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Assessment of Carbon Stock Dynamics in the Kuinima Classified Forest in Western Burkina Faso

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ABSTRACT

In the context of the fight against climate change, information on carbon stock estimates and the state of evolution of these stocks is more than vital for better management of the REDD+policy in protected areas. The main objective of this study was to assess the dynamics of carbon stocks in the Kuinima Classified Forest using cartographic data combined with dendrometric data. The cartographic database of the Kuinima Classified Forest in 1990 and 2018 was used to generate statistics for the land-use classes of interest. To collect dendrometric data, a forest inventory was carried out using the Global Forest Observation Initiative method. The results of the carbon stock calculations showed that the forest plantation class had the highest carbon stock per hectare, at 399.59 tC/ha, compared with 4.04 tC/ha for the shrub savannah class. Analysis of carbon stock dynamics showed that agroforestry parks absorbed the most carbon between 1990 and 2018, at 20822.36 tC, while the open shrub savannah class emitted more carbon over the same period, at 11355.42 tC. An in-depth analysis of the whole of the Classified Forest shows that there have been carbon emissions of around 1,685.31 tC in 28 years. The authorization given to local people for agricultural activities and the lack of appropriate supervision by forestry officers are thought to be the cause of the degradation of this Classified Forest. It is clear that, in the absence of a good policy for restoring and rehabilitating this forest, we could see its total anthropization in the short term.

Keywords Carbon stock, Woody biomass, Methods and guidance, Allometric equations, Burkina faso.

INTRODUCTION

Tropical forest ecosystems account for 60% of all forests, i.e., a total area of 13.76 million km2. They

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play a crucial role in the carbon cycle (Imorou *et al.* 2021) and contain 40 to 50% of terrestrial carbon (Pan *et al.* 2011). However, these forests are currently under heavy human activity pressure (Van Breugel *et al.* 2011, Bogaert *et al.* 2011, Mama *et al.* 2013, Avakoudjo *et al.* 2014, Amoussou *et al*. 2016). These pressures are causing major changes to forests. The various changes are having severe repercussions across the globe (Shackleton and Shackleton 2000, Sop and Oldeland 2011, Bognounou *et al.* 2013). These repercussions manifest themselves in the loss of large areas of forest (Van der Werf *et al.* 2009, Imorou *et al.* 2021), leading to the release of large quantities of carbon (Houghton 2005). Worldwide, 14.6 million hectares of forest were destroyed between 1990 and 2000 (FAO 2002, Tchatchou *et al.* 2015). Deforestation is estimated to contribute between 20 and 25% of annual global CO_2 emissions (IPCC 2013). Although CO_2 is essential to life on Earth through its greenhouse effect, which keeps the average temperature at 15°C instead of -18°C (Kooke *et al.* 2019), the exponential rise in its concentration is the main factor in global warming (IPCC 2007). Deforestation is compounded by forest degradation, which increases global GHG emissions by 10% and 17% (IPCC 2007), exacerbating climate change.

In Burkina Faso, forest cover fell by around 1.26 million hectares between 1980 and 1992, and 17.5% was lost between 1990 and 2010 (FAO 2011). These forest losses can be explained by the growing need for arable land, energy, and non-timber forest products among rural and more vulnerable populations (Tankoano *et al.* 2016). These increased human activities are thought to have led to climate change on both a national and global scale. This climate change manifests itself in numerous natural disasters that intensify over time, while driving populations further into humanitarian emergencies (Kooke *et al*. 2019). It also disrupts the human environment, people's livelihoods and countries' economies (IPCC 2013). Because of their vulnerability and reduced resilience, developing countries are more exposed to the harmful effects of climate change (Makundi 2014, Kooke *et al.* 2019).

