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Dynamics of supply services provided by a protected forest in Côte d'Ivoire

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The classified forest of Haut-Sassandra (CFHS) located in the Center-West of Côte d'Ivoire was infiltrated by the population for agriculture in the 2000s. This forest, initially devoted to timber production before its degradation, is today a vast cocoa-growing area associated with food crops, mainly plantains. The objective of the present study is to assess the overall production of wood, cocoa, and plantain in this state-owned area before (2000) and after its degradation (2019). Processed satellite images covering the CFHS showed an increase in anthropogenic vegetation classes and a decrease in the forest cover class from 2000 to 2019. These transformations resulted in an expansion of cocoa (from 146 t to 18,384 t) and plantain production (from 3,087 t to 187,061 t) at the expense of logging in the CFHS, 16,388 and 3,844 m^3 respectively in 2000 and 2019. In addition, there was a loss of about 57% of the expected income from the sale of timber and a 15,912% increase in profits from the sale of agricultural products in 2019 compared to 2000. In such circumstances, it is recommended to implement a sustainable cropping system that will integrate timber production and agricultural production within the same area.

Key words: Ecosystem service, timber, cocoa production, plantain, anthropogenic pressure, Côte-d'Ivoire, West Africa.

INTRODUCTION

Ecosystems provide different services to society (MEA, 2005; Fisher and Turner, 2008; TEEB, 2010; Maresca et al., 2011). These services, known as ecosystem services, are subdivided into four categories: supporting,

provisioning, regulating, and socio-cultural services (MEA, 2005). However, the rapid growth of the human population in recent centuries, from 1 billion people in 1800 to 7.7 billion in 2019 (Pison, 2019), is leading to overexploitation of ecosystems for the provision of raw materials for both food and amenities. Thus, while some of the ecosystems are still natural, most of them have been profoundly transformed (IUCN, 2012; Leménager et al., 2014).

Côte d'Ivoire, a tropical African country whose forest ecosystem amounted to 15 million ha in the 1900s (SODEFOR, 1996), was only around 3 million ha in 2015 (FAO, 2017). Several forest areas have been destroyed and transformed either into farms (food, commercial or agro-industrial plantations) or fallow land (Yeo et al., 2011; Gone Bi et al., 2013; Koné et al., 2014). To ensure the sustainability of its natural resources, the country has set up protected areas, consisting of 231 classified forests and 8 national parks, which were considered the last remnants of the dense Ivorian forest (Ministry of the Environment, 1996; Amani, 2011). These state-owned areas in general, and the classified forests, particularly, were relatively well conserved and provided timber for the management structure of Côte d'Ivoire's classified forests (SODEFOR). However, due to the anarchic exploitation of village estate forests, these protected areas became the target of farmers who settled there and rapidly developed farm activities (Oszwald, 2005), especially cocoa (Higonnet et al., 2019). This situation worsened from 2002 to 2011 with the weak presence of SODEFOR in the classified forest of Haut-Sassandra (CFHS) and the inefficiency of state institutions due to the political-military crisis in Côte d'Ivoire (Kouakou, 2019).

Several studies have shown that the CFHS is increasingly subject to anthropogenic disturbances linked to the development of cocoa farming (Koua et al., 2017; Kouakou et al., 2017) associated with food crops, the main one being plantain. Thus, the CFHS, originally devoted to timber exploitation and biodiversity conservation before its degradation, is now a large cocoa field associated with plantain banana. This situation leads to several questions. What would be the impact of anthropogenic pressure on the economic value of the CFHS? In other words, are the benefits of exploiting the CFHS when it was relatively well conserved (2000) more important than today? The present study, therefore, aims to assess the overall production of timber, cocoa, and plantain provided to the manager and the local populations by the CFHS before (2000) and after (2019) anthropogenic pressure. Specifically, it will include: (1) determine the areas occupied by CFHS land use classes in 2000 and 2019; (2) quantify the volumes of timber, cocoa, and plantain in the CFHS from 2000 and 2019

and evaluate their monetary value during this period.

MATERIALS AND METHODS

Presentation of the study area

The classified forest of Haut-Sassandra (CFHS), named after the Sassandra River which forms its western limit, is a classified forest of the State Permanent Forest Domain of Côte d'Ivoire. It is in the central-western part of Côte d'Ivoire between 6°50' and 7°24' north latitude and 6°51' and 7°05' west longitude (Figure 1). Delimited and classified in 1974, the CFHS covers an area of 102,400 ha (SODEFOR, 1994). It has been managed by SODEFOR since 1992. The vegetation described in 1998 is of a semi-deciduous forest type. The upper layers include the characteristic species of the association *Triplochiton scleroxylon, Celtis adolphifridericii, Celtis zenkeri* and *Celtis milbraedii* (SODEFOR, 1994) to which numerous species are added, most of them having an important commercial value. The surrounding population of the CFHS is cosmopolitan, consisting of people from the West African zone. The populations living near the classified forest are mainly engaged in subsistence agriculture as well as in the cultivation of cocoa (*Theobroma cacao* Linn.) and coffee (*Coffea* sp.) trees.

