Bionature, 42(1) 2022 : 1-12 ISSN: 0970-9835 (P), 0974-4282 (O) © *Bionature*

MAPPING CARBON STOCKS IN THE DIMAKO COMMUNAL FOREST, EAST-CAMEROON

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Article Information

DOI: 10.56557/BN/2022/v42i11548

Received: 02 December 2021
Accepted: 09 January 2022
Published: 10 January 2022

Original Research Article

ABSTRACT

In the global context of global warming, Cameroon's forests have a major role to play in mitigating climate change. The objectives of this study were to assess and spatialize carbon stocks in different types of land use/land cover types. To achieve these objectives, an approach based on the diachronic analysis of satellite images and the inventory of woody plants with a diameter greater than or equal to 10 cm in plots of 250 m x 20 m were carried out. The results show a 22.94% decrease in the area of mature forests and an 8.39% increase in the area of young forests in 2015. Results from field surveys show that carbon stocks vary from stratum to stratum and pool to pool. Stored carbon is higher in mature forests (133.52 tC/ha) and low in swamps (6.71 tC/ha). The aboveground compartment stores more carbon (224, 88 tC/ ha) followed by the belowground compartment (42.88 tC/ ha) and finally dead standing wood (2.59 tC/ ha). The mapping provided more account for the spatial variability of carbon stocks between land use/land cover types, providing arguments for fully meeting REDD+ targets.

Keywords: Mapping; carbon stocks; mitigating climate change; diachronic; Cameroon.

INTRODUCTION

The carbon cycle is central to the functioning of forests for the constitution of plant biomass, the formation of humus and soils. Tropical forests therefore have a major role in carbon storage, the maintenance of floristic diversity, and thereby contribute to the mitigation of climate change. These forests contain 40-50% of terrestrial carbon and play a major role in the global carbon cycle [1]. The loss of forest cover resulting from deforestation and degradation of these forests contributes to about 10-15% of annual global greenhouse gas (GHG) emissions [2]. Agriculture and logging are among the transformations that contribute more to the fragmentation and disappearance of forest cover [3]. These activities contribute to the release and increase of GHGs into the atmosphere. Atmospheric concentrations of these GHGs, mainly carbon dioxide (CO_2) and methane (CH_4) have been steadily increasing since pre-industrial periods. This increase represents one of the most studied environmental issues. Due to their radiative properties, these GHGs have the potential to disrupt the climate system on a global scale and this anthropogenic forcing would have already substantially altered the global climate [4]. In order to reduce emissions from forest degradation and deforestation and improve forest carbon stocks and sustainable forest management, several mechanisms have been envisaged. The most recent is the mechanism for reducing GHG emissions from deforestation and forest degradation, conservation, sustainable management and increasing forest carbon stocks initiated in 2005 under the United Nations Framework Convention on Climate Change (UNFCCC) [5]. The REDD+ mechanism aims to encourage developing countries to preserve forest areas through financial compensation from carbon credits [6]. However, its implementation depends on a Measurement, Reporting and Verification (NVM) system concerning, among other things, the estimation of biomass and carbon stocks contained in forests [7,8].

Cameroon has a reserve of about 16.5 million ha of dense humid forests thus occupying the third place after the Democratic Republic of Congo and the Republic of Gabon [9]. They also provide multiple services [10,11], contribute to the regulation of the greenhouse effect and the establishment of major climatic balances [12]. However, forest ecosystems are an endangered reservoir due to deforestation, which affects nearly 0.7% of the area per year [13,14]. In addition to deforestation, there is degradation caused by logging and land conversion. Faced with their accelerated disappearance and the resulting challenges, particularly in terms of greenhouse gas (GHG) emissions and the erosion of biodiversity, these are at the centre of major international concerns [15, 16]. The public authorities, to provide guidance and application of the conclusions produced by scientists, have engaged in the development of plans and policies that integrate the challenges of climate change.

In Cameroon, communal forests are created under the 1994 forestry law still have very inadequate management, because the actors are unable to implement sustainable forest management, taking into account the opportunities offered by the valorization of ecosystem services related to the conservation of biodiversity and the fight against climate change. In order to understand their potential role of forests in mitigating global warming, it is essential to accurately assess their carbon storage capacity.