Faced with this worrying situation, measures have been taken by the international community. These measures aim to protect vulnerable populations, particularly those in developing countries. Among the measures proposed and adopted by the international community to mitigate and adapt to the harmful effects of climate change is the REDD + mechanism (Reducing Emissions of Greenhouse Gases from Deforestation and Forest Degradation). This mechanism was created at the 13th session of the Conference of the Parties in 2007 in Bali to reduce the current rate of deforestation (Diatta 2015). Setting up such a mechanism involves measuring and monitoring carbon stocks (Saatchi *et al.* 2011, Baccini *et al.* 2012). However, the lack of a suitable method for accurately estimating carbon stocks is an obstacle to the successful implementation of REDD+. Like other countries involved in the REDD+process, Burkina Faso has received funding for its Forest Investment Program (PIF). Given the complexity of REDD+ projects and to help countries involved in the REDD+ mechanism to better estimate their carbon stocks, the Global Forest Observation Initiative (GFOI) has established a clear and more precise methodological approach through the Methods and Guidance Documentation (GFOI 2016). Therefore, to benefit from carbon credits, it is important to make reliable estimates of the carbon stocks sequestered in forests. For this study, we therefore took the GFOI's MGD as a reference.

The main objective of the study was to assess changes in carbon stocks over time and space by combining satellite images and dendrometric data. Specifically, the aim was to :

Estimate the above-ground woody biomass and carbon stocks of the FCK in 1990 and 2018.

Assess the dynamics of woody vegetation carbon stocks between 1990 and 2018.

MATERIALS AND METHODS

Study area

The Kuinima Classified Forest lies to the south of the town of Bobo-Dioulasso between latitudes 11°03 and 11°7 north and longitudes 04°19 and 04°36 west (Fig. 1). It is surrounded by three localities, including Kouakoualé, Dingasso and Farakoba. It was classified on 20 November 1935 with an initial area

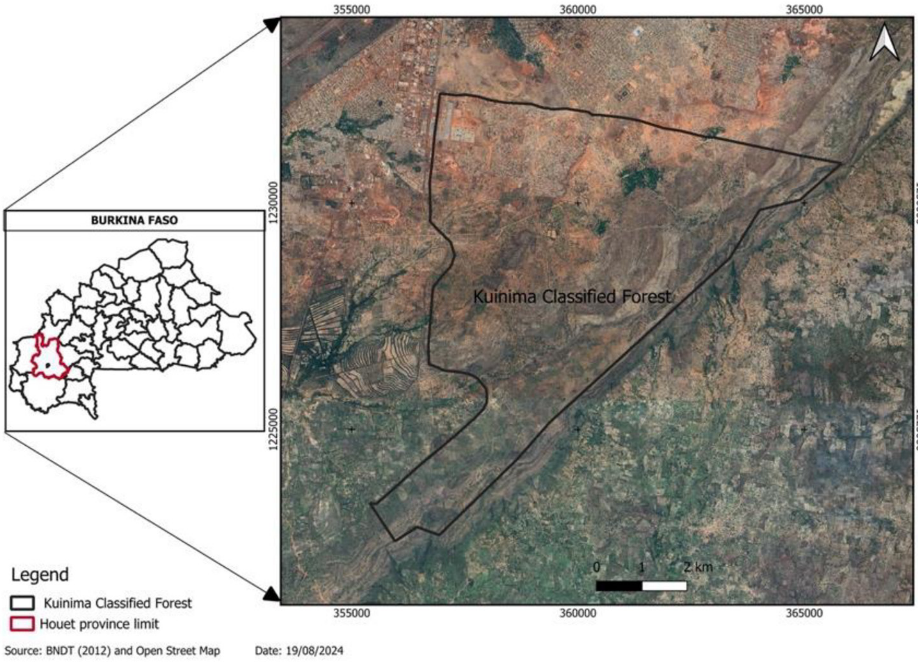

Fig. 1. Location of study area.

of 4,000 ha (Robineau 2012). But nowadays with the development of the town, part of it was declassified on 31 May 1947, bringing the area down to 2150 ha (Robineau 2012). According to Fontès and Guinko (1995), the climate of this forest is Sudanian.

Material

The following material was used in this study:

1990 and 2018 land-use maps (Tankoano *et al*. 2023) as a cartographic database (Fig. 2) for extracting areas by land-use classes,

Field equipment, consisting of a 50 m tape to delimit the plots, and a 1.50 m graduated tape to measure the circumferences of woody plants (≥ 16 cm) at breast height (CHP).

