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Deforestation and carbon stock in state forests in Côte d'Ivoire: The case of the Haut-Sassandra classified forest

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ABSTRACT

This study assesses the impact of deforestation, primarily due to the expansion of cocoa plantations, on carbon stocks in the Haut-Sassandra Classified Forest (HSCF) in Côte d'Ivoire. The methodology was based on the processing of a 2019 Landsat image and a forest inventory in 117 plots of 625 m² each, respectively, to map land use in the HSCF and quantify biomass and sequestered carbon using allometric equations applied to dendrometric data. Supervised classification of the 2019 Landsat image showed that cocoa plantations occupy 80% of the landscape, while natural forest covers only 7%. This cocoa expansion in the HSCF is resulting in a massive reduction of both biomass and carbon stocks. Indeed, analyses indicate an average total biomass of 202.01 tonnes of dry matter per hectare (tDM /ha), with significant variations: forests and fallow lands store 480.74 and 411.55 tDM /ha, respectively, compared to only 23.55 tDM /ha for old cocoa plantations (>10 years). The total carbon sequestered in the HSCF is approximately 9 million tonnes. Its distribution is strongly influenced by land use type. Forest ecosystems exhibit the highest storage capacities, with an average of approximately 240 tonnes of carbon per hectare (tC /ha), while mature cocoa plantations sequester only about 11.77 tC /ha. The study concludes that forest conversion for agriculture results in a net loss of carbon, highlighting the urgent need to integrate the preservation of forest fragments and the promotion of tree fallows into national climate change mitigation strategies, such as REDD + initiatives.

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INTRODUCTION

Deforestation and the degradation of tropical forests are among the main causes of carbon emissions into the atmosphere, contributing significantly to global climate change (FAO, 2017).

Côte d'Ivoire, a tropical African country whose forest ecosystem covered 15 million hectares in the 1900s (SODEFOR, 1996), represented only about 3 million hectares in 2015 (FAO, 2017).

According to the BNEDT (National Bureau for Sustainable Development), the forest cover was projected to shrink to just 2.8 million hectares in 2020. The country thus lost more than 86% of its forest cover in the 1960s and is among the countries with the highest deforestation rates in the world (MEDD, 2011; Fairhead and Leach, 2012). Several areas of forest have been destroyed and converted into agricultural operations such as food, commercial, or agro-industrial plantations (Gone Bi *et al.*, 2013; Koné *et al.*, 2014). In addition to agriculture, sustained logging and mining have led to massive deforestation (MEDD, 2011; Fairhead and Leach, 2012). This dynamic affects not only biodiversity, but also the carbon storage capacity of forest ecosystems, which is essential in mitigating the effects of greenhouse gases.

Due to increased deforestation outside state boundaries, state forests have become the target of populations who have settled there and quickly developed agricultural operations (Barima *et al.*, 2016). Indeed, since the 1960s, Côte d'Ivoire has experienced a significant influx of people into its forest areas in order to develop agricultural activities, the main one being cocoa farming (Balac, 2002). Such a transformation of the territory has direct implications for biomass and carbon stocks.

This study aims to quantify the impact of forest conversion on carbon stocks in the Haut-Sassandra Classified Forest (HSCF) located in west-central Côte d'Ivoire. This forest, which was once one of the country's main biodiversity reservoirs (SODEFOR, 1996; Oszwald, 2005), has been illegally encroached upon, like several state-owned forests, for cocoa farming (Sangne *et al.*, 2015; Kouakou *et al.*, 2018; Timité *et al.*, 2019). By combining remote sensing data with field measurements of aboveground and belowground biomass, we assess the quality of landscapes and their carbon sequestration capacity.

MATERIALS AND METHODS

To estimate the amount of carbon (C) stored in the vegetation of the HSFC, the rate of carbon sequestration per unit area is calculated for the different land use types identified during mapping and then extrapolated across the entire HSFC. Furthermore, the carbon estimation methodology sequestered per unit area recommended by the Intergovernmental Panel on Climate Change has been adopted.