Determination of spatial-temporal dynamics of the CFHS land use classes from 2000 to 2019

To determine the CFHS land cover classes in 2000 and 2019, two multispectral Landsat satellite images with a spatial resolution of 30 m were used. The 2000 image is from the « Thematic Mapper » (TM) sensor and the 2019 image is from the « Operational Land Imager-Thermal Infrared Sensor » (OLI-TIRS) sensor. Image processing was done using ENVI 4.7 and QGIS 2.14.3 software. Processing in ENVI involved extracting the CFHS from the entire scene, performing the CFHS color composition, and supervised classification using the maximum likelihood algorithm using ground truth points. The accuracy of the classification was estimated using confusion matrices. For each map, the Kappa coefficient and the overall precision were calculated. Transition matrices were generated to identify the transition frequencies between land-use types from 2000 to 2019 to understand the evolving landscape composition in these periods. The land use types selected for this study are "Forest", "Fallow", "bare soil-habitat", "Cocoa plantations 1 to 5-year-old", "Cocoa plantations 6 to 10-year-old" and "Cocoa plantations more than 10-year-old". This classification of cocoa trees is justified by the production phase of this crop. Indeed, between 1 and 5 years, the crop is young; between 6 and 10 years, it is considered mature and after 10 years, the crop is considered as adult (Koulibaly, 2008). The type "bare soil-habitat" corresponds to bare areas as well as dwellings. The type "Fallow" represents abandoned areas after anthropogenic activities.

Quantification and monetary valuation of timber, cocoa, and plantain from the classified forest of Haut-Sassandra in 2000 and 2019

Data collection

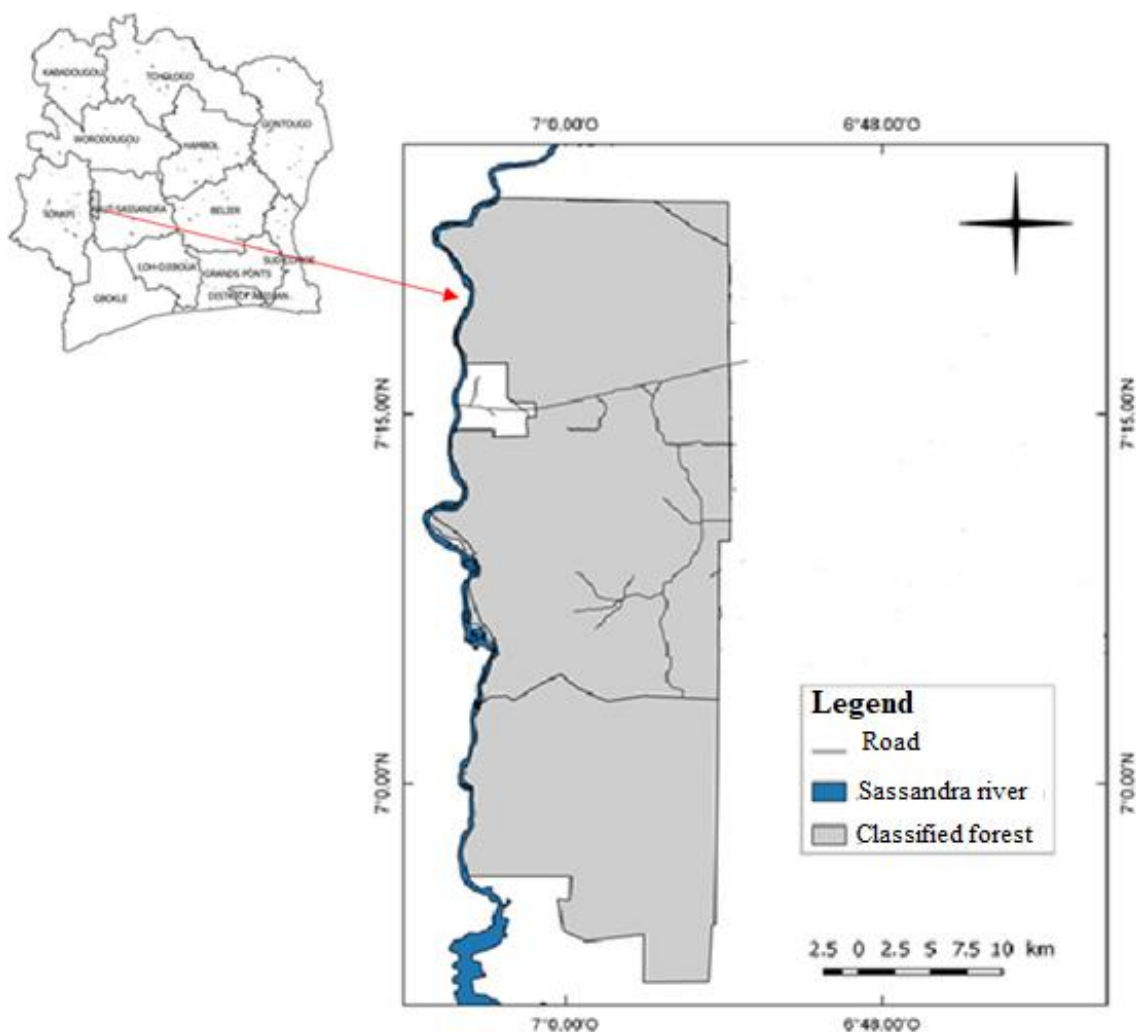We conducted a literature search to assess the timber provided to

Figure 1. Location of the classified forest of Haut-Sassandra in Côte d'Ivoire.

the manager. The source of information was the SODEFOR archive. The literature review included the following: (1) the species exploited as timber in the CFHS in 2000 and 2019; (2) the volume of timber logged in 2000 and 2019; and (3) the economic value of the timber exploited in 2000 and 2019. The quantification of cocoa and plantain from the CFHS was carried out by an individual survey of the populations infiltrated in the area using a socioeconomic questionnaire of the direct type. These surveys aimed to determine the yield of cocoa beans (*Theobroma cacao*) and plantain (*Musa paradisiaca*) in the CFHS in 2019. Cocoa speculation was considered to be the one that changed the landscape of the CFHS (Timité et al., 2019) as well as plantain, the main cocoa-associated species used as a food source by the riparian populations of the CFHS (Assalé et al., 2020). The yields of the cocoa bean and plantain banana farms produced per unit area were extrapolated over the entire CFHS in 2019 and 2000, considering the surface areas covered by the farms during these two periods based on the classification of the images.