Notwithstanding the gradual decline in forest cover, its maintenance remains a major challenge for decades to come. Meeting such a challenge requires knowledge of the dynamics of vegetation cover through a diachronic analysis of vegetation [17]. This analysis involves the use of geographic information system (GIS) [18] and remote sensing. This is in order to equip the various actors and decision-makers with the basic tools that can contribute to the sustainable management of natural resources, by providing answers to the questions of the implementation of REDD+ in production forests. The mapping of carbon stocks in semi-deciduous forests remains little explored in Cameroon. Previous studies have focused on the dynamics of vegetation cover [19,5]. Despite the efforts made, the impacts of deforestation and consequent climate change are likely to increase at both the local and regional levels, for which mitigation measures are imperative. For this reason, a good knowledge of the spatialization of carbon stocks is essential to ensure the success and sustainability of international actions, particularly in the context of the REDD and REDD+ programs. It is with this in mind that this study proposes to assess and map the carbon stored in the Dimako Communal Forest (DCF).

MATERIALS AND METHODS

The DCF is located in the, Upper Nyong Department, Dimako District of the East region of Cameroon (Fig. 1). It is located between latitudes North 4°10' and 4°20' and longitudes East 13°30' and 13°50'. It is subjected to the Guinean equatorial climate characterized by the annual succession of four seasons. The average rainfall varies between 1,500 and 1,800 mm/year and the average temperature is 24° C. The order of magnitude of the slopes is from 0 to 15% and the altitude varies between 596 and 689 m [20]. Phytogeographically, its vegetation is that of a semi-deciduous dense forest [21]. The great majority of the forest is described by [22] as being of the Guinean-Congolese semi-deciduous dense forest type, also referred to as "forest of Malvaceae and Ulmaceae".