Study area

The HSCF, located in the Centre-West of Côte d'Ivoire, has belonged to the permanent forest estate of the Ivorian state since 1974 and covers an area of 102,400 ha. It is situated between 6°52' and 7°24' North latitude and between 6°59' and 7°10' West longitude (Fig. 1) and belongs, for the most part, to the *Celtis* semi-deciduous humid dense forest zone, *Celtis* spp. and *Triplochiton scleroxylon* of the mesophilic sector (Guillaumet and Adjanohoun, 1971). Originally, the HSCF was subdivided into a natural production series (81,144 ha), a natural protection series west of the forest (15,954 ha) and an agricultural series (4,920 ha) corresponding to the agricultural enclaves (Boba *et al.*, 1994). Initially managed by the Ministry of Water and Forests, it was made available to SODEFOR, along with many other classified forests in the country, in 1992. As part of this work, the digitization of the HSCF, excluding an inhabited enclave V12 (Southwest), yielded an area of 95,953 ha. The study focuses on this part of the HSCF.

Land use mapping

Land use mapping of the HSCF was carried out using satellite imagery. A multispectral image from the Landsat satellite with a spatial resolution of 30 m was obtained from the Operational Land Imager-Thermal Infrared sensor. Sensor » (OLI-TIRS) and dated June 20, 2019 downloaded from the Earth explorer portal (http://earthexplorer.usgs.gov) was used. Image processing and land use map creation were performed using ENVI 4.7 and QGIS 2.14.3 software, respectively. The acquired satellite image was a large scene containing the study area.

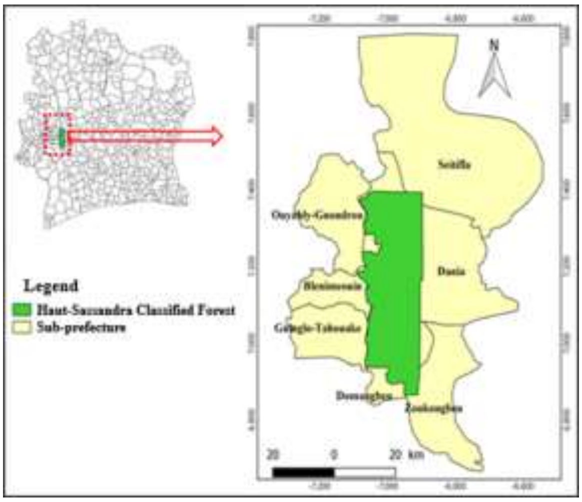

Fig. 1. Location of the Haut-Sassandra classified forest in Ivory Coast

This area was extracted using ENVI 4.7. Following this step, we performed color compositing of the image. Based on this color composite, 450 points (training area) were selected, each exhibiting various hues, and their geographic coordinates were recorded. Field missions were conducted to describe the different corresponding classes on the color composite. A portion of these areas was used to perform supervised classification of the image using the maximum likelihood algorithm, which, according to Auda *et al.* (2002) is the most suitable for vegetation mapping. The remaining points were used to validate the classification. The classes selected for this study are "forest," "bare soil-habitation," and "crop-fallow." The "forest" class corresponds to relatively well-preserved forest patches, and the "bare soil-habitation" class corresponds to denuded areas and dwellings. The "crop-fallow" class represents cash and food crops present in the HSCF, as well as areas abandoned after agricultural activities of varying types and ages. The quality of the classification obtained was evaluated using parameters calculated from the confusion matrix, namely overall precision and the Kappa coefficient (Abdel- Kawy *et al.*, 2011).

In a tropical environment, a Kappa index ranging from 0.75 to 1 is considered satisfactory within the framework of maximum likelihood assisted classification (N'Doumé *et al.*, 2000). It is obtained using the following equation:

$$K=\frac{n\sum_{i=1}^{r} Mc(\mathrm{i})-\sum_{i=1}^{r} m1m2}{(n)^2-\sum_{i=1}^{r} m1m2} \qquad \text{Eq. 1}$$

Reference data for verifying the classifications were obtained in each land use class from *in situ* observations. After the classification evaluation, a thematic map of the study area was created using QGIS Desktop 2.14.3 software.

