate. However, SPOT5 sensor imagery does not have a blue spectral channel does not allow the use of the EVI. In any case, the NDVI and EVI are both suitable for the detection of changes in land cover [9]. Thus, we calculated and compared the images NDVI of 2001 and 2013. The NDVI is calculated according to equation 1:

$$NDVI = \frac{PIR-R}{PIR+R} \quad (1)$$

2.3.2. Floristic Data

The collected botanical data were used to determine the present floristic composition of our study area. Endemic species were also determined and their typology was obtained based on the IUCN Red List [10]. Changes in the floristic composition of our study area were identified by comparing our data with those from the work done in the study area before the conflict by [5] and [4]. The Sørensen similarity coefficient was calculated to quantify the degree of resemblance of the two lists. It is obtained as follows:

$$Ps = \frac{2c}{a+b} \times 100 \quad (2)$$

with PS the Sørensen similarity coefficient; a, the number of species at the end of conflicts; b, the number of species before the conflict; and c, the number of common species to both periods. A comparison of the lists of endemic species and dominant families was assured. We considered dominant family every family whose species number collected was greater than or equal to 10.

3. Results

3.1. Composition of the Landscape and Spatial Dynamics

Table 1. *Confusion matrix (percentage of pixels) of 2001 and 2013 image classification.*

2001	Classes	Dense forest	Forest on hydromorphic soil	Crop-degraded forest
	Dense forest	88.08	10.18	1.60
	Forest on hydromorphic soil	9.79	85.42	11.64
	Crop-degraded forest	2.13	4.40	86.76
	Kappa Coefficient		0.75	
2013	**Classes**	**Dense forest**	**Crop-degraded forest**	
	Dense forest	88.96	6.94	
	Crop-degraded forest	11.04	93.06	
	Kappa Coefficient		0.80	

Table 2. *Area of land cover classes (in hectare), the proportion (in brackets) in 2001 and 2013 and their rates of evolution.*

	2001	2013	Rate of change between 2001 and 2013
Dense forest	15005 (49.51 %)	10400 (34.32 %)	-30.69 %
Forest on hydromorphic soil	13771(45.44 %)	0.00 (0.00 %)	-100 %
Crop-degraded forest	1531 (5.05 %)	19907(65.68 %)	1200.64 %

The Kappa coefficient obtained from the confusion matrix (Table 1) of 2001image classification was 74.9 %. All classes were relatively classified well, the best pixel classification rate in class « dense forests » (88.1 %), while 11.6 % of the pixels belonging to the class «forest on hydromorphic soils » were classified in class «crop-degraded forest». The resulting confusion matrix for 2013 image classification (Table 1) also reflects a good performance with a value of Kappa coefficient of 80.4 %. In 2013, the class « forest on hydromorphic soils » has disappeared of the forest landscape and only the classes «dense forests» and «crop-forest degraded» were still visible in the landscape. Despite the high value of the Kappa coefficient, confusion was observed

between these two classes, with 11.0 % of pixels to the class «degraded forests» classified in «dense forest» and 6.9 % of pixels of «dense forests» class put into the « crop-degraded forest » class. The land cover map of 2001 (Fig. 2, map A) showed a landscape in which forests represented 94.9 % of the matrix (Table 2). Large forests on hydromorphic soils were located in the northern part of the study area around the rivers. In 2001, only 5 % of the landscape was occupied by crops (Table 2). In 2013, the landscape matrix now consists of «crop-degraded forests» (Fig. 2, map B) with a proportion of 65.7 % at the expense of «dense forest» (34.3 %) (Table 2). Cultivated areas and degraded forests exhibit a growth rate of 1200 % against a sharp decline of forest areas marked by a 30 % regression rate. These are now represented by forest fragments and occupy only 34 % of the total superficies of study area, against 94 % in 2001 (Table 2). This conversion of forest areas is confirmed by the values of NDVI of the two images. Calculating means NDVI values gives a value of 0.319 for 2001 image, and 0.044 for 2013 whither 86.2 % regression.