Practically, an individual survey was carried out among farmers owning at least one farm in the mentioned forest to determine the yield of cocoa beans and plantain bananas of the farms present in the CFHS in 2019 based on their age classes. The empirical or non-probability sampling method was used to interview the maximum number of individuals from the target population. In total, a random number of 143 people were interviewed to overcome the unavailability of the number of people owning exploitation within the CFHS. The questionnaire aimed to obtain biophysical and functional information from farms. In fact, it was intended to quantify cocoa and plantain supplied by the CFHS. Thus, the questions focused on the age, area, and the annual yield of cocoa beans and plantain bananas.

The documentary research was carried out to determine the economic value of cocoa and plantain supplied by the CFHS in 2000 and 2019. It consisted of determining the average price per kg of cocoa set at the national price in 2000 and 2019. The price per kg of cocoa was 325 FCFA (1 FCFA = € 655.957) in 2000 and 750

FCFA in 2019. For plantain, the price per kg of banana was derived from a survey of the local population. It was 25 FCFA in 2000 and 75 FCFA in 2019.

Data analysis

For every identified species, the conservation status as well as the category of exploitation (P1, P2, P3) were determined. The wood species in category P1 correspond to the major species, those in category P2 are sporadically traded species and those in category P3 are related to the species to be promoted. The conservation status referred to rare species as well as species on the IUCN Red List (2015). Rare species were identified according to the research of Aké-Assi (1998, 2001, 2002) while the nomenclature of forest species followed that of Cronquist (1988) which is the latest version of the major classifications of plant species based essentially on morphological, anatomical, and chemical criteria.

The yield was established based on the annual production reported by each farmer. It was calculated according to the following formula:

$$R = (Pt/S) \times 100 \tag{1}$$

With R = Yield (kg/ha/year), Pt = Total production (kg/year) and S = Total area (ha).

The total quantity (kg) of each speculation produced in 2000 and 2019 (Qt) was determined by multiplying the average yield per hectare (R) by the total area of cocoa trees (s) in 2000 and 2019.

$$Qt = R \times s \tag{2}$$

The economic value of timber harvested (EV) in the CFHS was determined by multiplying the total volume of harvested timber (Vt) and the average price per m^3 of harvested timber. The unit of measurement is the FCFA currency (1 FCFA = € 655.957). The economic value (EV) of cocoa and banana production in the CFHS was determined by multiplying the quantity of each agricultural speculation by the unit price of speculation during the period under consideration. The total economic value (TEV) of timber, cocoa, and banana production in the CFHS is determined by combining the economic value of exploited timber production with the economic value of cocoa and plantain production.

Comparison tests are used to highlight relationships between explanatory variables and variables to be explained (Alignier, 2011). They aim to describe the distribution characteristics of a variable through its dispersion parameters (standard deviation, quartiles, minimum and maximum value, etc.) and position (mean, median). In this study, the distribution parameters of the different samples were compared using two statistical tests: standard deviation and analysis of variance (ANOVA). The statistical analyses were performed using the program Statistica 7.1 (Statsoft.Link. 1984-2005).

The normality of the data was verified using the Kolmogorov Smirnov test. To determine the differences in quantities and monetary values of cocoa and plantain by cocoa age class between the years 2000 and 2019, an analysis of variance (ANOVA) was performed on the quantities and monetary values of cocoa and plantain by cocoa age class. Next, when a significant difference is observed between the two periods (2000 and 2019), Tukey's multiple comparison test is performed to determine homogeneous groups. Standard deviation is the most commonly used measure of dispersion in statistics when the mean is used to calculate a central

tendency. It, therefore, measures the dispersion around the mean. In this study, the standard deviation was calculated to measure the dispersions around the mean quantities and monetary values of cocoa and plantain evaluated by cocoa age class in 2000 and 2019.

RESULTS AND DISCUSSION

Land-use in the classified forest of Haut-Sassandra in 2000 and 2019

Digital processing of the 2000 and 2019 images revealed six (06) land-use types: "Forest", "Fallow", "Cocoa plantations 1 to 5-year-old", "Cocoa plantations 6 to 10-year-old", "Cocoa plantations more than 10-year-old" and "Bare soil/Habitat" (Figure 2). The different classifications of these images were evaluated via the confusion matrix through the overall precision and Kappa coefficient (Table 1). The overall accuracy for the 2000 Landsat ETM image was 90.69% with a Kappa coefficient of 81%. The evaluation of the 2019 Landsat OLI-TIRS image gave an overall accuracy of 99.88% with a Kappa coefficient of 97%. These indices reveal a high degree of discrimination between the types defined in the supervised classifications. However, there is some confusion between "Fallow land" and "1 to 5-year-old cocoa trees" in 2000. The rate of confusion is 38.14%. As regards the processing of 2019 images, the greatest confusion is observed for the bare soil/habitat class, which is confused at 12.5% with the "fallow" type. The type "bare soil-habitat" corresponds to bare areas as well as dwellings.