Collection of dendrometric data

The dendrometric data were collected using stratified

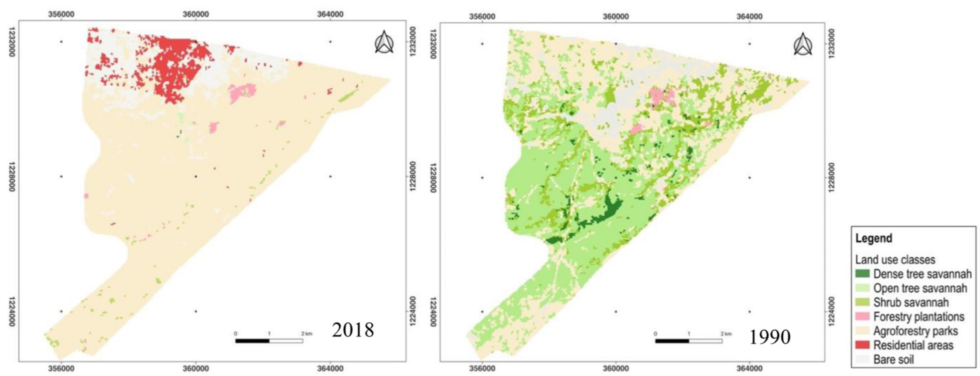

Fig. 2. Land use maps 1990 and 2018 (Reproduced by CC BY 3.0).

sampling based on the land-use types of the FCK. A total of 30 vegetation survey plots were installed. Both square and rectangular plots were used in the field. The size of the plots differed depending on whether the plant formation was predominantly monospecific or multispecific. Thus, in plantations, plots of 200 m^2 and of one (01) ha in natural formations such as savannah formations were laid out. For dendrometric parameters, the diameter at breast height (DBH) of all trees with a diameter greater than or equal to 5 cm was measured.

Estimation of woody biomass and carbon stocks in the KCF

Estimation of aboveground and boveground biomass

Aboveground tree biomass was estimated using allometric equations based on DBH values from the forest inventory. Allometric models are built using destructive methods, but once the model has been obtained for a given ecosystem, it is possible to make non-destructive estimates of biomass and therefore carbon for similar plant formations. We therefore chose one of the allometric models established by Mbow (2009). The polynomial model was developed based on data collected in the Sudanian and Sudano-Guinean savannahs of Senegal. The similarity between the plant formations of Burkina Faso and those of Senegal therefore guided our choice of this model. The model's formula is as follows:

$$y = (0.0225 \times DBH^3) - (0,517 \times DBH^2) + 13,61 \times DBH - 58,18 \quad \text{Equation (1)}$$

Where, DBH: diameter at breast height in cm and y: biomass in kg

The boveground biomass of standing woody plants was estimated using the method indicated in the guidelines drawn up by the Intergovernmental Panel on Climate Change (IPCC 2007). According to the latter, the root biomass equivalence of standing woody plants is found by multiplying the value of above-ground biomass (AGB) by a coefficient R (root/stem ratio), the value of which is estimated at 0.24 (Tsoumou *et al.* 2016).

$$BGR = AGB \times R \quad \text{Equation (2)}$$

Where, BGR: Boveground biomass, AGB: Above-ground biomass, R: Root-stem ratio factor. The total biomass was determined by summing the above-ground and below-ground biomass according to the following formula :

$$TB = BGB + AGB \quad \text{Equation (3)}$$

Where, TB: Total biomass, BGB: Boveground biomass and AGB: Aboveground biomass

Estimating carbon stocks in the KCF

To determine the carbon stock of the KCF, the total quantity of biomass was multiplied by an average carbon rate or conversion factor (CF). This conversion factor is 50% (GFOI 2016). The formula for calculating the carbon stock is as follows:

$$SC = TB \times CF \quad \text{Equation (4)}$$

SC: Carbon stock, CF = conversion factor with CF = 50% (GFOI 2016).

Thus, the average value per hectare of the carbon stock of each land use type in 2018 was multiplied by the area of the same land use type in 1990 and 2018. The carbon stocks of the CCF in 1990 and 2018 were obtained by summing the carbon stocks of the land-use classes. Total carbon stocks were calculated using the following formula :

$$SCT = \sum_{i}^{n} (Si * SCi) \quad \text{Equation (5)}$$

SCT: total carbon stock, Si: area of LULC i, SCi: carbon stock of LULC i.

