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Vegetation dynamics in a forest management context in Cameroon: Case of Dimako Communal Forest

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Abstract

The Communal forests allocated in Cameroon are of increasing interest for an ecologically acceptable, economically viable and socially equitable management. The main objective of this research is to highlight the implication of forest management on the dynamics of land use units (LUU) through a spatio-temporal analysis of satellite images. This aiming to providing decision-makers with basic tools that can contribute to the sustainable management of natural resources, by providing answers to questions related to the implementation of REDD+ in the production forests in Cameroon. To this end, the processing of Landsat images from 1984, 2000 and Sentinel images from 2015 was carried out. The methodological approach adopted consisted of a supervised classification with maximum like - data coupled with true field data. The results obtained made possible to identify five LUUs in the years 1984 and 2000 and six land use units in 2015. These are mature forests, young forests, wetlands, plantations, savannas and naked soils. Woody systems represent the most dominant land use categories. The results showed a regression of young forests of the order of -94.07ha/year between 1984 and 2000. However, in between 2000 and 2015, a progression of young forests was observed with an evolution rate of 100.59ha/year. In the light of the various analyses carried out within the framework of this study, it will be remarkable to stress out the importance of forest management in maintaining and restoring the plant cover and, by so, the conservation of biodiversity.

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Introduction

Africa's tropical rainforests contain an exceptional biodiversity and constitute an invaluable potential for the socio-economic development of the sub-region (Doetinchem and Megevand, 2013; Onana, 2013; MINFOF, 2015). These forest ecosystems represent useful conservation areas for humankind because of the role they play in maintaining biodiversity, climatic and ecological balances (FAO, 2007; Ngoufo *et al.*, 2019). Moreover, they provide multiple ecosystem services and are therefore threatened (Lambin *et al.*, 2001; FAO, 2015). However, changes in occupation and land use strongly and rapidly affect biogeochemical cycles at local, regional and even international scales (Barima *et al.*, 2009; Noumi *et al.*, 2011; Adjonou *et al.*, 2018). The ecological richness of these forests thus stimulates many empirical and theoretical research aimed at better understanding of their origins and the mechanisms of their maintenance. The forests of the Congo Basin are subject to various disturbances, mainly anthropogenic (Souza *et al.*, 2015). According to FAO 2012, Arouna *et al.* (2011), Eva *et al.* (2010) anthropogenic disturbances are mainly represented by the unsustainable exploitation of timber and Non-Timber Forest Products (NTFPs), the development of infrastructural activities exposing the forest cover and large-scale agricultural activities. Indeed, these different forms of land use have been identified as major drivers of global environmental change (Minta *et al.*, 2018; Zoungrana *et al.*, 2018). However, the impacts of land cover conversions on biodiversity (Sala *et al.*, 2000), land degradation (Trimble & Crosson, 2000; Choudhury *et al.*, 2018), and the capacity of biological systems to support human needs (Vitousek *et al.*, 1997) are a major concern worldwide.

Since its classification in 2001, the Dimako Communal Forest (DCF) represents an integral conservation forest under the management of the Dimako commune, and the first communal forest granted after forest reforms in Cameroon (FAO, 2007; Ezzine *et al.*, 2006). The DCF, like any other forest in the Congo Basin, is not spared from anthropogenic disturbances before and after its classification; these include selective logging. All these factors put pressure on the natural landscape (Aldwaik & Pontius, 2012; Ngoufo *et al.*, 2019). Highlighting and controlling these factors constitute a step forward on the effective conservation of ecosystems and associated biodiversity (Eba'a, 2006; Leroy *et al.*, 2013).

In Africa, important work on the study of the spatio-temporal dynamics of land use and vegetation cover types has been carried out in classified forests, protected areas, forest galleries and localities. These include the work of Djiongo *et al.* (2020) in the Boouba Ndjidda National Park in Cameroon, Zekeng *et al.* (2019) in the communal forest of Doumé, Jiagho *et al.* (2019) in the periphery of the Waza National Park, Momo *et al.* (2018) in the forest galleries of Koupa-Matapit in Cameroon, Koffi *et al.* (2016) in the Prefecture of Yoto in south-eastern Togo, Soulama *et al.* (2018) in the forest galleries of Koupa-Matapit in Cameroon, Koffi *et al.* (2016) in the Prefecture of Yoto in south-eastern Togo, and Soulama *et al.* (2017) in the Partial Wildlife Reserve of Pama and its peripheries in Burkina-Faso, Avakoudjo *et al.* (2014) in the W National Park and its periphery in north-west Benin, Sandjong *et al.* (2013) in the Mozogo-Gokoro National Park in Cameroon, Momo *et al.* (2012) in the forests of Mount Oku in Cameroon, Diallo *et al.* (2011) in the Fina Reserve in Mali, etc. However, these studies were limited to disturbances that act on the natural landscape, i.e. on the vegetation succession process.