In 2000, the "Forest" type was the dominant matrix of the CFHS landscape with a proportion of 91% (Figure 3). The other types occupied 9% of the landscape. In 2019, the "Forest" type experienced a sharp decline in area and now occupies 7% of the CFHS. On the other hand, the anthropogenic types experienced a substantial increase in surface area and now occupy 93% of the space. The crop class alone occupies 80% of the CFHS. In addition, the 1-5-year-old, 6-10-year-old, and more than 10-year-old cocoa types cover 44, 16, and 17.17% of the CFHS, respectively. The changes among the different land-use types in the CFHS between 2000 and 2019 were highlighted through the transition matrix (Table 2). The transition matrix indicates that 55.63, 6.50, 17.89, 4.97, and 1.24% of the forest type in 2000 were converted to 1-5-year-old, 6-10-year-old, over 10-year-old, bare soil/habitat, and fallow in 2019, respectively. The proportion of the forest type remaining stable is 13% of the existing forest cover in 2000. The largest conversions of the fallow type occurred towards 1-5-year-old cocoa trees (51.59%) and bare soil/habitat (27.74%).
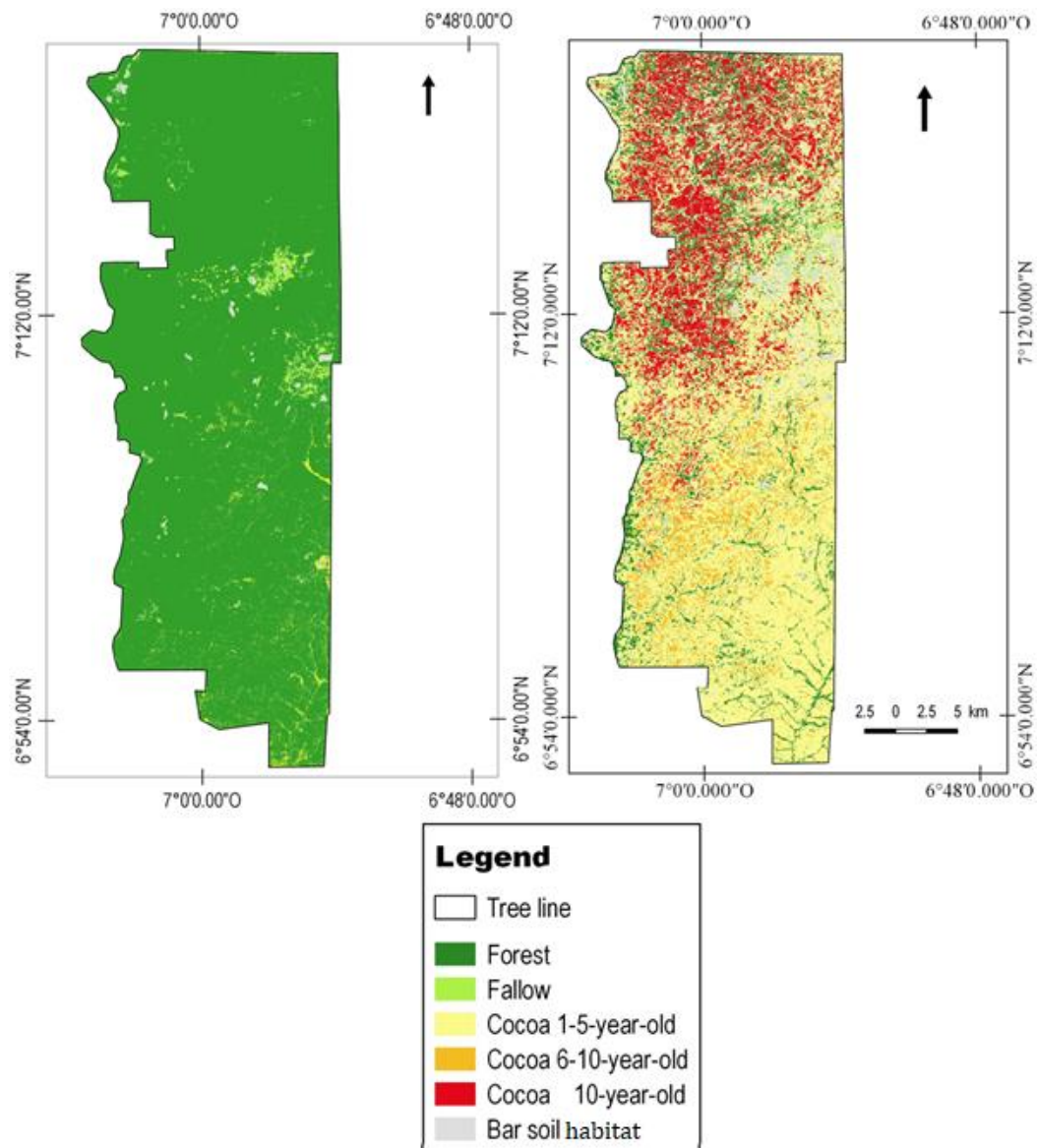
Figure 2. Land use maps of the classified forest of Haut-Sassandra in 2000 (left) and 2019 (right).

Quantification and monetary valuation of timber, cocoa, and plantain supplied by the classified forest of Haut-Sassandra in 2000 and 2019

Data collected from SODEFOR revealed that 28 species belonging to 25 genera and 9 families were exploited in the CFHS in 2000. In 2019, only 2 species belonging to 2 genera and 2 families were exploited in the CFHS (Table 3). The species exploited in 2019 represent 7.14% of those exploited by SODEFOR in 2000. These species

are *Terminalia superba* and *Triplochiton scleroxylon*. The specimens exploited in the CFHS are of 2 categories, the main species (P1) and the sporadically exploited species (P2). Those exploited in 2000 are mainly composed of species of category P1 (89%). In 2019, only P2 species were exploited. Eighteen (18) of the species harvested as timber in 2000 have a special status. They represented approximately 64% of the species harvested. Most of these species are vulnerable (14 species). For the year 2019, one (01) of the two species harvested is at low risk

Table 1. Confusion matrices assessing the accuracy of the supervised classification of the 2000 and 2019 Landsat images of the classified forest of Haut-Sassandra.