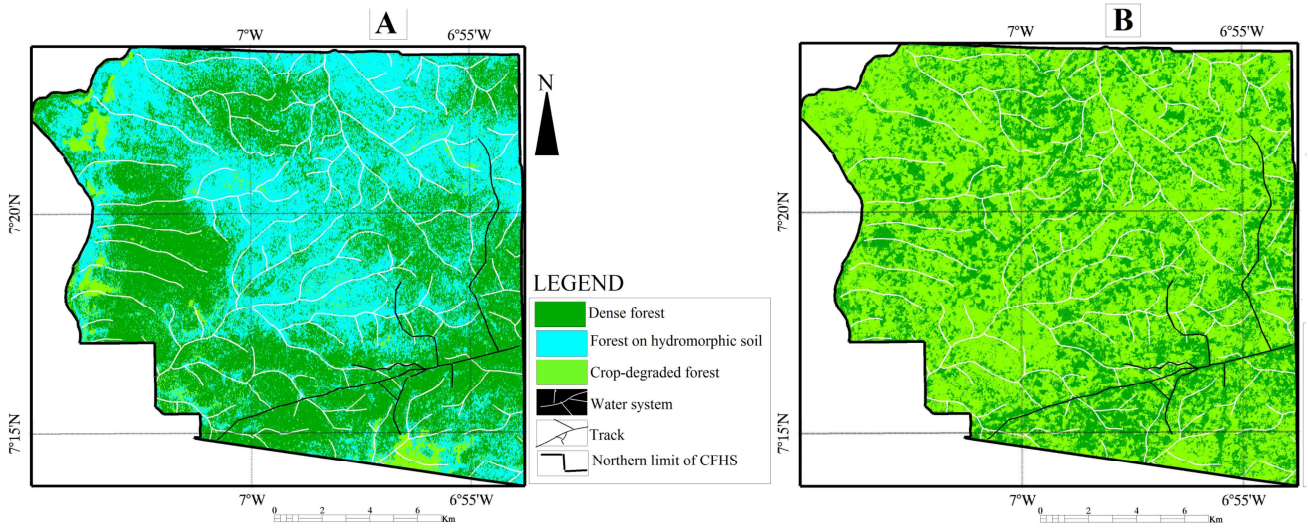

Figure 2. *Land use map of 2001 (A) and 2013 (B) in northern classified forest of Haut-Sassandra.*

3.2. Floristic Diversity

The synthesis of the literature on the northern part of CFHS before conflicts in Ivory Coast has identified 273 species distributed among 200 genera and 59 families (Table 3). Of the 273 recorded species, three are endemic to Ivory Coast: *Eugenia tabouensis* (Myrtaceae), *Gymnostemon zaizou* (Simaroubaceae) and *Septum aubrevillei* (Euphorbiaceae). The most represented families were decreasing order Rubiaceae, Annonaceae, Fabaceae, Hippocrateaceae, Mimosaceae, Euphorbiaceae, Apocynaceae, Caesalpiniaceae and Sterculiaceae (Table 3). The inventories carried at the end of the decade of conflicts identified 239 species distributed among 179 genera and 61 families (Table 3). The most represented families in number of species were Rubiaceae, Euphorbiaceae, Fabaceae, the Sterculiaceae, the Apocynaceae and Moraceae (Table 3). The floristic list at conflicts end presented three Ivorian endemic species: *Ficus bongouanensis* (Moraceae), *Baphia bancoensis (Fabaceae)* and *Chrysophyllum taiense* (Sapotaceae). The list also presented West African endemic species, rain forest species of Guinea-Congo region, the common species at the Guinea-Congo region and the Sudan-Zambezian region, species of Sudano-Zambezian region (savannas and open forests) and introduced or cultivated species (Fig. 3).