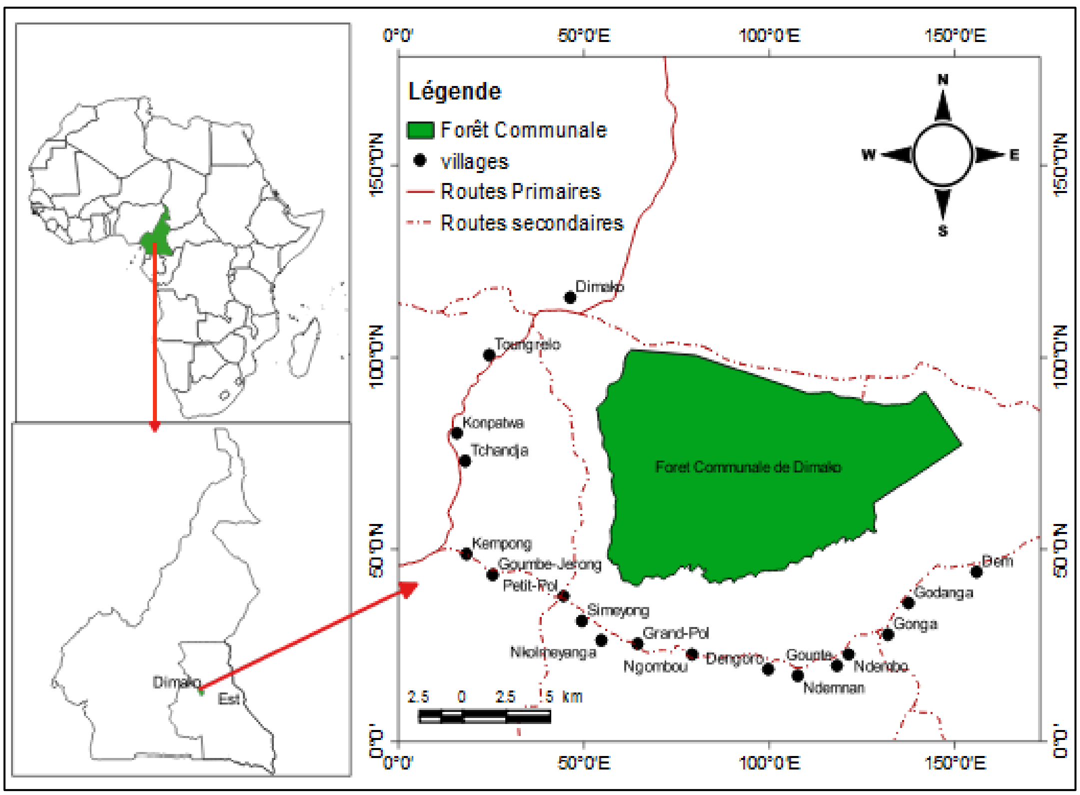

Fig. 1. Location map of the study area

Collecting Floristic Inventory Data

A sampling plan consisted of a plot of 0.5 ha (250 m × 20 m), subdivided into ten sub-plots of 25 m × 20 m for inventories of all trees of dhp ≥ 10 cm was used. This method was adapted from that used by [23] and [24]. The plots were arranged in a row with 500 m equidistance along the 2.5 km transect. A total of 24 plots of 0.5 ha were sampled in the DCF.

Data Analysis

Image processing

The processing of satellite images was carried out by encompassing a set of operations ranging from pre-processing to supervised composition. Image pre-processing increased the readability of the data, facilitated its interpretation and better extraction of information. Unsupervised classification/colour composition: this procedure consisted of classifying digital image data by computer processing. Computer processing is based solely on image statistics without the need for training samples. In order to extract the study sites, a coloured composition was done as a result of several combinations. The colour composition of the 4-5-7 bands was chosen for the Landsat satellite images (TM and ETM+) and the 4-3-2 bands for the Sentinel 2A images.

Estimation of Above-ground Biomass

In this study, biomass was evaluated using the non-destructive or indirect method based on regression equations. It relies on allometric equations to estimate biomass in an ecosystem.

The assessment of the biomass of individual trees with a diameter greater than 10 cm was carried out using the allometric equation of [25]. The mathematical formulas are as follows:

$$\mathrm{AGB} = e^{(a+bxlog(\rho)+cx\log(D)+dx(\log(D))^2+exE)}$$ [25].

Where AGB: Aboveground biomass in Kg; D: Diameter (cm); ρ: species-specific density expressed in g/cm^3; E: climate index; a, b, c and d are estimates of the coefficient (a = -2.3027; b = 1.1599; c = 3.0484; d = -0.0807; e = 0.3197).

Wood density values of the sampled trees were obtained from the literature. For species with several densities from different authors for the same ecosystem, the average density was considered. For species for which there is no available literature on density, the default value (default_ρ = 0.58 g/cm^3) for tropical forests in Africa was used [26].

Estimation of Belowground Biomass

Root biomass was estimated using the equation of [27]. The mathematical equation is:

$$\mathrm{BGB} = Exp^{(-2{,}331+2{,}596\mathrm{x}\ln(\mathrm{D}))}$$

D: diameter (cm); BGB: Belowground biomass.

Dead Standing Wood (Snags)

The biomass of standing dead wood was calculated using the allometric equation defined by [28]. This method converts the volume of wood on bark (V) into total biomass (AGB or Y), by applying the anhydrous wood density (WD) and a Coefficient of Expansion (EC).

$$Y = V \times WD \times CE$$

With Y: Aboveground biomass in t/ha; V: Volume of dead trees; WD: basal density of trees in $t/m^{3;}$ for African forest species WD = 0.58; EC: biomass expansion coefficient; EC = 1.74.

$$V = x\ h\frac{\pi D^2}{4}$$

With D: dbh of dead standing wood; h: height for dead standing wood.

Assessment of Carbon Stocks

Carbon stocks were deducted from above-ground biomass by multiplying it by the constant 0.475 [29].

Carbon Stock Mapping

The spatialization of carbon stock data in the DCF was carried out using the method of [30]. It uses the geographical coordinates of each plot and its carbon stock as input data and then extrapolate to the extent of the land cover map following the principle that a plot corresponds to a pixel class and all identical pixel classes correspond to carbon stocks assessed at the scale of several parcels.

RESULTS

Map of Land Use/Land Cover

Landsat (2000) and sentinel 2A (2015) image processing identified 5 land use classes in 2000 and 6 land use classes in 2015 (Fig. 2). Of the identified classes, 4 were selected for carbon stock mapping. These are mature forests, young forests, plantations and swamps.