2000	Cocoa plantation 1-5-year-old	Forest	Fallow	Bar soil/habitat
Cocoa plantation 1-5-year-old	43.75	0	0	0
Forest	17.71	100	11.43	0
Fallow	38.14	0	88.57	0
Bar soil/habitat	0	0	0	100
Overall accuracy : 90.69 %				
Kappa : 0.81				

2019	Cocoa plantation 1-5-year-old	Cocoa plantation 6-10-year-old	Cocoa plantation >=10-year-old	Forest	Fallow	Bar soil/habitat
Cocoa plantation 1-5-year-old	95.28	0	0	2.78	0	0
Cocoa plantation 6-10-year-old	4.72	100	3.49	0	0	0
Cocoa plantation >=10-year-old	0	0	96.51	0	0	0
Forest	0	0	0	97.22	0	0
Fallow	0	0	0	0	100	12.5
Bar soil/habitat	0	0	0	0	0	87.5
Overall accuracy : 97.22 %						
Kappa : 0.97						

(LR); it is *Triplochiton scleroxylon.*

The volume of wood harvested in the CFHS during both periods is 20,236 m³. However, there is a disparity across the years. While 16,388 m³ of wood was harvested in the CFHS in 2000, the amount was only 3,848 m³ in 2019. Hence, the volume of wood harvested in 2019 represents 23.5% of the amount in 2000. The monetary value of the CFHS estimated from the wood harvested in 2000 is about 48,932,000 FCFA, compared to 21,040,000 FCFA in 2019. There is therefore a loss of about 27,892,000 FCFA or 57% of the profits made in 2000 (Table 4).

The annual average yield of cocoa from the related plantations established in the CFHS is 0.28 t/ha. This rate varies according to cocoa plantation age classes. Maximum yield values are obtained for plantations older than 10 years (0.37 t/ha) and minimum values for those younger than five (05) years (0.16 t/ha). In 2000, for example, the production of the beans in cocoa plantations under 5-year-old was 146.92 t with an average standard deviation of 83.26 t. In 2019, the total quantity of cocoa beans supplied by the CFHS is 18,384.05 t with an average standard deviation of 10,994 t, corresponding to a positive gap of 18,237.13 t between the two dates. The analysis of variance on the mean average quantities of cocoa supplied by the FCHS in 2000 and 2019 indicates a significant difference ($p<0.05$). Thus, the total amount of cocoa supplied in 2000 is statistically different from that supplied in 2019.

For plantain bananas, the average yield is 1.95 t/ha. The average quantity of banana produced is 3.36 t/ha in the youngest cocoa farms (< 5-year-old), 1.82 t/ha in cocoa farms between 6 and 10-year-old, and 0.67 t/ha for those over 10-year-old. Besides, in 2000, the amount of plantain produced in the CFHS was 3,087.02 t with an average standard deviation of 1,779.29 t. In 2019, banana production reached187,061.17 t with an average standard deviation of 94,886 t; that is a
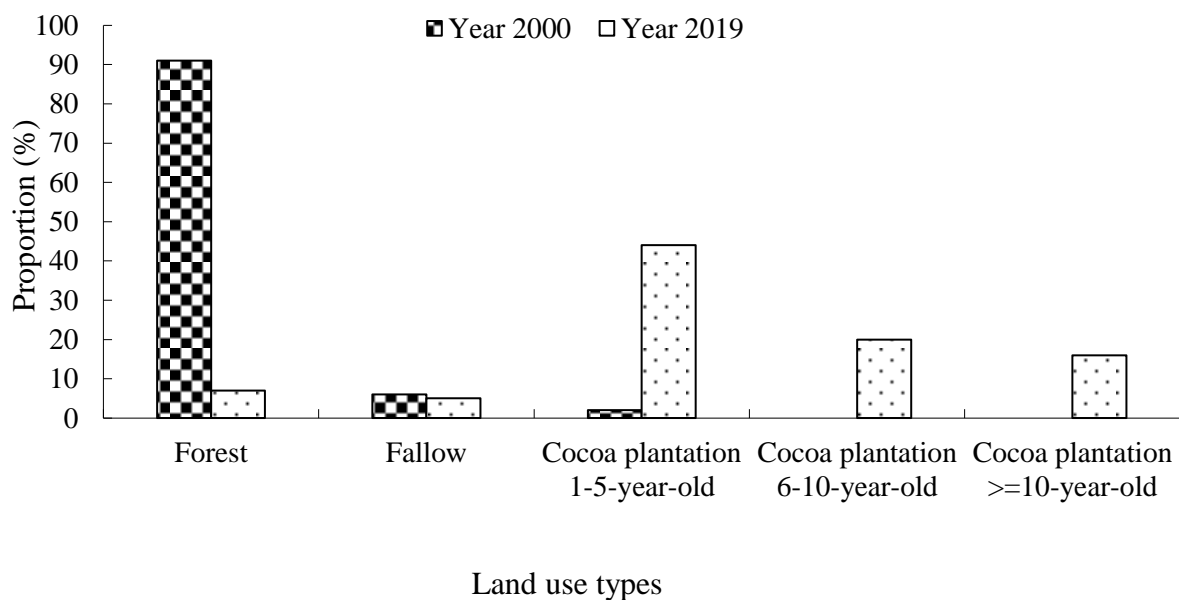
Figure 3. Proportions of land use types in the classified forest of Haut-Sassandra in 2000 and 2019.

Table 2. Transition matrix of land use types for the classified forest of Haut-Sassandra (FCHS) from 2000 to 2019.