In Cameroon, references in terms of land use and their dynamics based on scientific foundations are currently very poorly documented in the Communal Forests (CF). So far in the CFs in Cameroon, no studies have been carried out on the impact of forest management on the evolution of land use since the forest reform. Moreover, almost two decades after the first CFs were allocated the contrast between the efforts made and the results obtained by the Cameroonian government is so far insufficient. They come up against a lack of knowledge on the complexity of the dynamics of forest cover in the exploited plots. However, the dynamics help to have a better understanding of the different trends in the spatial transformation processes (Lambin *et al.*, 2001; Gidey *et al.*, 2017). Clear resolution and spatial explicit data on natural landscape fragmentation are needed to understand the impact of land-use change on biodiversity (Margules and Pressey, 2000; Liu *et al.*, 2001; Ghilardi *et al.*, 2016). Predicting how land-use and land-cover changes affect land degradation requires a good understanding of the dynamic interactions between humans and the environment associated with land-use change (Kasperson *et al.*, 1995; Tabari *et al.*, 2015). However, maintaining forest cover is a major challenge for the coming decades. Meeting such a challenge requires knowledge of land use dynamics through multi-date analysis of vegetation using satellite images (Sarr, 2008; Mama *et al.*, 2013; Gidey *et al.*, 2017). This analysis involves the use of Geographic Information Systems (GIS) and remote sensing (Momo *et al.*, 2018; Botlhe *et al.*, 2019). With a view of providing the various stakeholders and decision-makers with the basic tools (Tankoano *et al.*, 2016) that can contribute to sustainable natural resource management, this analysis is of relative importance. It provides answers to the questions on the implementation of REDD+ (Kankeu *et al.*, 2013) in the production forests in Cameroon. Thus, in the context of forest management, the study of land use dynamics in CFs has become a leitmotiv both for the knowledge of an ecosystem and for its planning. Since then, the concept of forest management has raised up many questions: what is its implication in the maintenance of natural resources? Does it take place in time or in space? The study of spatio-temporal monitoring of land use on the scale of the DCF will provide answers to these questions. The objective of this research is to assess the impact of forest management on the spatio-temporal dynamics of land use in the DCF. It is based on the hypothesis that DCF classification has improved the state of vegetation with a progression of dense formations.

Material and methods

Study site

DCF is located in the East Region of Cameroon, Haut-Nyong Department, Dimako District (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. Average rainfall varies between 1500 and 1800 mm/year and the average temperature is 2.4°C. The order of magnitude of the slopes is from 0 to 15% and the altitude varies between 596 and 689 m (Plan d'aménagement, 2006). Phytogeographically, its vegetation is that of a semi-deciduous dense forest (Letouzey, 1985).

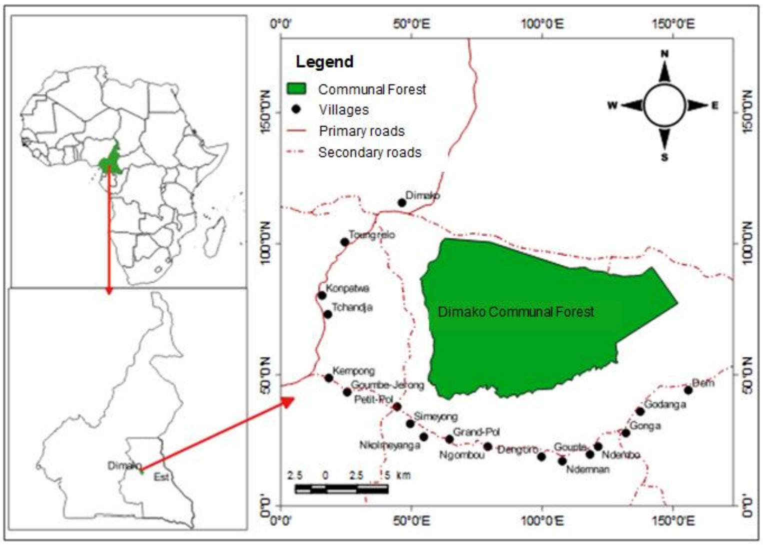


Fig. 1. Study area location map.

Methodology

Geo-spatial data

The occupancy dynamics within the DCF were established from satellite images from the Landsat ETM (1984) and ETM (2000) series sensors and Sentinel 2A from 2015, which are considered as reference years. These images were selected before classification/development, during classification/ development and after classification/ development respectively. Landsat satellite images are selected for their synoptic nature over a large area, their availability over a long period of time and the potential they offer in relation to the scale of the documents to be developed. In addition, the spatial resolution of these data (79-80m for MSS: Multi Spectral Scanner; 30m for TM: Thematic Mapper and ETM +: Enhanced Thematic Mapper plus) makes it possible to characterize landscape features on the ground at 900m² (Oszwald *et al.*, 2010). This is then sufficient to identify homogeneous landscape structures specific to the study area. In addition to these satellite images, cartographic data from Cameroon was also added. Fig. 2 explains the methodology adopted for this study.