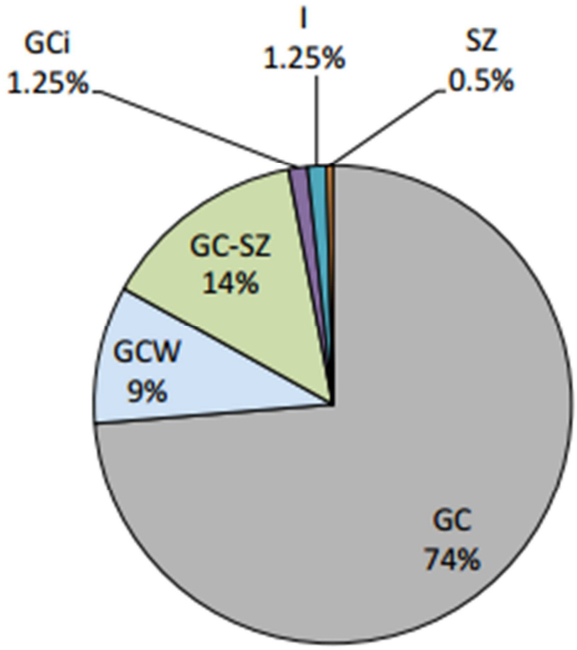

Figure 3. *Chorological affinities of northern species of the classified forest of Haut-Sassandra after conflicts in 2013. GC: rainforest species of Guinean-Congolese field; GC-SZ: species common to the Guinea-Congo region and the Sudan-Zambezian region; GCW: West African endemic species; GCi: Ivorian endemic species; SZ: species of the Sudano-Zambezian region I: introduced species or cultivated species.*

Table 3. *Diversity of classified forest of Haut-Sassandra before and after the period of conflicts.*

Families	Number of species		Families	Number of species	
	Before conflits	After conflits		Before conflits	After conflits
Acanthaceae	4	4	Malpighiaceae	2	1
Amaranthaceae	1	0	Malvaceae	0	3
Amaryllidaceae	0	1	Marantaceae	3	3
Anacardiaceae	1	2	Melastomataceae	2	1
Annonaceae	16	10	Meliaceae	0	7
Apocynaceae	12	10	Menispermaceae	1	4
Araceae	1	2	Mimosaceae	15	6
Asclepiadaceae	4	6	Moraceae	8	11
Asteraceae	1	1	Myristicaceae	1	1
Balanophoraceae	0	1	Myrtaceae	1	0
Bignoniaceae	4	2	Napoleonaeaceae	0	1
Bombacaceae	2	1	Ochnaceae	2	0
Boraginaceae	2	3	Olacaceae	2	3
Buxaceae	2	1	Opiliaceae	1	0
Caesalpiniaceae	11	9	Orchidaceae	0	1
Capparidaceae	5	3	Pandaceae	1	1
Caricaceae	0	1	Passifloraceae	2	2
Cecropiaceae	0	2	Periplocaceae	0	1
Chrysobalanaceae	0	1	Poaceae	5	7
Clusiaceae	1	0	Phytolacaceae	1	0
Combretaceae	6	5	Polygalaceae	1	0
Commelinaceae	0	1	Rhamnaceae	3	0
Connaraceae	2	4	Rubiaceae	23	16
Convolvulaceae	4	3	Rutaceae	4	3
Cucurbitaceae	1	1	Sapindaceae	9	5
Dichapetalaceae	2	0	Sapotaceae	4	6
Dioscoreaceae	4	4	Simaroubaceae	2	1
Dracaenaceae	2	0	Smilacaceae	1	0
Ebenaceae	4	7	Sterculiaceae	11	12
Euphorbiaceae	13	11	Tiliaceae	4	4
Fabaceae	16	12	Ulmaceae	5	5
Flacourtiaceae	3	4	Urticaceae	0	1
Hippocrateaceae	16	7	Verbenaceae	3	1
Icacinaceae	3	1	Violaceae	6	5
Irvingiaceae	2	1	Vitaceae	3	2
Ixonanthaceae	0	1	Zingiberaceae	1	3
Lecythidaceae	1	0			