Estimation of the biomass of the classified forest of Haut-Sassandra

Tree biomass represents the mass of the plant's living tissue and is generally expressed in metric tons (t) (Cornet, 1981). Biomass can be estimated using two approaches: direct or destructive methods and indirect methods (Segura and Kanninen, 2001). Direct methods generally involve collecting samples and sometimes even whole plants in the field. Indirect methods consist of applying regression models, volume tables, or geometric formulas with measurements taken in the field through floristic inventories (Chave *et al.*, 2005). In the present study, biomass estimation was carried out using the indirect, or non-destructive, method.

The floristic inventory was based on surface survey methods. In each land use type, three (3) plots of 625 m² (25 m x 25 m) were established along 500 m long transects for data collection. In total, 39 transects comprising 117 plots were surveyed. All plant species found in the plots were identified. Tree species with a diameter at breast height (DBH) of 5 cm or greater were measured using a tape measure. Measurements were taken 30 cm above the buttresses for buttressed trees. Aboveground biomass (AGB) was calculated using specific allometric equations (Table 1).

Table 1. Specific allometric equations for calculating carbon

Species	Allometric equations		References
Cocoa trees	$\text{Log AGB} = (-1.684 + 2.158 \times \text{Log (D)} + 0.892 \times \text{Log (H)}$	Eq. 2	Segura *et al.* (2005)
Palm trees	$\text{AGB} = \exp(-2.134 + 2.530 \times \ln(D))$	Eq. 3	Brown (1997)
Banana trees	$\text{AGB} = 0.030 \times D^{2,13}$	Eq. 4	Hairiah *et al.* (2010)
Coffee	$\text{AGB} = 0.281 \times D^{2.06}$	Eq. 5	Hairiah *et al.* (2010)
Vines	$\text{AGB}_{liana} = e^{(-7.094 + 1.690 \times \ln(d))}$	Eq. 6	Gehring *et al.* (2004)
Other woody species	$\text{AGB} = \rho \times \exp(-1{,}499 + 2{,}148 \times \ln(d) + 0{,}207 \times (\ln(d))^2 - 0{,}0281 \times (\ln(d))^3)$	Eq. 7	Chave *et al.* (2005)

In addition, the allometric equation established by Segura *et al.* (2005) is used for the calculation of the aboveground biomass of cocoa trees for individuals with a diameter between 1.3 cm and 26.8. In order to calculate the underground biomass (BGB), the aboveground biomass (AGB) was multiplied by the root/stem ratio (R), estimated at 0.24 (IPCC, 2006).

The calculation of total biomass (BT) was carried out by adding aboveground (AGB) and underground (BGB) biomass. The total biomass estimate has been determined by extrapolating the values obtained per unit area to the total area of each class. Specifically, the aboveground (AGB), belowground (BGB), and total (BT) biomass estimated per unit area (s) is extrapolated over the entire HSCF, taking into account the areas occupied by each land use type (S) during that period. This method has already been used by Maresca *et al.* (2011).

Estimation of the carbon sequestration rate at the HSCF scale in 2019

The amount of carbon sequestered by vegetation was determined by multiplying aboveground (AGB), belowground (BGB), and total (BT) biomass by the wood content estimated at 0.5 by the IPCC in 2006. The quantification of carbon sequestered by HSCF was carried out using the MEA method (2005), adopted by N'Goufo *et al.* (2019). Thus, the amount of carbon sequestered at the HSCF scale by vegetation in 2019 was determined by multiplying the aboveground (Ca), subsurface (Cs), and total (TC) carbon sequestered in each land use type per unit area by the area of each land use type during that period. This method has already been used by Ouedraogo *et al.* (2019). The unit of measurement for biomass is the tonne of dry matter (tDM). Sequestered carbon is measured in tonnes of carbon (tC).

RESULTS

Land use of the classified forest of Haut-Sassandra

Digital processing of the 2019 image revealed six land-use classes: "Forest," "Fallow," "Cocoa Orchards 1-5 Years Old," "Cocoa Orchards 6-10 Years Old," "Cocoa Orchards Over 10 Years Old," and "Bare Soil/Habitation" (Fig. 2).