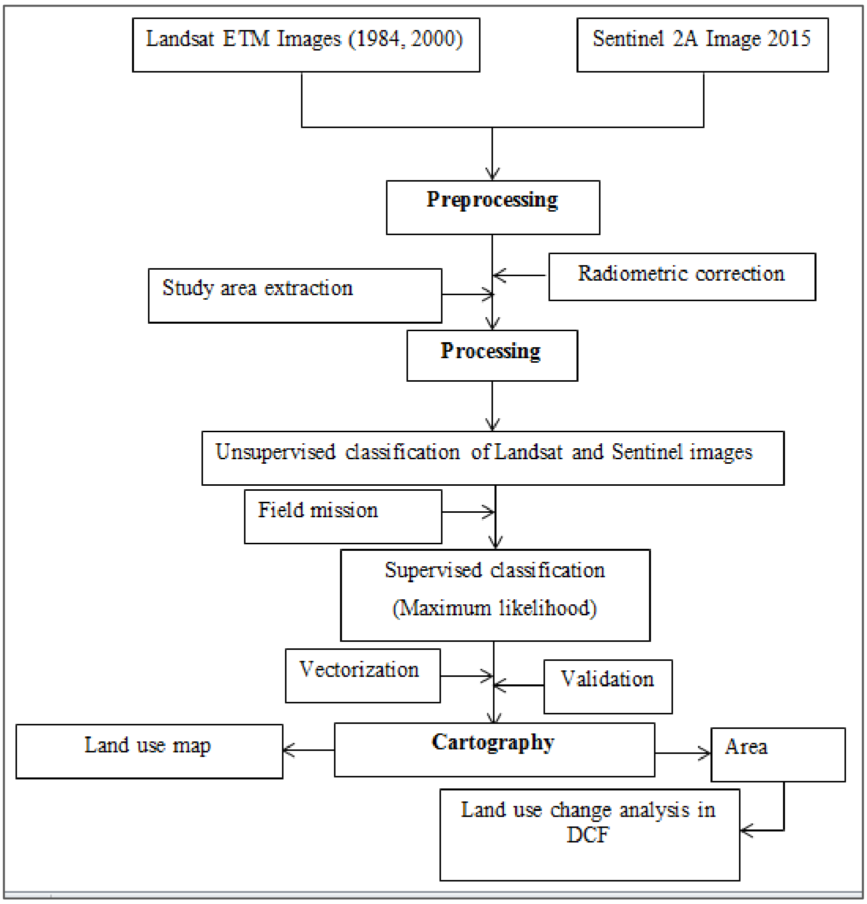


Fig. 2. Method of producing the map of land use dynamics in the CDF.

Satellite image processing

The processing of satellite images was observed in several stages:

- Image pre-processing: image pre-processing has made it possible to increase the readability of the data and facilitate their interpretation and better information extraction. These preliminary operations have been applied through radiometric improvements and geographic resetting after the linear spreading of the histograms of each spectral band to improve the contrast. These correction operations, geometric and/or radiometric distortions of the satellite images ensured good quality images for better use.

- Field control: the aim of the field mission carried out was to identify and define the landscape features of the study site and to survey GPS (Global

Positioning System) points representative of each land use class previously defined. The data thus obtained was to enable the understanding of satellite data, then of ground true-points for the validation of the most recent classification (2015). The points were collected along a 2500 m x 20 m transects.

- Unsupervised Classification/Coloured Composition: This procedure involved classifying digital image data by computer processing. This is based solely on image statistics without the use of training samples. In order to extract the study sites, coloured composition was performed following several combinations. Coloured composition of bands 4-5-7 was chosen for Landsat satellite images (TM and ETM+) and bands 4-3-2 for the Sentinel 2A image (Mama *et al.*, 2013). Indeed, it represents the best discrimination of land cover types. Following this operation, training sites are selected based on their spatial distribution and knowledge of the study site.

- Supervised classification: This is used to identify "spectrally similar" areas of an image. It consists of assigning each group of pixels the most plausible class based on the spectral similarity between pixels and the class signature. The maximum likelihood algorithm was used to determine the digital signature of each class. This step is mathematically very satisfactory because the pixels are classified according to a probabilistic method. This method considers that all the classes have the same a priori probability. However, the accuracy of the classification was evaluated by projecting onto the classified images the GPS points containing exact information of the sampled sites.

- Detection of change between different dates (2000 and 1984, 2015 and 2000): This process allowed the unsealing of land cover changes between Landsat (TM (1984), ETM (2000)) and Sentinel 2A images. According to Girard and Girard (1999), it is not always easy to assign a pixel to a given class, nor to associate a specific class to a survey in the field, hence the need to evaluate the overall effectiveness of the classification. Two approaches have been used to define classification quality:

- - The confusion matrix: here, the accuracy of a classification corresponds to the percentages of well-classified pixels translated by the values on the diagonal. These matrices allow us to judge the relevance of the classification algorithm (Omari, 2005).
- - The Kappa coefficient designates a value slightly lower than the total accuracy. Dos Santos (2001) mentions that the latter expresses the error rates to be avoided and that would be obtained in sampling that must be completely random. The critical value beyond which a classification is considered acceptable is 75% (Girard and Girard, 1999; Caloz and Collet, 2001). The Kappa index is given by the following formula:

$$\text{Kappa} = \frac{P_{0} - P_{c}}{P_{p} - P_{c}}$$

With P_o: correct proportion observed; P_c: correct proportion except at random and P_p: correct proportion when the classification is perfect.

CDF land cover and land use analysis

The quantitative analysis performed provides a matrix for detecting changes resulting from the comparison between pixels of the classifications between two dates (Girard and Girard, 1999).

Calculation of the average annual rate of spatial expansion and the overall rate change

The average annual rate of spatial expansion expresses the proportion of each unit of land use that changes annually (Toko, 2014). The mathematical formulae are as follows:

(1) Annual expansion rate

$$\mathbf{Re} = \frac{\ln(S_2) - \ln(S_1)}{(t_2 - t_1) x \ln(e)} x100$$

With S_1: area of a unit of land occupation at date t_1; S_2: area of the same land occupation at date t_2; $(t_2 - t_1)$: difference in years between t_1 and t_2; ln: Naperian logarithm; e: base of the Naperian logarithms (e=2.71828).