	Land use	2000			
		Cocoa plantation 1-5-year-old	Fallow	Forest	Bar soil / habitat
2019	Cocoa plantation 1-5-year-old	71.12	51.59	55.63	7.91
	Cocoa plantation 6-10-year-old	5.51	0.72	6.50	0.04
	Cocoa plantation >=10-year-old	1.73	1.22	17.89	0.04
	Forest	12.57	14.27	13.76	4.22
	Bar soil/habitat	7.44	27.74	4.97	86.54
	Fallow	1.62	4.46	1.24	1.25

that is a difference of 184,574.15 t between 2000 and 2019. The analysis of variance on the average quantities of banana supplied by the FCHS in 2000 and 2019 indicates a significant difference ($p < 0.05$). Thus, the total amount of banana supplied in 2000 is statistically different from that supplied in 2019. The total monetary value of cocoa supplied by the CFHS in 2000 was close to 48 million FCFA (FCFA 47,750,040) with an average standard deviation of about 27 million compared to almost 14 billion FCFA (13,788,037,500 FCFA) in 2019 with an average standard deviation of about 8 billion. Thus, there was a 14.10% gain in profits from the sale of CFHS cocoa in 2000. In addition, there is a significant difference between the monetary values of FCHS cocoa in 2000 and 2019 ($p < 0.05$). The total monetary value

derived from the sale of plantain bananas in 2000 is about 77 million FCFA with an average standard deviation of nearly 44 million. By 2019, this value has increased to about 14 billion FCFA with an average standard deviation of around 7 billion. There is a significant difference between the monetary values of FCHS banana in 2000 and 2019 ($p < 0.05$).

Thus, the total monetary value of the CFHS estimated from the cocoa beans as well as plantain bananas supplied to the local populations in 2000 reached 124,924,640 FCFA with an average standard deviation of about 72 million. In 2019, this value amounted to +/- 28 billion FCFA (27,817,624,974 FCFA) with an average standard deviation of about 15 billion. Therefore, from 2000 to 2019, the CFHS gained monetary value for the

Table 3. Richness, categories, and conservation status of species harvested in the Classified Forest of Haut-Sassandra in 2000 and 2019.

Features	Indicators	Year 2000	Year 2019
Specific richness	Species	28	2
	Genus	25	2
	Family	9	2
Conservation status	LC	1	0
	LR	3	1
	VU	14	0
	Total	18	1
Categories	P1 (%)	89.29	0
	P2 (%)	10.71	100
	Total	100	100

LC: Species of minor concern; LR: Low-risk species; VU: Vulnerable species; P1: Main species; P2: Sporadically exploited species.

riparian populations and this gain is 27,735,674,434 FCFA. In the end, the total economic value (TEV) of timber, cocoa, and plantain from the CFHS in 2000 amounted to ±174 million FCFA (173,856,640 FCFA) versus ±28 billion FCFA (27,838,664,974 FCFA) in 2019, i.e. about 15.91% compared to 2000 (Table 4).

DISCUSSION

Regression of the forest type land use area and increase in the anthropogenic land use type area

The classification of the Landsat 7 ETM+ image covering the CFHS in 2000 reveals a landscape matrix controlled by dense forest (91.39% of the total area of the CFHS). The results confirmed those of N'Guessan et al. (2003), Oszwald (2005), Sangne et al. (2015) and Koua et al. (2017), who revealed that the CFHS in the early 2000s was relatively well conserved. The good state of conservation of the CFHS in the early 2000s is due, according to these authors, to two factors: the proper delineation of the CFHS enclaves and the effective monitoring of the CFHS by the agents in charge of the management of classified forests. In fact, these two factors are reported to have discouraged farmers who would be tempted to set up plantations within the forest (Oszwald et al., 2003). Anthropogenic land use type within the CFHS represented at the time, only about 8% of the total surface area of this state-owned area. The presence of fallow land (6.31% of the area) is related to legal logging (Kouamé et al., 1998) supervised by

SODEFOR.

Unlike the year 2000, the CFHS is considerably degraded in 2019. Indeed, the processing of the Landsat OLI-TIRS image showed that the "Forest" type now occupies 7.24% of this state-owned forest. The anthropogenic land use type constitutes the dominant landscape matrix in the CFHS with a proportion of 92.76% of the space. This strong deterioration of the CFHS in 2019 was mainly due to the infiltration of this domain during the political-military crisis period in Côte d'Ivoire, from 2002 to 2011. Indeed, Barima et al. (2016) have shown that the period of conflicts was pivotal in the degradation of the CFHS. This severe forest damage would be attributed to the absence of security agents (SODEFOR) mobilized on the different fronts during the crises, resulting in massive infiltration of populations within the CFHS in search of land suitable for cocoa production (Kouakou et al., 2015).

This observation is justified by the presence of cocoa trees older than 10-year-old (17% of the area). The high degradation of the CFHS in 2019 is also due to the persistence of anthropogenic activities in the CFHS after conflicts. Indeed, the end of conflicts did not lead to a reduction of deforestation in the CFHS according to Koua et al. (2017). The analyses revealed that younger cocoa trees (1 to 5-year-old cocoa trees) constitute the dominant landscape matrix in the CFHS with a proportion of 44% of the landscape. Thus, after the conflicts, the infiltration into the CFHS continued to the extent that the new matrix of the landscape was transformed from the dense forest type in 2000 to the degraded forest-crop/fallow type in 2015 (Kouakou et al.,

Table 4. Total economic value (TEV) of the classified forest of Haut-Sassandra assessed in 2000 and 2019 from supply services.