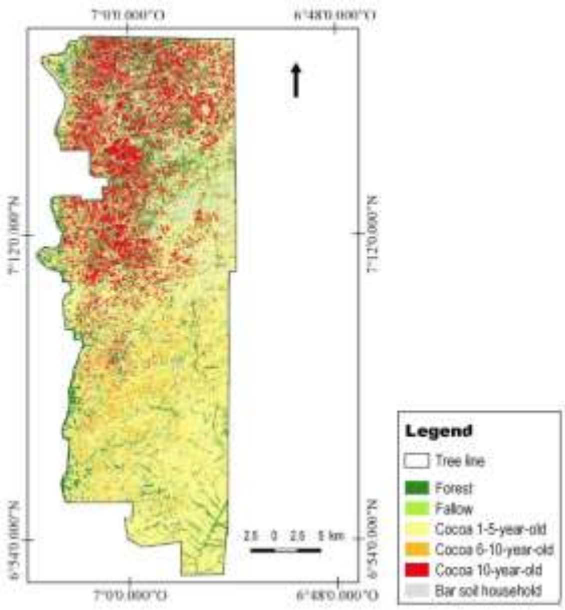

Fig. 2. Land use maps of the Haut-Sassandra classified forest

The classification was evaluated using a confusion matrix (Table 2) based on overall accuracy and the Kappa coefficient. The table displays the percentage of correctly classified pixels along the diagonal and the percentage of incorrectly classified pixels off the diagonal. The classification evaluation yielded an overall accuracy of 99.88% with a Kappa coefficient of 0.97 (Table 2). These indicators show that the classes defined during the supervised classification are mostly well distinguished. However, some confusion exists between different classes. These confusions are observed in the classes "Cocoa plantations 1 to 5 years old", "Cocoa plantations over 10 years old", "Forest" and "Bare soil/Dwelling". However, the greatest confusion is observed in the Bare soil/Dwelling class and the "Fallow land" class at 12.5% (Table 2).

Table 2. Confusion matrix (%), overall accuracy (%), and Kappa coefficient evaluating the accuracy of the supervised classification of the 2019 landsat image of the Haut-Sassandra classified forest

	Cocoa 1-5-years-old	Cocoa 6-10 years-old	Cocoa 10-years- old	Forest	Fallow	Bare soil/ household
Cocoa 1-5-years-old	95.28	0	0	2.78	0	0
Cocoa 6-10 years-old	4.72	100	3.49	0	0	0
Cocoa 10-years-old	0	0	96.51	0	0	0
Forest	0	0	0	97.22	0	0
Fallow	0	0	0	0	100	12.5
Bare soil/household	0	0	0	0	0	87.5
Overall accuracy: 97.22%						
Kappa: 0.97						

The "Forest" class has experienced a significant decrease in area and now occupies 7% of the landscape. Conversely, the cultivated and fallow land classes have seen a substantial increase in area and now cover 85% of the landscape. Of these, the cultivated land class alone accounts for 80% of the landscape. Cocoa plantations aged 1 to 5 years, 6 to 10 years, and over 10 years occupy 44%, 20%, and 16% of the landscape, respectively. The "bare land-habitation" class occupies 8% of the landscape (Table 3).

Table 3. Proportions of land use classes in the Haut-Sassandra classified forest in 2019

Land uses	Area (ha)	Proportion (%)
Forest	6717	7
Fallow	4798	5
Bare soil/household	7676	8
Cocoa 1-5-years-old	42219	44
Cocoa 6-10 years-old	19191	20
Cocoa 10-years-old	15352	16

Biomass of the Haut-Sassandra classified forest

The values of aboveground, belowground and total biomass of the species recorded in the different land use types of the HSCF are recorded in Table 4. The average aboveground biomass in the HSCF is 117.96 tonnes of dry matter per hectare (tDM /ha). The highest values were recorded in forest fragments, fallow land, and cocoa plantations aged 5 years or younger, with respective values of 387.69 t DM /ha, 331.89 t DM /ha, and 138.80 t DM /ha. The lowest aboveground biomass was recorded in cocoa plantations older than 10 years, with an average value of 18.99 t DM /ha.