(2) Global change rate

$$\mathbf{Rg} = \frac{S_2 - S_1}{S_1} x100$$

Where S_1: area of a unit of land occupation at date t; S_2: area of the same land occupation at date t_2.

Calculation of conversion rate

The conversion rate of a unit of land occupancy refers to the degree to which this class has been transformed by converting to other units of occupancy. It is obtained from a transition matrix (Issiako and Arouna, 2018). The mathematical formula is as follows:

$$\mathbf{CR} = \frac{S_{it} - S_{is}}{S_{it}} \mathbf{x100}$$

With Sit: area of the land occupancy unit i at initial date t; Sis: area of the same unit that remained stable at date t_1.

Calculation of the change rate of LUU

The rate change of the identified LUU was calculated according to the formula (Zakari *et al.*, 2018):

$$\Delta_s = \frac{S_{p2} - S_{p1}}{t_2 - t_1}$$

With Δs: rate of change (progression or regression inha/year); SP_1: area occupied by the land use unit considered in year 1 (ha); SP_2: area occupied by the land use unit considered in year 2 (ha); t_1: year 1; t_2: year 2.

Calculation of deforestation rate

The deforestation rate represents the fraction of forest transformed by other types of land use other than forestry. It was calculated using the formula proposed by Zakari *et al.* (2018) and adjusted in this analysis. Its mathematical equation is as follows:

$$R = \frac{1}{t_2 - t_1} \ln\left(\frac{A_2}{A_1}\right) x100$$

With R: deforestation rate; A_1 and A_2 is the sum of the share of land use units for each year; ln: Neperian logarithm; t_1: year 1; t_2: year 2.

Calculation of the annual degradation rate (ADR)

The rate of degradation represents the fraction of the forest disturbed at a given time. It has been assessed using the formula developed by Kamungandu (2009).

$$ADR = \left(\frac{S_2}{S_1}\right)/tx100$$

With S_1: initial forest area; S_2: area of forest lost; ADR: average annual rate of degradation (%); t: number of years between the two dates.

Stratification of occupancy classes

The forest stratification standards developed in 2016 in the Democratic Republic of Congo (MINECNDD, 2016) and the inventory standards for management and pre-investment in Cameroon (MINFOF, 1991) served as a basis for identifying the different occupation units in this work.

Results

Dynamics of land use in the DCF

Land use in 2015

Fig. 3 shows the land use categories identified after classification of the 2015 Sentinel image. A total of six land use units were mapped in 2015; these are mature forests, young forests, wetlands, savannas, plantations and bare soils. Mature forests and young forests are the most dominant land use classes in the study site

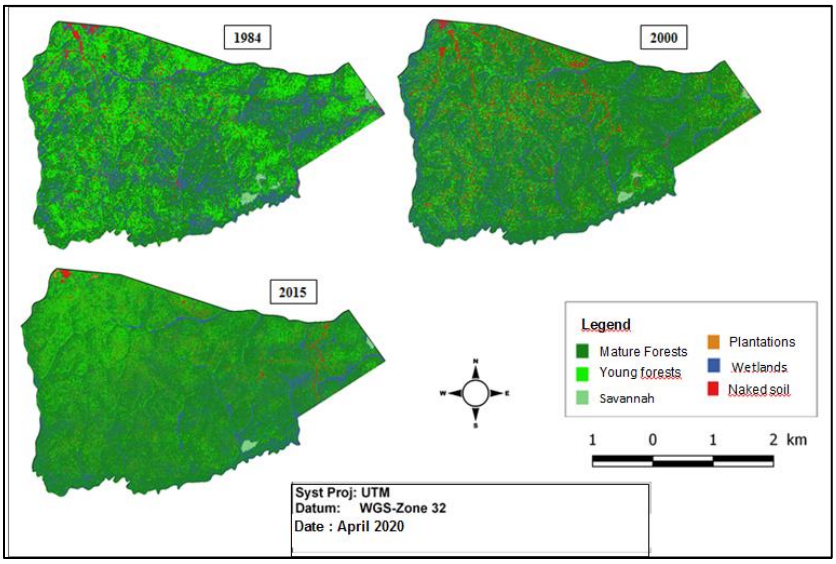


Fig. 3. Land use map.

From this analysis, six (06) categories of land occupation in 2015 in the DCF emerge, unevenly distributed according to the different dates.

- *Mature or old forests:* these represent forests with trees of harvestable age or harvestable diameters. These formations are in the form of forest patches distributed in the DCF. This distribution is due to selective logging for a long time by the SFID (Société Forestière Industrielle de la Doumé) in the area before classification. They occupy an area of 9,427.85 ha, i.e. 52.42% of the total area of the study zone.
- *Young or secondary forests:* this land use unit group together forests that have been subject to anthropic action. These forests systems represent forest stands in which the majority of the trees are not of harvestable age or harvestable diameter. They are the result of the re-vegetation after logging in the past by the SFID and the reforestation carried out by the Dimako commune. They occupy a total area of 5,403.04 ha i.e. 30.04% of the entire DCF.
- *Wetlands:* These include permanently flooded swamps (PFS) made up of *Raphia hookeri*, *Allanblackia floribunda* and *Xylopia staudtii*, temporarily flooded swamps (TFS) made up of *Uapaca guineensis* and *Diospyros crassiflora*, ravines crossed by non-shrubby swamps and water bodies. These wetlands are mostly concentrated in the northern part of the communal forest. They occupy an area of 2,085.03 ha i.e 11.59% of the total area of the DCF.
- *Plantations:* These are oil palm plantations with species of *Baillonnella toxisperma* that have been reforested by the Dimako Commune officers. They are located in the north-western part of the forest and occupy an area estimated at 50.88 ha i.e 0.28% of this communal forest.
- *Savannahs:* These are shrubby savannahs located mostly in the eastern and south-eastern part of the forest, with most of it been at a stable state. They occupy an area of 53.88 ha i.e 0.3% of the total forest area.
- *Naked soils:* Naked soils represents lands located on the periphery of the communal forest; open spaces by roads access, timber parks, logging yards and felling holes. They occupy a surface area of 964.04 ha, i.e. 5.36% of the entire forest massif.