Determination of the quantities of carbon absorbed and emitted

The quantity of carbon emitted or absorbed was calculated using the following formula :

SC forestier (T1) - SC forestier (T0) = Émission ou absorption forestière Equation (6)

With Forest SC (T1) = Carbon stock at a time (T1) and Carbon stock (T0): Carbon stock at a time (T0), T0= initial time and T1= final time.

RESULTS AND DISCUSSION

Woody biomass and carbon stocks as a function of LULC

Forest plantations had the highest value of woody biomass per hectare, at 799.9 t/ha. This was followed by an open wooded savannah with a value of 39.85 t/ha. By contrast, shrub savannah had the lowest biomass value at 8.08 t/ha. The same applies to carbon stock values (Table 1).

Biomass stock values varied according to land use type. The forest plantation class had the highest biomass value at 799.18 t/ha, while the shrub savannah class had the lowest value at 8.08 t/ha. This variation from one class to another could be explained by the difference in wood potential. According to several authors, this spatial variation in biomass can be explained by the variation in tree density in the vegetation types, but also by the unequal distribution of predominant species (Day *et al.* 2013, Panzou *et al.* 2016). The different specific compositions of the vegetation types would also explain this observed variation (Marshall *et al.* 2012, Djomo *et al.* 2011). The sampling method and allometric model used have a considerable influence on the variation in biomass and carbon stocks (Chave *et al.* 2008, Mbow 2009). The dense tree savannah class had a low biomass stock level of around 21.30 t/ha compared with 39.85 t/ha for the open tree savannah class. It should be noted that in the open tree savannah class there were more large-diameter individuals than in the dense tree savannah class. In savannahs, carbon stocks vary enormously depending on whether there is a high presence of large trees or not (Mbow 2009). According to Tankoano (2014), large individuals concentrate the majority of biomass, despite their small proportion. According to Mbow (2009), individuals with a diameter greater than 20 cm generally account for more than 50% of the total biomass (Mbow 2009). According to Mbow, this is due to the significant jump in the amount of biomass produced when the diameter of the tree exceeds 17 cm. Several studies have already revealed the remarkable contribution of large-diameter trees to biomass stocks (Clark and Clark 2000, Joosten *et al.* 2004). The carbon stocks obtained in savannah formations are relatively low compared with those obtained in shrub and tree savannahs by Woomer *et al.* (2004). This source obtained 20 to 25 tC/ha for standing woody biomass. This could be explained by the fact that regeneration is not taken into account. The high level of human activity in the FCK could be the reason for the low biomass and carbon stock levels.

Carbon stock dynamics between 1990 and 2018

Fig. 3 shows that, except for the forest plantation class, all the other classes experienced a downward trend in their stocks between 1990 and 2018. Analysis of Table 2 confirms that only agroforestry parks saw their stocks increase between 1990 and 2018, rising from 17023.44 tC to 37845.80 tC, an increase of 20822.36 tC. At the FCK level, carbon emissions between 1990 and 2018 amounted to 1685.31 tC.

Table 2 shows that open wooded savannah emitted the most, 11355.42 tC, between 1990 and

Table 1. Estimates of biomass and carbon stocks per hectare by LULC classes. Legend: AP (Agroforestry parks), FP (Forestry plantations), OTS (Open tree savannah), DTS (Dense tree savannah), SS (Shrub savannah), AGB : Aboveground biomass, BGB : Boveground biomass, BT : Biomass total, CT : Carbone total.

LULC Classes	AGB (t)	BGB (t)	BT (t)	Area sampled (ha)	BT (t/ha)	CT (t/ha)
AP	132.30	31.75	164.06	7.24	22.66	11.33
FP	77.34	18.56	95.90	0.12	799.18	399.59
OTS	32.14	7.71	39.85	1.00	39.85	19.93
DTS	34.36	8.25	42.60	2.00	21.30	10.65
SS	13.03	3.13	16.16	2.00	8.08	4.04