The average belowground biomass for the different land use types in the HSCF was 39.10 tDM /ha. Its highest value was recorded in forest fragments (93.05 tDM /ha) and its lowest in cocoa plantations older than 10 years (4.56 tDM /ha). The total biomass (aboveground and belowground) in the HSCF was 202.01 t DM /ha. The highest biomass values were recorded in forest fragments (480 tDM /ha) and cocoa plantations older than 10 years, with the lowest biomass at 23.55 tDM /ha. Thus, the total biomass of the HSCF is estimated at 13,563,311.58 tDM (Table 5). Distributed across the different inventoried habitats, the biomass of cocoa plantations older than 5 years was highest, totaling 7,255,812.34 tDM, followed by forest fragments at 3,228,991.17 tDM. Cocoa plantations older than 10 years recorded the lowest biomass at 361,550.90 tDM.

Carbon sequestered by the Haut-Sassandra classified forest

The aboveground, subsurface, and total carbon sequestered per unit area in the different land use types of the HSCF is recorded in Table 6.

Table 4. Values of aboveground, belowground and total biomass in the different biotopes in tonnes of dry matter per hectare

Land uses	Species	Aerial biomass	Underground biomass	Total biomass
Forest	Cocoa trees	0	0	0
	Forest species	387.69	93.04	480.74
	Total	387.69	93.05	480.74
Fallow	Cocoa trees	0.01	0	0.01
	Forest species	331.88	79.65	411.53
	Total	331.89	79.65	411.55
Cocoa 1-5-years-old	Cocoa trees	5.38	1.29	6.67
	Forest species	133.22	31.97	165.19
	Total	138.6	33.26	171.86
Cocoa 6-10 years-old	Cocoa trees	14.18	3.4	17.58
	Forest species	17.03	4.09	21.11
	Total	31.21	7.49	38.69
Cocoa 10-years-old	Cocoa trees	15.72	3.77	19.5
	Forest species	3.27	0.78	4.05
	Total	18.99	4.56	23.55

Table 5. Total biomass of each type of land use in the Haut-Sassandra classified forest

Land uses	Species	Aerial biomass (HSCF)	Underground biomass (HSCF)	Total biomass (HSCF)
Forest	Cocoa trees	0	0	0
	Forest species	2,604,001.30	624,922.70	3228991.17
	Total	2,604,001.30	624,989.87	3,228,991.17
Fallow	Cocoa trees	47.98	0.00	47.98
	Forest species	1,592,244.08	382132.82	1974376.90
	Total	1,592,292.06	382132.82	1,974,472.86
Cocoa 1-5-years-old	Cocoa trees	227,139.94	54462.92	281602.86
	Forest species	5,624,457.81	1349751.66	6974209.47
	Total	5,851,597.75	1404214.58	7,255,812.34
Cocoa 6-10 years-old	Cocoa trees	272,122.71	65,248.04	337,370.75
	Forest species	326,815.92	78,489.55	405,113.57
	Total	598,938.63	143,737.59	742,484.31
Cocoa 10-years-old	Cocoa trees	241340.99	57,878.85	299,373.36
	Forest species	50202.61	11,974.93	62,177.54
	Total	291543.60	70,007.31	361,550.90

Table 6. Quantity of aboveground, subsurface and total carbon sequestered per unit area in the different land use types of the Haut-Sassandra classified forest

Land use	Species	Aerial carbon	Underground carbon	Total Carbon
Forest	Cocoa trees	0	0	0.00
	Forest species	193.85	46.52	240.37
	Total	193.85	46.52	240.37
Fallow	Cocoa trees	0.01	0	0.01
	Forest species	165.94	39.83	205.77
	Total	165.95	39.83	205.77
Cocoa 1-5-years-old	Cocoa trees	2.69	0.65	3.34
	Forest species	66.61	15.99	82.59
	Total	69.3	16.63	85.93
Cocoa 6-10 years-old	Cocoa trees	7.09	1.7	8.79
	Forest species	8.51	2.04	10.56
	Total	15.6	3.74	19.35
Cocoa 10-years-old	Cocoa trees	7.86	1.89	9.75
	Forest species	1.63	0.39	2.02
	Total	9.49	2.28	11.77

Table 7. Total carbon sequestered in the Haut-Sassandra classified forest in 2019