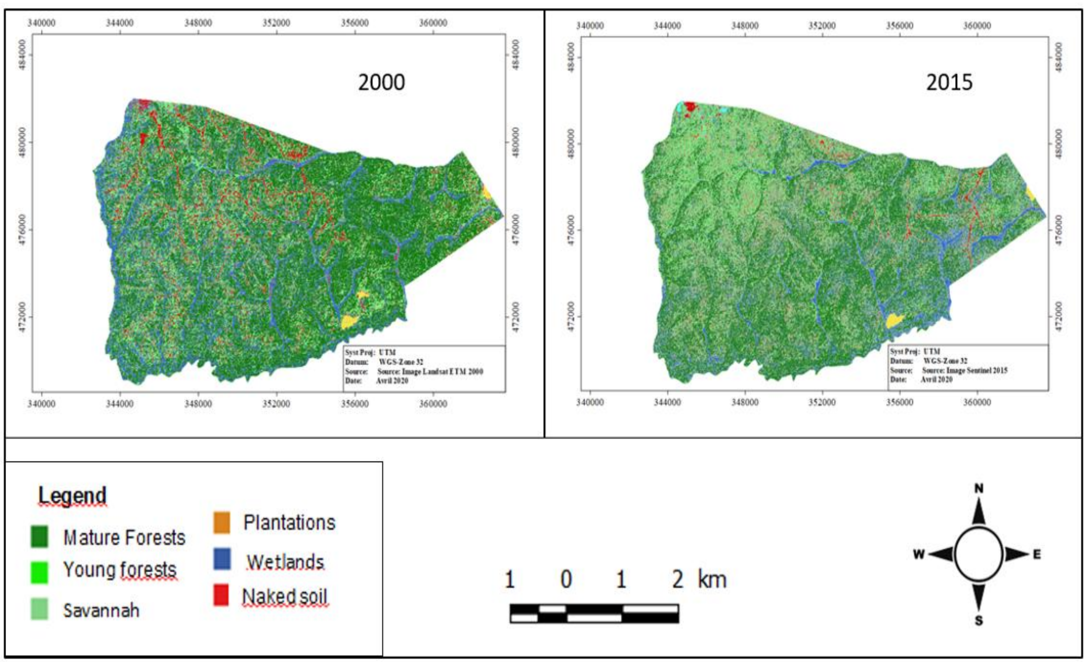

Fig. 2. Maps of land use types

Evolution of Land Use/Land Cover

An examination of Table 1 shows that between 2000 and 2015 mature forests decreased by 22.94 % in their area. Of the 56.04 % of the area occupied in 2000 by mature forests, 33.10 remained stable: 14.84 % were transformed into young forests, 6.04 % into wetlands, 0.01 % into savannah and 2.06 % into bare soils. The proportion of young forests was 21.65% in 2000 and 30.04% in 2015, with an increase of 8.39% in area.

Until 2000, the DCF was dominated by mature forests (56.04 %), followed by young forests (21.65 %) and savannahs were less represented (0.36 %). In 2015, the dominance of the DCF by mature forests has not changed much since they occupy 52.42% of the space (Table 2).

Table 3 shows that carbon stocks vary across carbon strata and pools. Carbon stocks are higher in mature forests (133.42 tC/ha) and low in swamps (6.71 tC/ha). Regarding the pools, the aboveground compartment stores more carbon (224.88 tC/ha), followed by the underground compartment (42.88 tC/ha) and finally dead standing wood (2.59 tC/ha).

Carbon Stock Mapping

The examination of Fig. 3 showed a high concentration of carbon in forest formations (mature and young forests) with 98.14 tC/ha and 93.24 tC/ha, respectively. Swamps sequestered less carbon (5.39 tC/ha). The spatialization map of carbon stocks show its density, which varies according to the intensity of the coloration (Fig. 3) at the scale of the territory concerned in this study. Thus, dark-coloured

Table 1. 2000 and 2015 land cover transition matrix (percentage)

		Land use in 2015						
	Land use/land cover types	**Mature forests**	**Young forests**	**Wet-lands**	**Planta-tions**	**Savan-nahs**	**Niked soils**	**Total in 2000**
Land use in 2000	Mature forests	**33,10**	14,84	6,04	0,01	0,00	2,06	56,04
	Young forests	9,02	**8,92**	1,76	0,18	0,00	1,78	21,65
	Wetlands	8,40	3,16	**3,25**	0,06	0,01	0,43	15,31
	Savannahs	0,05	0,01	0,04	**0,00**	**0,27**	0,00	0,36
	Niked soils	1,86	3,12	0,51	0,04	0,02	**1,10**	6,64
	Total in 2015	52,42	30,04	11,59	0,28	0,30	5,36	100