4. Discussion

4.1. Spatial Evolution of the Forest

Using remote sensing for characterizing changes in CFHS allowed to characterize the spatial and temporal evolution of this forest. A classification of the remote sensing images has highlighted the evolution of each thematic class during the study period. In 2001, a prevalence of the rainforest and the forest on hydromorphic soils in northern CFHS was observed. However, we noted that there were some farm plots inside the forest, suggesting that populations had started penetration this forest for agriculture prior conflicts, as observed by [7] and [1]. These agricultural zones are generally located on the outskirts of CFHS, and consequently, come into contact with the rural sector (Fig. 2, map A). There were little or no farms in the heart of the forest. At that time, the human impact on the reserved forest was mainly due to the extension of plantations of perennial crops (coffee and cocoa) maintained by indigenous populations living in enclaves, including that Gbeubly located north of classified forest. However, [11] argued that despite its cover forest was radically modified, this same forest has not been the cause of the anthropisation of the classified area. Until 2001, conversions of forests surfaces were exclusively happening inside the enclave. Classified forest infiltrations would be rather the fact of non-indigenous populations in search of arable land. Changes in the forest cover of the CFHS were not solely due to agriculture, but were also the result of logging. This forest harvesting was entrusted to a private company (named SIFCI), which, in turn, was expected to undertake forest management. The establishment of this company resulted in forest degradation or conversion of the forest cover to a savannah system [1]. After conflicts, the land use map revealed a fragmented forest landscape with an extension of agricultural plots to the detriment of the forest. This fact is borne out by 86.2 % decrease in the NDVI, compared to its value in 2001. However, decreases in the NDVI does not equate to a decrease in vegetation, because this index is likely to be influenced by climate-related factors such as precipitation [9]. Precipitation data of our study area showed little variation between the two periods under

consideration. In December 2001, zero precipitation was registered, while in 2013 only 6 mm of precipitation was registered.

During conflicts, populations penetrated the classified forest, mainly because forest policy agents were mobilized on the various war fronts. During this period, forest areas declined to more than 30 % of the original cover (Table 2) in our study area, with a "disappearance" of the «forest on hydromorphic soils». The absence of this class in 2013 could be linked to the classification method used. In fact, the sizes of island forest on hydromorphic soils that are still likely to be found in northern CFHS are smaller than 100 m² (pixel resolution), and does not allow the classification algorithm to create a homogeneous class. Using a finer-resolution image (2.5 m) would help correct this artifact. Despite this probable error, the «forests on hydromorphic soils» observed before the beginning of conflicts disappeared from the CFHS in 2013. Indeed, during our field visits, we noted that there were cocoa crops in river beds or grasses will significantly different from «forest on hydromorphic soils». This decline in the forest area is part of the spatial dynamics of forests worldwide, and particularly in Africa. The net loss of forest area per year is estimated at 5.3 million hectares for the whole of Africa that is 0.78 % of the total forest area [12]. West African forest countries are the most affected by such decline [13]. In this area, the loss of forest cover is essentially caused by agriculture. Indeed, indigenous people consider the forest as a setting with the most suitable lands for farming. As a matter of fact, forest ensures soil fertility, lowers the proliferation of weeds and insects, favors good moisture retention, limits the effect of wind and erosion, etc. [14]. Indigenous people believe that cocoa, for example, can only be sown on a newly deforested plot. In such process, and in striving to increase their production or renew their old orchards, farmers are constantly clearing sites, therefore reducing protected areas. Consequently, the forest is now replaced by cocoa plantations. Degraded forests shown by 2013 map are just the first phase of the introduction of cocoa farming. Indeed, this class shows crops under forests. Due to their illegal presence in this protected area, farmers strive to keep the forest landscape intact in the early stages of plant development in order to cover them up. The cocoa tree is a rainforest plant, and this cultivation technique serves it well. In this context, if action is not taken to curb human intrusion in our study area, the whole surface will be covered by crops.