Land uses	Species	Aerial carbon	Underground carbon	Carbon total
Forest	Cocoa trees	0.00	0.00	0.00
	Forest species	1,302,000.65	312,461.35	1,614,495.58
	Total	1,302,000.65	312,494.93	1,614,495.58
Fallow	Cocoa trees	23.99	0.00	23.99
	Forest species	796122.04	191066,41	987188.45
	Total	796,146.03	191,066.41	987,236.43
Cocoa 1-5-years-old	Cocoa trees	113,569.97	27,231.46	140,801.43
	Forest species	2,812,228.91	674,875.83	3,487,104.74
	Total	2,925,798.88	702,107.29	3,627,906.17
Cocoa 6-10 years-old	Cocoa trees	136,061.35	32,624.02	168,685.37
	Forest species	163,407.96	39,244.78	202,556.78
	Total	299,469.31	71,868.80	371,242.16
Cocoa 10-years-old	Cocoa trees	120,670.49	28,939.42	149,686.68
	Forest species	25,101.30	5,987.47	31,088.77
	Total	145771.80	35003.65	180,775.45

The average amount of aboveground carbon sequestered in the HSCF is 58.98 tC /ha. The highest values of sequestered carbon are recorded in forests (193.15 tC /ha) and fallow land (165.95 tC /ha). The lowest amount of carbon is sequestered by cocoa plantations older than 10 years (9.49 tC /ha). The average amount of subsurface carbon sequestered by the HSCF is 19.55 tC /ha. Considering the different land use types, forests sequester the most subsurface carbon (46.52 tC /ha) than the other land use types. Thus, the average amount of carbon sequestered in the HSCF per unit area is 101.01 tC /ha. The highest carbon sequestration rates are found in forests (240 tC /ha) and fallow land (205.77 tC /ha). The lowest carbon sequestration rates are recorded in cocoa plantations older than 10 years (11.77 tC /ha). Furthermore, considering only cocoa plantations, a decrease in the sequestered carbon rate is observed as the crops age.

The carbon sequestered by the HSCF in 2019 was approximately 6 million tonnes. This carbon sequestration rate, distributed throughout all environments, was highest in young cocoa plantations (371,362,906.17 t) and forest pockets (1,614,495.58 t), while the lowest rates were noted in cocoa plantations between 6 and 10 years old (371,242.16 t) and cocoa plantations over 10 years old (180,775.45 t) (Table 7).

DISCUSSION

The results of this study highlight the impact of cocoa expansion on carbon stocks in the Haut-Sassandra classified forest. This discussion aims to interpret these results in light of land-use dynamics and the challenges of carbon sequestration in the context of perennial crops.

The classification evaluation yielded an overall accuracy of 99.88% with a Kappa coefficient of 0.97. These results confirm the reliability of the data produced, although some confusion remains, particularly between the "Fallow" and " Bare soil/household " classes. This confusion could be explained by the spectral similarity between these two types of environments in satellite imagery, but it does not significantly affect the overall interpretation of territorial dynamics. The land-use classification of the HSCF reveals a dominance of cocoa plantations, which represent 80% of the total area, while natural forest now covers only 7% of the landscape.

This situation illustrates an advanced process of deforestation and human impact, characteristic of classified forests in Côte d'Ivoire, where agricultural pressure, particularly from cocoa, has led to severe fragmentation of forest landscapes (Beke, 2011; Barima *et al.*, 2016). Furthermore, this significant human impact on the HSCF in 2019 is due to the infiltration of this state-owned land during the period of political and military crises in Côte d'Ivoire and to the continuation of human activities in the HSCF after the conflicts (Barima *et al.*, 2016). Indeed, the period of conflict has been considered a pivotal period in anthropization (Kouakou *et al*., 2018). During this period, there were no monitoring activities resulting in a massive influx of people into the HSCF in search of land suitable for cocoa farming (Kouakou *et al*., 2015). This assertion is justified by the presence of cocoa plantations over 10 years old (17% of the area). Furthermore, the end of the conflicts did not result in the end or reduction of deforestation in the HSCF (Kouakou *et al*., 2018). Our results revealed that young cocoa plantations (1 to 5 years old) occupy 44% of the landscape. Thus, after the conflicts, encroachment into the HSCF continued to such an extent that the landscape matrix was transformed. The landscape matrix shifted from the dense forest class in 2000 to the degraded forest-cultivation/fallow class in 2015, as demonstrated by Kouakou *et al.* (2018), and then to the cultivation-fallow class in 2019.