Table 2. Areas in hectares and as a percentage of land cover classes

Land use/land cover types	**Land cover areas**			
	2000		**2015**	
	ha	**%**	**ha**	**%**
Mature Forests	10 079,02	56,04	9 427,85	52,42
Young Forests	3 894,12	21,66	5 403,04	30,04
Wetlands	2 752,89	15,31	2 085,03	11,59
Plantations			50,88	0,28
Savannahs	65,22	0,36	53,88	0,3
Niked soils	1 193,47	6,63	964,04	5,36
Total	17 984,73	100	17 984,73	100

Table 3. Carbon stocks per Land use/land cover types in the Dimako Communal Forest

Land use/land cover types	Carbon stocks			
	Above-groung	Dead standing wood	Underground	Total
Mature forests	98,14	2,24	33,04	133,42
Yong forests	93,24	0,11	3,74	97,09
Swamp	5,39	0,24	1,08	6,71
Plantation	28,11		5,02	33,13
Total	224,88	2,59	42,88	270,35

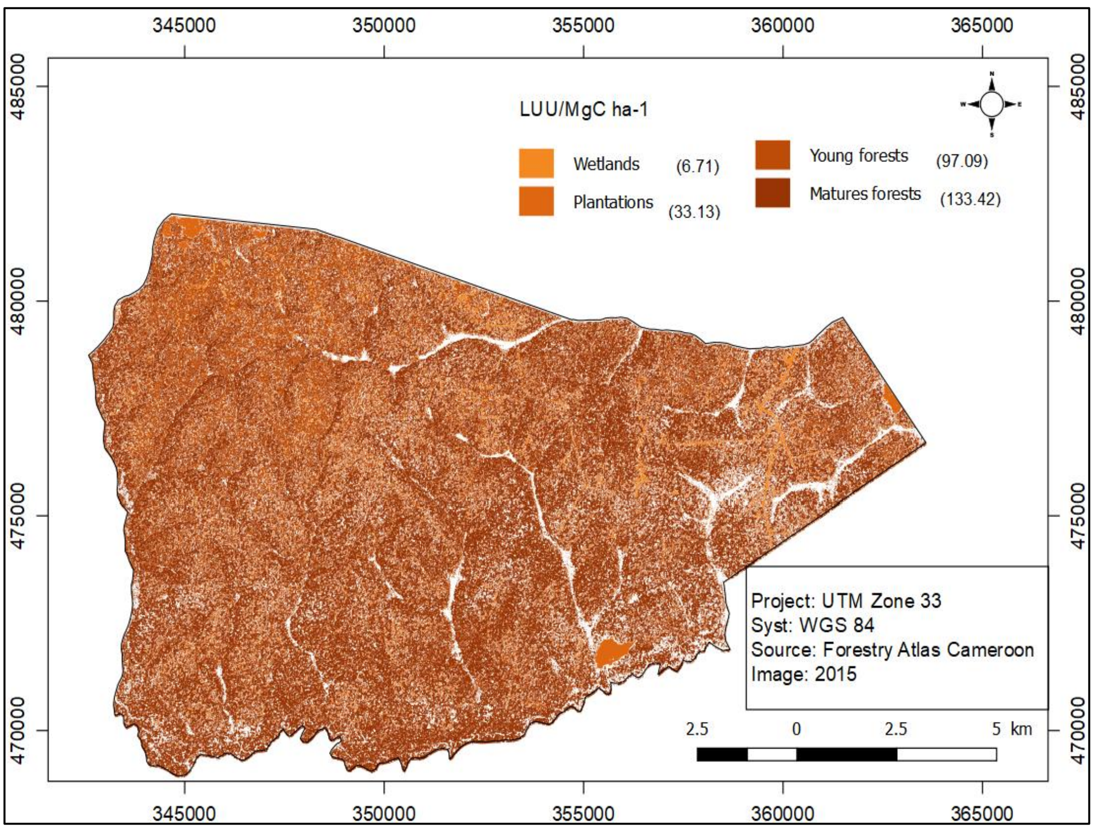

Fig. 3. Carbon map of the Dimako Communal Forest

areas represent mature forests in which carbon stocks are maximum. The intensity of the colour decreases with the carbon stocks contained in the vegetation. Uncoloured (white) surfaces represent areas that have not been inventoried. These include streams, built-up areas, roads and tracks, and other bare surfaces such as rocks or sand.