Moreover, analysis of the 1984 and 2000 images shows five categories of land use classes, namely mature forests, young forests, wetlands, savannahs and naked soils.

Dynamics of land tenure units in the DCF

Change in land use between 1984 and 2000

The information obtained by overlaying the maps of the years 1984 and 2000 on one hand, 2000 and 2015 on the other hand show that the DCF has undergone significant changes in terms of land use.

The results in Table I explain the average annual rate of spatial expansion and the rate change of LUU according to two dynamics states (progression and regression). Thus, from the five (05) identified LUU in the DCF between 1984 and 2000, three (03) expressed a relatively significant regression; notably young forests, wetlands and savannahs whose rates of change are -27.88% and -11.38% and -34.65% respectively. Mature forests and naked soils, on the other hand, increased in area ie 56.04 and 6.63% respectively, with an expansion rate of 3.08%. Wetlands represent the LUU that expressed the smallest regression with an expansion rate of -0.75% in the DCF between 1984 and 2000.

Table I. Average annual rate of spatial expansion and rate change of LUU (1984-2000).

LUU	Land use areas 1984		Land use areas 2000		Expansion rate (%)	Change rate (%)
	ha	%	ha	%		
Mature forests	8 650,46	48,1	10 079,02	56,04	0,95	16,51
Young forests	5 399,19	30,02	3 894,12	21,66	-2,04	-27,88
Wetlands	3 106,55	17,27	2 752,89	15,31	-0,75	-11,38
Savannah	99,81	0,56	65,22	0,36	-2,66	-34,65
Naked soils	728,71	4,05	1 193,47	6,63	3,08	63,78
Total	17 984,73	100	17 984,73	100		

LUU : Land Use Units

In Table II, six (06) categories of LUU have been identified between the years 2000 and 2015. The table II analysis shows a regression in four land use classes namely mature forests (-6.46%), wetlands (-24.26%), savannahs (-17.39%) and naked soils (-19.22%). In 2000, the vegetation systems was dominated by mature and young forests, which accounted for 48.05% and 30.06% of the total forest area respectively (table II). Till 2015, the area of mature forests decreased in favor of plantations and this to the detriment of savannahs whereas younger forests have intensified against naked soils. The presence of plantations is essentially linked to the initiatives undertaken by Non-Governmental Organizations (NGOs) and the Commune of Dimako to reduce its dependency on forest resources. These initiatives coupled with logging activities have led to a considerable reduction of naked soil with an average annual rate of spatial expansion of -1.42%.

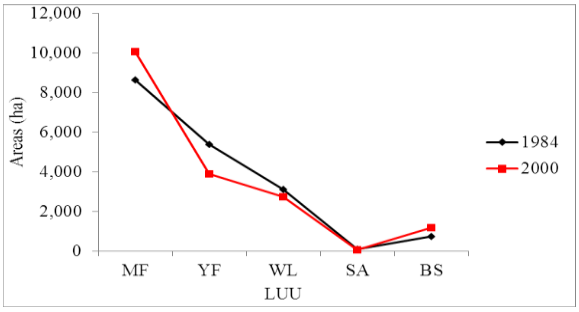
Table II. Average annual rate of spatial expansion and rate change of LUU (2000-1015).

LUU	Land use areas				Expansion rate (%)	Change rate (%)
	2000		2015			
	ha	%	ha	%		
Mature forests	10 079,02	56,04	9 427,85	52,42	-0,44	-6,46
Young forests	3 894,12	21,66	5 403,04	30,04	2,18	38,75
Wetlands	2 752,89	15,31	2 085,03	11,59	-1,85	-24,26
Plantations			50,88	0,28		
Savannah	65,22	0,36	53,88	0,3	-1,27	-17,39
Naked soils	1 193,47	6,63	964,04	5,36	-1,42	-19,22
Total	17 984,73	100	17 984,73	100		

LUU : Land Use Units

Change of occupancy units before and after DCF classification

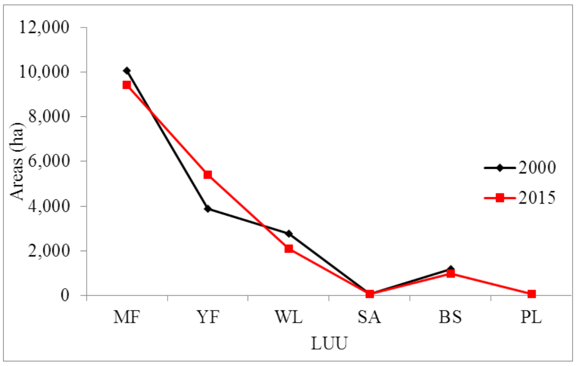
The analysis in Fig. 4 provides a reliable quantification of LUU dynamics between 1984 and 2000. This review shows that mature forests and naked soils have increased in area during this period. They changed respectively from 8 650.46 ha and 728.71 ha in 1984 to 1 0079.02 ha and 1 193.46 ha in 2000, i.e. a conversion of 2 548.73 ha to young forests, 1 675.26 ha to wetlands and 4.02 ha to savannahs. On the other hand, 1,775.84 ha of young forests remained unchanged. Wetlands and savannahs however, regressed between 1984 and 2000, changing from 3,106.55 ha to 2,752.89 ha and from 99.81 ha to 65.22 ha respectively. From all the above, it can be seen that forest systems have regressed undergoing two modes of conversion, through forest degradation and savannah establishment.



Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **WL** : Wetlands ; **SA** : Savannahs ; **BS** : Naked soils.

Fig. 4. LUU transition between 1984 and 2000.

Regarding to the forest transition from 2000 to 2015 (Fig.5), it can be seen that mature forests decreased in different proportions towards other types of land use: 2,668.12 ha in young forests; 1,086.23 ha in wetlands; 2.26 ha in plantations. On the other hand, an increase was observed in young forests that are being transformed into wetlands (316.23 ha) and plantations (31.52 ha), While 583.81 ha of wetlands remained unchanged.

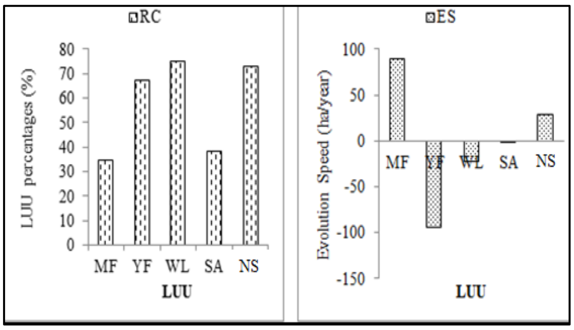


Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **WL** : Wetlands ; **SA** : Savannahs ; **BS** : Naked soils; **PL** : Plantations.

Fig. 5. LUU transition between 2000 and 2015.

Rate conversion and rate change of LUU between 1984 and 2000

Examining Fig. 6 shows that two types of change emerge: gain and loss. Young forests showed a negative rate of change (-94.07ha/year) with a conversion rate of 67.11%. The high pressure on young forests is due to conventional logging in the area during this period. Whereas mature forests exhibited a significant rate of evolution between the two dates, i.e. a gain of 89.28ha/year and a conversion rate of 34.82%. The rapid increase in mature forests is an indication of a transposition of young forests. Savannahs, on the other hand, represent the categories that evolved slowly into other types of land use, i.e. an evolution rate of -2.16ha/year between 1984 and 2000.



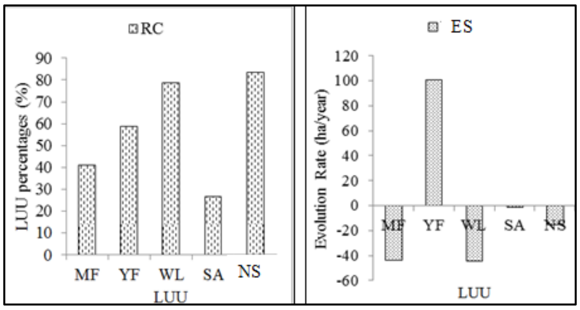
(a) Rate Conversion (RC) (b) Evolution Speed (ES)

Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **WL** : Wetlands ; **SA** : Savannahs ; **NS** : Naked soils.

Fig. 6. Rate conversion and rate change of LUU between 1984 and 2000.

Conversion rate and change rate of LUU between 2000 and 2015

Analyzing Fig. 7 shows that Naked land is the LUU with the highest conversion rate (83.48%) than other land use classes, i.e. a loss of 229.42 ha. They are followed by wetlands with a conversion rate of 78.79% and a change rate of -44.52ha/year. However, the savannahs are the land use units that expressed the lowest conversion rate (26.60%) between 2000 and 2015, i.e. 11.34 ha lost and an evolution rate of -0.76ha/year. Thus, between 2000 and 2015, young forests expressed an exponential evolution, i.e. a gain of 100.59ha/year. While, mature forests, savannahs and wetlands recorded a negative evolution. The significant increase showed by young forests is due to the rotational respect of Forest Exploitation Units (FEU) and Annual Cutting Plates (ACP), and the expulsion of indigenous populations into the forest.



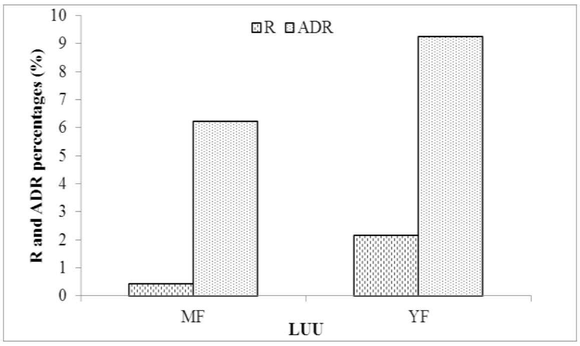
(a) Conversion Rate (RC) (b) Evolution Rate (ES)

Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **WL** : Wetlands ; **SA** : Savannah ; **NS** : Naked soils.

Fig. 7. Conversion and evolution rate of LUU between 2000 and 2015.