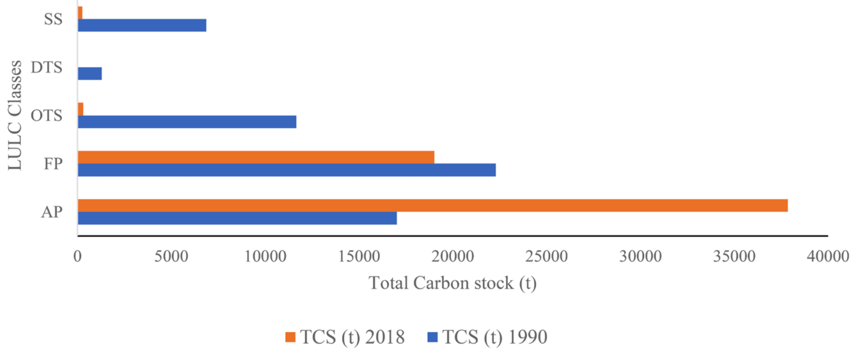

Fig. 3. Changes in carbon stocks by LULC class in the KCF. Legend: AP (Agroforestry Parks), FP (Forestry Plantations), OTS (Open Tree savannah), DTS (Dense Tree savannah), SS (Shrub savannah), TCS (t) 2018 (Total Carbon Stock en tonnes en 2018), TCS (t) 1990 (Total Carbon Stock en tonnes en 1990).

2018. It is followed by shrub savannah (6605.71 tC), forest plantations (3272.66 tC) and dense tree savannah (1273.88 tC). Much of the carbon emitted by the other plant formations was absorbed by agroforestry parks, which recorded an absorption level of 20,822.36 tC between 1990 and 2018. The FCK agroforestry system has had an impact on carbon stocks. Agroforestry parks recorded a high carbon uptake of around 20822.36 tC between 1990 and 2018. In contrast to agroforestry parks, other land-use units were characterized by high carbon emissions. According to Kombate *et al.* (2019), differences linked to soil and climate conditions, management methods, vegetation type, and ecosystem use patterns are potential explanatory variables for the observed spatiotemporal dynamics of carbon stocks. The FCK emitted approximately 1,685.31 tC between 1990 and 2018. This situation can be explained in part by the continued expansion of human activities within the forest, to the detriment of plant formations. Human activities, including agriculture and forestry, inevitably affect biomass and carbon stocks (Lindsell and Klop 2013, Willcock *et al.* 2014). In addition, there is the expansion of the city of Bobo-Dioulasso associated with high demographics and climate change that would have contributed to the inappropriate exploitation of resources. Anthropogenic factors are increasing with strong demographic growth (Kombate *et al.* 2019), which would have led to the carbon emissions observed in the FCK between 1990 and 2018. According to Toko *et al.* (2020), the transition from carbon sink to carbon source could be the result of the conversion of forest areas to agricultural zones, illegal logging, and the

Table 2. Carbon emissions and absorptions by LULC class. Legend: AP (Agroforestry Parks), FP (Forestry Plantations), OTS (Open Tree savannah), DTS (Dense Tree savannah), SS (Shrub savannah), TCS (Total Carbon Stock en tonnes), CS (Carbon stock).

LULC Classes	CS (t/ha)	1990 Area (ha)	TCS (t)	Area (ha)	2018 TCS (t)	Emissions/ Absorptions (tC)
AP	11.33	1502.52	17023.44	3340.34	37845.80	20822.36
FP	399.59	55.80	22297.22	47.61	19024.56	-3272.66
OTS	19.93	585.27	11662.08	15.39	306.66	-11355.42
DTS	10.65	122.31	1302.64	2.70	28.76	-1273.88
SS	4.04	1699.02	6863.48	63.81	257.77	-6605.71
Total			**59148.86**		**57463.55**	**-1685.31**

effects of climate change.

CONCLUSION

This study assessed carbon stocks in the Kuinima Classified Forest in Burkina Faso. The main results show that forest plantations store a significant amount of carbon, i.e. 399.59 tC/ha, while shrubby savannahs have low carbon stocks of around 4.04 tC/ha. Emissions were also noted for the savannah and forest plantation classes between 1990 and 2018. Only the agroforestry parkland class sequestered carbon over the same period, to the tune of 2,822.36 tC. The study also provided biomass and carbon estimates based on field data and Recommended Methods and Practices. These results can be used as a database for national greenhouse gas (GHG) inventories and carbon stock calculations as part of REDD+ projects. In view of the advanced degradation of the FCK's plant cover, it would be worth while stepping up monitoring by the forestry department to ensure that the commitments made by the local populations are respected.

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