DISCUSSION

The results of this study show that the DCF forest cover increased considerably between the two dates the forest area (mature and young forests) increasing from 77.69% in 2000 to 82.46% in 2015. This increase in area could be justified by the regulation of logging operations and the eviction of the population since the 2000. The same observation was made by [31] in the Lamto Scientific Reserve in Côte d'Ivoire. Notwithstanding the increase in forest area between the two dates, there has been a continuous decline in wetlands, savannahs and bare soils. Similar observations were made by [19] in the Doumé Communal Forest and [32] in the Bouba Ndjidda National Park in Cameroon.

The degradation of the environment translated by the regression of natural formations is essentially linked to socio-economic development activities (timber exploitation) in a context of demographic pressure [33]. Some authors have advanced certain modes of exploitation as being responsible for land degradation resulting in the disruption of ecological balances [34].

The averages of spatial carbon stocks obtained in the tropics are very contrasting. They differ according to the strata [35,36]. These authors claimed that the spatial variation of average carbon stocks is a function of the vegetation type, microclimate, forest age, but also forest structure. The results of this study support these claims.

The sequestered carbon value is higher in mature forests (133.42 tC/ha) and could be explained by the abundance of large diameter stems. These values are lower than those obtained by [37] in the Ngog-Mapubi/Dibang forest massif (177.42 tC/ha); by [38] in the forest management unit 03-008 located in the district of Ngambé-Tikar in Cameroon (169.1 tC/ha).

This large spatial variation could also be explained by several factors such as the biodiversity of forest species, the local climate, the geological and soil substrate, the influence of anthropogenic factors such as deforestation and forest degradation, relief, forest structure and forest stratum [39, 40]. It has also been shown that the sampling methodology, and the type of allometric equation used could explain the variability of the carbon stocks [41].

Carbon stock values are very low in swamps (6.71 tC/ha) due to the absence of large diameter trees in this type of biotope. In addition, the swamps of the study site are characterized by the abundance of species *raffia* sp. On the other hand, the carbon stocks of young forests (97.09 tC/ha) are similar compared to those obtained by [37].

The total carbon stocks for dead standing wood obtained in this study differ from stratum to stratum. The high value in mature forests could be accounted for by: natural windfalls that might have led to the death of certain trees; competition for light that could inhibit the evolution of certain trees thereby causing their death; soil pedology and climate change.

In addition to the factors cited above, other facts could explain the differences in dead wood carbon stocks noted. [42] point out that carbon stocks of dead wood vary according to study sites and methods of assessment.

CONCLUSION

The diachronic study of changes is an effective approach allowing rapid assessment through mapping, highlighting the dynamics of land use/land cover change and their repercussions on the natural environment. Remote sensing tools (satellite imagery) combined with geographic information systems were of great use in this study. The evaluation of the land cover maps from the supervised classifications of the two Landsat images (TM and OLI-TIRS) made it possible to highlight the issues and threats to the ecological balance in the DCF. The present study highlighted the existence of very high variability of carbon stocks in four types of land use/land cover types. The results reveal that carbon stocks vary from one stratum to another. They are influenced by factors such as: the allometric equation, climate change, anthropogenic action, pedology, wood diversity, sampling methodology and geological substrate.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, et al. A large and persistent carbon sink in the world's forests. Science. 2011;333: 988-993.
2. Van der Werf GR, Morton DC, DeFries RS, Olivier JGJ, Kasibhatla PS, Jackson RB, Collatz GJ, Randerson JT. CO_2 emissions from forest loss. Nat. Geosci. 2009;2(11): 737-738.
3. Maxwell S, Fuller R, Brooks T, Watson J. Biodiversity: The ravages of guns, net and bulldozers. Nature. 2016;536(143).
4. IPCC. Climate Change Review 2007: Contribution of Working Groups I, II and III to the IPCC Fourth Assessment Report. 2007;104.
5. Mounmemi KH, Zapfack L, Maffo MLN, Arouna O, Chimi DC, Kabelong BLPR, Temegne NC, Ntonmen YFA, Tchoupou VM, Tabue MR, Kenmougne GPM, Daghela MRG, Leukefack A. Vegetation dynamics in a forest management context in Cameroon: case of Dimako Communal Forest. J.Bio. & Env. Sci. 2020;17(3):139-155.
6. Angelsen A, Brockhaus M, Sunderlin WD, Verchot LV. RedD+ analysis: the challenges and choices. Bogor, Indonesia: CIFOR; 2013.
7. Gibbs HK, Brown S, Niles JO, Fole JA. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environ. Res. Lett. 2007;2(4): 045023.
8. Baccini A, Goetz SJ, Walker WS, Laporte NT, Sun M, Sulla-Menashe D, et al. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. Nat. Clim. Change. 2012;2(3):182-185.
9. Betti JL, Mebere YSR. Contribution to the knowledge of non-timber forest products in Kalamaloué National Park, Far North Cameroon: food plants. International Journal of Biological and Chemical Sciences. 2011;5(1):291-303.
10. Lambin EF, et al. The causes of land-use and land-cover change: moving beyond the myths. Glob Environ Change. 2001;11:261–269.
11. Ngo MK, Turner LB, Muller-Landau CH, Stuart J, Davies SJ, Larjavaara J, Hassan NFN, Lum S. Carbon stocks in primary and secondary tropical forests in Singapore. Forest Ecology and Management. 2013;296: 81-89.
12. Dupuy B. Silviculture and productivity of dense humid forest in Côte d'Ivoire.