4.2. Analysis of the Floristic Composition of the Classified Forest

Sampling conducted before conflicts outbreak has given a total of 273 species [5] of which 106 are common to our list obtained at the end of conflicts. Sørensen similarity coefficient (41 %) calculated based on the two lists is less than 50 %. This floristic dissimilarity appears in Table 3. The Moraceae family, poorly represented in 1998 represented a significant proportion (4.06 %) in the current list to the point of being part of the ruling families, and may result from changes in environmental conditions [15]. At local scale, northern CFHS is currently dominated by cocoa plantations. This conversion of forest cover leads to a proliferation of species adapted to environmental constraints attached to it. The Rubiaceae family remained the best represented, confirming the membership of the CFHS to the Guinea-Congolese region that has the right conditions for the proliferation of Rubiaceae [5]; [16]; [17]. Nine endemic species to West Africa and three endemic to Ivory Coast before the conflicts identified in CFHS were not found in the current list (Table 4). We only inventoried the northern CFHS, cumulating in plots surface 9200 m^2 and transects which, placed end to end, reaching 2300 m. But one of the direct consequences of human impact on protected areas during the conflicts seems to be changing biodiversity according to what is generally observed in protected areas of West Africa [18]; [19]; [20]. Although much of the CFHS has been converted to crops, it has kept a high species richness with 239 species against 273 species over 10 years earlier. However, species richness is not always synonymous with diversity [20]. Indeed, environment anthropisation could bring up a new procession of pioneer species and / or better adapted to the disturbed environment [21].

Table 4. *List and status of West African endemic species (GCW) and Ivorian (GCi) present in Northern classified forest of Haut-Sassandra in 1998 (before conflicts) and have not been found in 2013 (after conflicts).*

Espèces	Familles	Statut
Afzeliabella var. gracilior	Fabaceae	GCW
Caloncoba echinata	Flacourtiaceae	GCW
Crossostemma laurifolium	Passifloraceae	GCW
Dialium aubrevillei	Caesalpiniaceae	GCW
Diospyros vignei	Ebenaceae	GCW
Drypetes ivorensis	Euphorbiaceae	GCW
Eugenia salicioides	Myrtaceae	GCW
Eugenia tabouensis	Myrtaceae	GCi
Gymnostemon zaizou	Simaroubaceae	GCi
Sapium aubrevillei	Euphorbiaceae	GCi
Uvariodendron occidentalis	Annonaceae	GCW
Whitfieldia colorata	Acanthaceae	GCW

4.3. Conflict, Dynamics of Forest Landscapes and Floristic Diversity

African tropical forest ecosystems are recognized for their biodiversity is nonetheless an alarming deterioration. The technical use of existing land in this region of the world, such as slash and burn agriculture and industrial monoculture, lead serious degradation of forest resources [22]. Armed conflict has intensified during the last decade natural resource degradation as to cause a considerable regression of protected areas superficies, a reduction in the density of the tree cover and changes in floristic composition, as has been manifest in the Democratic Republic of Congo [23]. This human pressure can lead to savannah forest landscape [19]. The main effect of human impact is the dominance of species with high growth capacity to the detriment of competitors within species [24] as is the case in tropical forest [25] and therefore in the CFHS, changing this protected area.

4.4. Armed Conflicts and Protected Areas

Logging and forests destruction to other purpose threaten greatly the preservation of several protected areas in Africa [26]. This is mainly due to the strong increase in population but also problems of political instability. Conflicts lead to destruction of these areas invaded by population looking for new farmland. The displacement of populations during armed conflicts periods causes changes occupation mode of space that affect land systems and exploitation of natural resources. In CFHS, these changes have led to environmental degradation reducing the forest cover. In the Haut-Sassandra region in general, human action was accentuated by the dispossession of landowners in the conflict period, which has resulted in extensive land clearing.

5. Conclusion

This study highlighted the large spatial configurations of different classes of land use and the development of their respective superficies to the northern part of the CFHS during the conflicts in Ivory Coast. The results obtained from the images classifications from 2001 and 2013 show a significant decline in forest area of this protected area for the benefit of agricultural areas. Indeed, over 60 % of forest surface were converted to agriculture land or degraded forest during and after decade of conflicts. Regarding the floristic composition of this area, 12.4 % of the species appear to have disappeared during the crisis. Restoration and conservation measures should be taken to safeguard the still existing forest relics and rebuild areas covered by agriculture

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