Analysis of biomass and sequestered carbon reveals considerable differences between land use types. The results show that forest fragments and fallow land retain high biomass and carbon stocks (480.74 tDM /ha and 411.55 tDM /ha, respectively), consistent with typical values for tropical rainforests (Gibbs *et al*., 2007), highlighting their crucial role as carbon sinks and biodiversity reservoirs. The high rate of carbon sequestration by forests (240 tC /ha) and fallow land (205.77 tC /ha) is explained by the presence of large-diameter trees and species with high species density (Bakayoko *et al*., 2012). Indeed, according to the work of Saj *et al.* (2013) and Anobla and N'Dja (2016) indicate that trees, especially those with large diameters, are the most effective at sequestering carbon (Bah *et al*., 2019). Thus, well-maintained protected forests contribute significantly to climate regulation through carbon sequestration. The role of state-owned lands in combating climate change has also been highlighted by several authors, including McNeely and Mainka (2009) and Yang *et al.* (2017). According to these authors, protected areas store 15% of global terrestrial carbon, or 312 gigatonnes. Conversely, cocoa plantations, particularly those over 10 years old, record the lowest values (23.55 t DM /ha and 11.77 tC /ha). This decline is primarily explained by the drastic reduction of forest tree cover in favor of cocoa trees, which store less carbon (Mitchard, 2018). Secondly, due to their smaller circumference and height compared to trees left in the fields (Bakayoko *et al*., 2012), and secondly, due to the intensive management of older cocoa plantations, often associated with reduced shade and the removal of native trees (Gockowski and Sonwa, 2011), young cocoa plantations (≤ 5 years) exhibit higher biomass and carbon stocks than older plantations, but these remain far below the capacities of forests and fallow land. This finding suggests that even in the early years, forest conversion for agriculture results in a net loss of carbon. This finding aligns with the work of Zomer *et al.* (2016) emphasize that young agroforestry systems do not compensate for the initial carbon loss due to deforestation. The carbon loss associated with cocoa expansion raises the question of the sustainability of this sector in Côte d'Ivoire. Agroforestry practices, often promoted as a sustainable alternative, appear to reach their full potential only under certain conditions: maintaining a significant density of forest trees, diversifying species, and limiting the conversion of primary forests (Tscharntke *et al*., 2011). Furthermore, the distribution of total carbon sequestered in the HSCF (approximately 6 million tonnes) shows that young cocoa plantations (≤ 5 years old) and fallow land contribute the most to the total stock, primarily due to their large area. However, this contribution should be qualified: while young cocoa plantations still contain a significant proportion of forest species, their capacity to maintain this stock in the long term is uncertain, given the shift towards less diverse and older systems.

Furthermore, these results highlight the urgent need to integrate the "carbon stock" dimension into the management plans of classified forests and into national REDD+ strategies. The preservation of residual forest fragments and the promotion of wooded fallow land appear to be priority levers for mitigating greenhouse gas emissions linked to deforestation.

CONCLUSION

This study assesses the impact of deforestation, primarily due to cocoa farming, on carbon stocks in the Haut-Sassandra Classified Forest in Côte d'Ivoire. Digital processing of the 2019 satellite image covering the HSCF revealed a dominance of the agricultural class in the HSCF landscape matrix. This significant human impact on the HSCF has led to a reduction in carbon stocks within this forest massif. The total carbon sequestered in the HSCF is approximately 6 million tons. Its distribution is strongly influenced by land use: forests sequester 240 tC /ha, compared to only 11.77 tC /ha for mature cocoa plantations. This study thus demonstrates that the conversion of forests to cocoa plantations results in a drastic loss of biomass and carbon, with direct implications for national and international commitments to combat climate change. The preservation of remaining forest fragments and the promotion of sustainable agroforestry practices appear to be essential levers for reconciling cocoa production and ecosystem conservation.

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