	Volume (m³) or amount (t)		Market value (FCFA)	
	2000	**2019**	**2000**	**2019**
Lumber	16 388	3,844	48 932 000	21 040 000
Cocoa				
Cocoa plantation 1-5-year-old	146.92[a] ±83.26	6 754.89[b]±3 827.91	47 749 000[a]±27 058 741	5 066 167 500[b]±2 870 931 574
Cocoa plantation 6-10-year-old	0[a]	5 948.91[b]±3 851.68	0[a]	4 416 682 500[b]±2 888 760 631
Cocoa plantation >=10-year-old	0[a]	5 680.25[b]±3 315.06	0[a]	4 260 187 500[b]±2 486 299 320
Subtotal	146.92[a]±83.26	18 384.05[b]±10 994.65	47 749 000[a]±27 058 741	13 788 037 500[b]±8 245 991 526
Plantain banana				
Cocoa plantation 1-5-year-old	3 087.02[b]±1 779.29	141 931.11[b]±82 725.56	77 175 640[a]±44 982 372	10 644 833 020[b]±6 204 416 960
Cocoa plantation 6-10-year-old	0[a]	34 804.26[b]±10 074.92	0[a]	2 610 320 144[b]±755 618 980
Cocoa plantation >=10-year-old	0[a]	10 325.79[b]±2 086.12	0[a]	774 434 339[b]±156 459 364
Subtotal	3 087.02[a]±1 779.29	187 061.17[b]±94 886.60	77 175 640[a]±44 982 372	14 029 587 474[b]±7 116 495 304
TEV			173 856 640[a]±72 041 113	27 838 664 974[b]±15 362 486 830

TEV = Total Economic Value ; t = Tonne. The same superscript letters (a or b) represent no statistically significant difference in the amount and market values ($p < 0.05$).

2018) and then to the crop-fallow type in 2019. This last observation confirms the results of N'Goran (2010) and Vadrot (2005) who showed that the post-conflict environmental impacts in Côte d'Ivoire are mainly the result of the continuation of those that occurred during the conflict period, namely, the abusive exploitation of natural resources to meet food and energy needs. Moreover, given the state of deterioration of the CFHS, its management would be out-of-control for SODEFOR agents. This similar observation of the ongoing cocoa production in the state-owned areas after the conflicts was reported by Sidibé et al. (2020).

Decrease in logs harvested in 2019 compared to 2000

Digital processing of the 2000 satellite image of the CFHS revealed the dominance of the forest type in the landscape of this state-owned area (91.39% of the landscape). However, the spots of forest found in the classified forests abound with a great floristic diversity (IUCN, 2013), including the high availability of commercial species (Kouamé, 1998). Thus, the availability of harvestable species in the CFHS when it was relatively well conserved favoured the extraction of a substantial volume of timber belonging to a variety of forest

species. Indeed, data collected from the CFHS management structure (SODEFOR) revealed that 28 species belonging to 25 genera and 11 families were exploited in the CFHS in 2000 for a volume of 16,388 m³. Although data on the volume of timber logged in 2019 is not currently available from the CFHS management structure, deductions can be made from the quantity. Indeed, with the radical decreases in forest area recorded in the CFHS, the current volume of exploitable timber would be less than in 2000; since the forest patches are the areas that abound in timber forest potential products (N'Da et al., 2008). Only two species of timber, *Terminalia*

superba and *Triplochiton scleroxylon*, are harvested in the CFHS in 2019. This reduced number of species logged in 2019 would result from the inexistence of other species in the area after their destruction during the establishment of cocoa farms in the CFHS as reported by Barima et al. (2016). Also, several studies highlighted how agricultural activities reduce the floristic diversity of an ecosystem (Adou Yao and N'Guessan, 2006; Koulibaly, 2008; Koulibaly et al., 2010; Akoudjin et al., 2016).

Increase in cocoa and plantain banana harvested in 2019 compared to 2000

The dynamics in the farm tenure in the CFHS from 2000 to 2019 have also led to a dynamic of crop production in this state-owned area. Indeed, our work showed that in 2000, about 147 t of cocoa beans were produced in the CFHS compared to about 18,384 t in 2019. Today, this state-owned area, formerly devoted to forestry, contributes greatly to supplying the world market with cocoa beans. These findings are corroborated by Higonnet et al. (2019) who found that several protected areas in Côte d'Ivoire have been entirely cleared to be converted to cocoa, the raw material for chocolate, to meet the demand of chocolate giants such as Nestlé, Cadbury, and Mars. According to Luc (2002) and Kouakou et al. (2009), cocoa farming requires small investments and provides large profits, leading farmers to practice this activity in extensive areas. The infiltration of peasant farmers into state-owned areas in Côte d'Ivoire for cocoa production has also been observed in numerous protected areas including the national parks of Marahoué and Mont Péko (Kadet, 2015; Kouamé, 2016; Sidbé et al., 2020), in the classified forests of Béki (Atta et al., 2017) and the Cavally region (RAIDH, 2017), etc. The degradation of protected areas for cocoa production has also been observed in Ghana, the world's second-largest cocoa producer (Wardell and Lund, 2004). In that country, between 2001 and 2014, 117,866 ha of protected areas were cleared, and Ghana lost more than 7,000 km^2 of forest, that is, at least 10% of the entire forestcover (Higonnet et al., 2019). Besides, the cocoa beans produced in the CFHS appear to be a real strategic opportunity for local, national, and international communities. However, behind this strategic opportunity stands the disappearance of the state-owned areas that make up the last remnants of the Ivorian forest (Kouamé Kra, 2019).

From the analyses, it is noticeable that the quantity of plantain produced in the CFHS has increased from around 3,087 t in 2000 to over 187,061 t in 2019.