IDEFOR/D.F.O., CIRAD-Forêt, Paris. 1998;22.
13. Djomo AN. A structure qnalysis for ecological management of moist tropical forests. International Journal of Forestry Research; 2015. Article ID 161645, 12 p.
14. Bergonzini. Climate change, desertification, biodiversity andforests. RIAT and SYLVA, Paris. 2004;140.
15. ITTO. ITTO/IUCN Guidelines for the Conservation and Sustainable Use of the biodiversity in timber-producing tropical forests, ITTO/IUCN, Genève. 2009;127.
16. Smith P, Chapman SJ, Scott WA, Black HIJ, Wattenbach M, Milne R, et al. Climate change cannot be entirely responsible for soil carbon loss observed in England and Wales, 1978-2003. Global Change Biology. 2011;13:2605-2609.
17. Gidey E, Dikinya O, Sebego R, Segosebe E, Zenebe A. Modeling the spatio-temporal dynamics and evolution of land use and land cover (1984–2015) using remote sensing and GIS in Raya, Northern Ethiopia. Model Earth System Environ. 2017;3: 1285–1301.
18. Abdelbaki A. Use of GIS and remote sensing in the study of the dynamics of vegetation cover in the sub-watershed Oued Bouguedfine (Wilaya of Chlef). Memory of magister, University Hassiba Ben Bouali Chlef of Algeria. 2012;95.
19. Zekeng JC, Reuben S, Wanda NM, Morati M, Dileswar N, Fobane JL, et al. Land use and land cover changes in Doume Communal Forest in eastern Cameroon: implications for conservation and sustainable management. Modeling Earth Systems and Environment. 2019;5: 1801–1814.
20. PA. Revised management plan of the communal forest of Dimako, MINFOF, Yaoundé. 2006;74.
21. Letouzey R. Notice of the Phytogeographical Map of Cameroon at 1/500000. IRA/Inst. Cart. Intern. Vegetation: Toulouse. 1985;240.
22. Letouzey R. Phytogeographical study of Cameroon. Biological Encyclopedia, LXIX, Paris. 1968; 512.
23. Tchiengue B. Ecological and floristic study of the vegetation of a massif of the line of the Cameroon: Mont Koupe, Doctoral Thesis 3rd cycle, University of Yaoundé. 2004;1:238.
24. Hakizimana P, Bangirinama F, Havyarimana F, Habonimana B, Bogaert J. Analysis of the effect of the spatial structure of trees on the natural regeneration of the forest claire de Rumonge au Burundi. Sciences Institut of Natural Environment and Conservation. 2011;9:46-52.
25. Fayolle A, Ngomanda A, Mbasi M, Barbier N, Bocko Y, Boyemba F, et al. A regional allometry for Congo bassin forests on the largest ever destructive sampling. Forest Ecology and Management. 2018 ;430:228-240.
26. Reyes G, Brown S, Chapman J, Lugo A. Wood densities of tropical tree species. Gen. Tech. Rep. SO-88, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 1992;15.
27. Fayolle A, Doucet JL, Gillet JF, Bourland N, Lejeune P. Tree allometry in Central Africa: Testing the validity of pantropical multi-species allometric equations for estimating biomass and carbon stocks. Forest Ecology and Management. 2013 ;305: 29–37.
28. Brown S. Estimating biomass and biomass change of tropical forests: a

primer. FAO Forestry Paper n° 134, Rome. 1997;53.