Annual rate of deforestation and forest degradation before the ranking (1984-2000)

Figs 8 shows the level of deforestation and degradation that occurred between 1984 and 2000 in the DCF. These phenomena are observed in both mature and young forests.



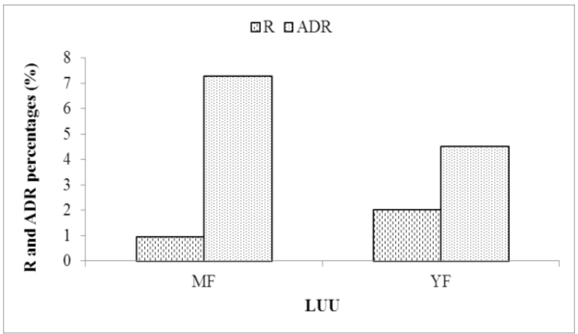
Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **ADR :** Annual Degradation Rate ; **R** : Annual Deforestation Rate.

Fig. 8. Annual deforestation rate and forest degradation between 1985-2000.

The results from Fig. 8 showed a strong disturbance and reduction of young forests in favor of other land use types with deforestation and forest degradation rates of 2.04% and 4.51% respectively. These perceptible negative impacts on young forests are the result of the combined action of forestry and agricultural activities. Mature forests are the types of vegetation with a low rate of deforestation (0.95%) with a gradual degradation of its vegetation (7.28%).

Deforestation and forest degradation Statuses between 2000 and 2015

Fig. 9 shows that from 2000 to 2015, young forests have suffered significant degradation (9.25%) and deforestation of 2.18%; of the 30.04% of the surface area occupied in 2000, 6.04% was transformed into wetlands and 2.05% into naked soils. The increase in the degradation rate showed in young forests is the result of a combination of logging, plantations establishment and the silvicultural method adopted. While 8.92% has remained stable and 9.02% is being converted to mature forests. Mature forests have suffered 6.23% disturbance and 0.44% loss of area (degradation and deforestation).



Legend : **LUU** : Land Use Units ; **MF** : Mature Forests ; **YF** : Young Forests ; **ADR :** Annual Degradation Rate ; **R** : Annual Deforestation Rate.

Fig. 9. Annual deforestation rate and forest degradation between 2000 and 2015.

Review of the spatial distribution of changes before and after the DCF ranking

The typology of the changes shows that between 1984 and 2000, 2.99% of the study area surface that used to consist of more or less dense woody formations disappeared completely and was converted to naked soils (deforestation). Nevertheless, between 2000 and 2015, the deforestation of woody species accounted for 2.62% of the total area of woody systems, making it a reduction of 0.37% of the naked soil area. Thus 11.79% of the woody area was degraded between 1984 and 2000. Moreover, between 2000 and 2015, woody areas increased by 15.48%. This increase in the annual rate of forest degradation reflects the establishment of an oil palm plantation by the Commune in 2003 and reforestation initiatives.

Discussion

The sustainable management of forested areas logged for the first time remains entirely dependent on the physical and ecological state in which the forest was left after disturbance.

Classification and mapping

The results from processing Landsat ETM (1984 and 2000) and Sentinel 2A (2015) images from a supervised classification are of sufficient quality. The overall accuracy is 86.42% for the 1984 Landsat TM image, 85.11% for the 2000 TM and 89.64% for the 2015 Sentinel 2A image. Several authors have previously demonstrated the effectiveness of these images in several studies of the spatial dynamics of ecosystems (Soulama *et al.*, 2015; Koffi *et al.*, 2016; Hounton, 2017; Jiagho *et al.*, 2019; Zekeng *et al.*, 2019; Djiongo *et al.*, 2020). However, the supervised classification adopted in this study appears to be the best among the methods relating to the study of land-use dynamics using remote sensing (Pontius *et al.*, 2004; Gidey *et al.*, 2017) as it involves field verification (Nagendra *et al.*, 2006).

The values of the Kappa coefficients (0.75, 0.72 and 0.87) obtained in 1984, 2000 and 2015 respectively attest to the quality and validity of the classification carried out. The results of this analysis are statistically significants. According to Landis and Koch (1977), land-use study is good and acceptable if the Kappa index is between 0.50 and 0.75. These values obtained in this study are similar to 0.74, 0.78 and 0.89 found respectively in 2000, 2009 and 2018 by Zekeng *et al.* (2019) in the Doumé Communal Forest.

Land use dynamics in DCF

The change in area of the different land use categories shows an increase in both mature forests and naked soil between 1984 and 2000. The increase in area (1428.04 ha) observed at mature forests is due to a vertical evolution of young forests. The significant conversion of young forests to mature forests could be attributed to the fact that young forests are close to mature forests. On the other hand, the extension of naked soil (6.63%) indicates an increase in pressure from logging operations on young forests. The heavy activities pressure on young forests is a main factor for reducing the area of wetlands. This decrease in wetlands could be explained by the fact that opening the vegetation canopies favors the increase of light in the forest landscape and intensifies the evaporation of ground and surface water, which dries out the wetlands.

Moreover, between 2000 and 2015, there was a spectacular 8.38% increase in young forests, i.e. an increase of 1,508.92 ha. This increase can be explained by the modernization of logging activities. This proliferation of young forests considerably reduces the densification of naked soils and wetlands. However, the abundance of young forests indicates an environment in full regeneration and regular forest stand dynamics (Mounmemi, 2016). This recent expansion of forest cover should not, however, conceal the internal degradation of the forest environment, insidious but nevertheless detectable on satellite images and confirmed by field trips (Momo *et al.*, 2010).