Therefore, the CFHS, dedicated to logging, is also helping to ensure food security for the local population. The cultivation of plantain bananas in the CFHS suggests that although the principal reason for infiltration is cocoa production, these producers would combine this speculation to ensure their food self-sufficiency and generate a marketable bonus that provides a regular income. This production system is also widespread in most regions of Côte d'Ivoire outside protected areas (Deheuvels, 2007). However, the yield of plantain banana decreases as cocoa trees increase in age. Indeed, banana trees are planted in interspersed with cocoa trees, at the same density to provide shade for cocoa seedlings with an average association period of two to three years (Sonwa, 2002). After a few years, banana trees, like other food crops associated with cocoa trees, tend to disappear from plantations, leading to a monoculture cash crop (cocoa). This implies that plantain, as in the current state, would not be able to guarantee the food security of local populations in the long term.

Increase in CFHS market value in 2019 compared to 2000

The data collected showed that the marketing value of timber produced in CFHS fell from about FCFA 48 million in 2000 to FCFA 21 million in 2019, which is a declining trend. An opposite tendency is found for crops of cocoa and plantain banana production which was less than 124 million FCFA in 2000 and reached about 27,817 million FCFA in 2019. Thus, based on exploited timber, the CFHS had a higher monetary value in 2000 than in 2019. Based on illegally grown cocoa and plantain, the CFHS had a lower monetary value in 2000 than in 2019. Also taken together, the market value of timber, cocoa, and plantain in 2000 is FCFA 173,856,640 while the market value in 2019 is FCFA 27,838,664,974, a difference of FCFA 27,664,808,334. Consequently, depending on the services assessed, the value of the CFHS in its degraded state seems to have a higher pecuniary value than when it is well preserved. The economic benefit resulting from the degradation of natural areas for agriculture was also highlighted by the MEA (2005). According to these authors, changes in ecosystems have contributed to substantial net gains in terms of human well-being and economic development. Therefore, what will be the future of these already seriously degraded state-owned areas? In other words, should the economic benefits generated by agricultural production in the CFHS justify the total abandonment of this territory to agriculture? Or, on the other hand, should the drastic reduction of the timber

supply service induce the manager to evacuate the infiltrated populations to reconstitute this state-owned domain infiltrated for agriculture? Or should the manager rather consider implementing a cropping system that would make it possible to reconcile timber production and agricultural production in the same area?

Switching the CFHS completely to agriculture is essential when it comes to fulfilling people's food needs, something that could reduce the proportion of malnutrition and improve human health. Another benefit of these anthropogenic activities is the enhancement of the Ivorian economy due to cocoa production (Higonnet et al., 2019). However, this in turn could drive infrastructure development and then urbanization, worsen poverty for some categories of people (MEA, 2005) and lead to the degradation of many ecosystem services (in addition to timber supply). Indeed, Assalé et al. (2020) have shown that the services provided by the CFHS in 2019 are a benefit for non-indigenous communities and a loss for indigenous and mostly non-indigenous people, even though the latter were the beneficiaries of the services provided by the CFHS when it was relatively well conserved. These authors also state that anthropogenic activities have led to a decline in services related to forest species, with the loss of 98.11, 93.18, and 78.67%, respectively, in handicrafts, construction, and traditional pharmacopeia services. The deterioration of natural areas also leads to the breakdown of several services including wastewater treatment and detoxification, protection against natural hazards, regulation of air quality, regional and local climate, erosion, and a large number of cultural benefits (spiritual, aesthetic, recreational and others) (MEA, 2005; TEEB, 2010). As a result, the abandonment of the CFHS to agriculture appears to generate more drawbacks than benefits.

Another managerial alternative to anthropogenic pressure could be the relocation of infiltrated populations so this state-owned could be reestablished naturally or artificially. This option is essential for the restoration of protected areas in Côte d'Ivoire and, by extension, the restoration of supply services related to forest species, as well as ecological and socio-cultural services. Nevertheless, it will result in a loss of benefits related to agricultural production in these areas. At the same time, would the infiltrated populations be willing to abandon their farms since they are barely producing and are reaping great benefits to them? The long-term maintenance of the world's leading cocoa producer and the food security of the populations should require a sustainable development of the sector through the integration into the national strategy for mitigation and adaptation to climate change as well as the national strategy to combat deforestation (REDD + strategy) in

particular. Therefore, in the CFHS, the implementation of an agroforestry system combining timber production and agricultural production could be an appropriate solution facing the degradation of protected areas.

Conclusion

This study shows that the CFHS landscape matrix in 2019 was dominated by cocoa while that of 2000 was dominated by forest. Hence, from 2000 to 2019, there was an increase in the anthropogenic types and a decrease in the forest type. As far as the manager is concerned, the degradation of the CFHS has resulted in a loss of more than 90% of the species exploited as timber in the CFHS in 2019. This decline in timber also resulted in a reduction in 2019 of more than 75% of the annual volume of timber harvested in the CFHS in 2000. Regarding local populations, analyses showed that in 2019, the CFHS provides 18,384 t of cocoa and 187,061 t of bananas, compared to 146 t of cocoa and 3087 t of bananas in 2000. In monetary terms, based on the timber harvested, the CFHS is less advantageous today than it was in 2000 for the manager. Therefore, with cocoa and plantains grown illegally, CFHS has a higher monetary value in 2019 than in 2000 for local people. Overall, the monetary value of wood, cocoa and plantain provided by FCHS is more numerous in 2019 than in 2000. In such circumstances, it is recommended to put in place a sustainable cropping system that will integrate wood production and agricultural production in the same area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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