29. Zapfack L, Noiha NV, Dziedjou KPJ, Zemagho L, Fomete NT. Deforestation and carbon stocks in the surroundings of Lobéké National Parc (Cameroon) in Congo Basin. Environment and Natural Resources Research. 2013;3(2):1-9.
30. Ponce-H. A Modelling Framework for addressing the Synergies between Global Conventions through Land Use Changes: Carbon Sequestration, Biodiversity Conservation, Prevention of Land Degradation and Food Security in Agricultural and Forested Lands in Developing Countries. FEEM Working Paper No. 30.2007; 2007. Available :http://dx.doi.org/10.2139/ssrn.976600
31. Gueulou N, Douffi KGC, Soro Y, Kone M, Bakayoko A. The forest cover and the forest carbon stock assessment of Lamto Scientific Reserve (Côte d'Ivoire). International Journal of Innovation and Applied Studies. 2020;28(3):682-689.
32. Djiongo BEJ, Desrochers A, Avana TLM, Khasa D, Zapfack L, Fotsing É. Analysis of spatio-temporel dynamics of land use in the Bouba Ndjidda national Park and its adjacent zone (North Cameroon). Open Journal of Forestry. 2020;10:39-57.
33. Pale FK. The role of anthropogenic action in the degradation of natural resources in Niaogho-Beguedo. Berichte des Sonderforschungsbereichs. 2000;268 (14):521-533.
34. Atta S, Achard F, Ould MOMS. Recent evolution of the population, land use and floristic diversity on an agricultural terroir in south-west Niger. Science and Nature. 2010;7(2):119-129.
35. Mugnier A, Cassagne B, Bayol N, Lafon C. Estimation of carbon stocks of Congo Basin forests for REDD: comparative study conducted on 22 forest types, 4 countries and a management scheme –4.8 million ha. XIII World Forestry Congress, Buenos Aires. 2009;156.
36. Ifo SA, Binsangou S, Ibocko Ngala L, Madingou M, Sanchez AC. Seasonally flooded, and terra firme in northern Congo: Insights on their structure, diversity and biomass. African Journal of Ecology. 2018;1-12.
DOI: 10.1111/aje.12555.
37. Ngoufo R, Zapfack L, Tiomo ED, Goufo TRS, Guimdo MS. Assessment and spatialization of carbon stored in the Ngog-Mapubi forest massif (Cameroon). OSFACO Conference: Satellite images for sustainable land management in Africa, Mar 2019, Cotonou, hal-02189496; 2019.
38. Mounmemi Kpoumie Hubert, Tsouga Manga Milie Lionelle, Maffo Maffo Nicole Liliane, Ngodo Melingui Jean Baptiste, Chimi Djomo Cedric, Tchoupou Votio Carole Mireil, et al. Pre and post-logging carbon stocks: Case of the forest management unit (Fmu) 08 003. Asian Journal of Research in Biosciences. 2021;3(4): 1-11.
39. Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, et al. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. 2005;145:87–99.
40. Ifo SA, Binsangou SM. Spatial variability of the carbon stock of above-ground biomass from urban area to dense tropical forest in five localities in the Republic of Congo. OSFACO Conference: Satellite images for the sustainable

management of territories in Africa, Mar 2019, Cotonou, Benin. ffhal-02189395e; 2019.

41. Molto Q. Biomass estimation in tropical rainforest: Propagation of uncertainties in the modelling of the spatial distribution of biomass in French Guiana. Thesis Physiology and biology of organisms, populations interactions, University of the West Indies and Guyana. 2012; 184.

42. Baker TR, Coronado ENH, Phillips OL, Martin J, Van der Heijden GMF, Garcia M, Espejo JS. Low stocks of coarse woody debris in a southwest Amazonian forest. Oecologia. 2007; 152:495–504.