According to the World Meteorological Organization (OMM, 2005) in addition to natural factors of degradation and deforestation, socio-economic causes must also be taken into account. There is a close relationship between land degradation and land use. The creation of a palm plantation in the DCF, though it constitutes a preventive measure to reduce the financial dependence of the populations of this commune on forest resources, extremely triggers vegetation destruction. It was demonstrated by Adjonou *et al.* (2018) after his studies in the Momo Border Biosphere Reserve in Togo, that land use changes are accompanied by social and economic benefits at several levels. It should be noted that these changes are responsible for ecological degradation on different spatial scales. In the same vein, the International Tropical Timber Organization (ITTO) shows that tropical forests can only be conserved if value is added in the sustainable supply of their products and services (OIBT, 2019). This deforestation under anthropogenic pressure has led to the loss of 50.88 ha of woodland area between 2000 and 2015. This result corroborates with those found by Toko (2014), Mama *et al.* (2013) in their various studies, which showed that deforestation of natural systems is mainly attributable to anthropogenic activities.

With regard to the annual change per hectare of the different land-use classes, the results show a rapid regression of young forests between 1984 and 2000, i.e. -94.07ha/year. This change is much more perceptible in 2000 by the increase in naked soils. The degradation of the environment reflected by the increase in naked soil is the index of the presence of traces of the various logging activities (roads, wood yards, skidding tracks and logging gaps). This degradation is amplified by anthropic activities of the indegenous populations. Indeed, overexploitation of land is considered the main cause of forest degradation and reduction of biodiversity (Avakoudjo *et al.*, 2014; Zekeng *et al.*, 2019. Several authors (Pale, 2000; Issa, 2010; Atta *et al.*, 2010; Issiako & Arouna 2018) have accounted population growth and certain modes of exploitation as being responsible for land degradation resulting in the disruption of ecological balances.

The analysis of the results shows that after the expulsion of the population in the DCF in 2001, a considerable evolution of the forest cover was observed. This reconstitution of forest cover is marked by the evolution of young woody systems (100.59ha/year) between 2000 and 2015. This evolution, preceded by a reduction in these formations between 1984 and 2000, is reflected in a forest transition phenomenon (Garcia and Freintrenie, 2014; Mather, 1992).

The deforestation values obtained respectively between 1984-2000 (2.99%) and 2000-2015 (2.62%) in this study are different from the -7% found by Zekeng *et al.* (2019) in the Doumé Communal Forest. They are also lower than the 4.1% found in Mount Oku between 1978 and 2001 (Momo *et al.*, 2012) and higher than the 0.14% obtained in Cameroon between 2000 and 2005 (Duveiller *et al.*, 2008). This difference is due either to galloping population growth around the forest massif, the high presence of agroforestry systems or the forest types in which the study was conducted. The deforestation rate found between 1984 and 2000 is similar to the 2.91% obtained by Zakari (2015) in the Goungoun classified forest and its riparian terroirs in Benin between 2000 and 2015.

Involvement of forest management and biodiversity conservation in DCF

Analysis of satellite images combined with field data showed a negative change in the spatio-temporal evolution of the vegetation cover prior to the DCF classification (1984-2000). Land over-exploitation during this period is considered to be the main cause of deforestation and forest degradation and reduction of biodiversity (Avakoudjo *et al.*, 2014; Tsafack, 2015). Nevertheless, the continuous (progressive) evolution of the vegetation cover and the significant disappearance of bare soil observed between 2000 and 2015 explain the contribution of management in maintaining the vegetation cover. These results are similar to those obtained by Tankoano *et al.* (2016) who found a progressive evolution of vegetation classes in the Deux Balé National Park in western Burkina Faso between 2000 and 2015. However, the difference in the area of mature forest remaining unchanged before and after the DCF classification is 314.01 ha. This increase in area is of major ecological importance as mature forests are an irreplaceable reservoir for the maintenance of tropical biodiversity (Momo *et al.*, 2012; Gibson *et al.*, 2011) and for the mitigation of climate change through the reduction of greenhouse gases (Steffen *et al.*, 2015). Furthermore, it is observed that despite the changes and conversions observed between 1984 and 2015, the DCF remains largely covered by a relatively well conserved natural vegetation and has good potential for biodiversity conservation.

Thus, the reforestation of the forest, the rotational respect of FEU and ACP and the defense of the forest by the local population are also perceptible results of forest management. As a result, forest management appears to be a tool for the sustainable management of natural resources. For it ensures a balance between harvesting on one hand and natural resource renewal on the other hand (Picard *et al.*, 2012). The contribution of management to the maintenance and protection of forest ecosystems is also observed in the Deux Balé National Park in western Burkina Faso (Tankoano *et al.*, 2016).

Conclusion

The study of land cover and land use dynamics in the scientifically based DCF, based on the processing of satellite imagery and GIS coupled with field data, revealed the different changes that occurred during this period (1984-2000, 2000-2015). The results highlight the progression of woody formations such as young forests, the regression of naked soils and savannas between the years 2000 and 2015. Moreover, mature forests and bare soils experienced a progressive extension of their surface area between 1984 and 2000. Notwithstanding the changes in DCF between the two periods, it appears that it remains largely covered by relatively well conserved vegetation and has good potential for biodiversity conservation.

The implementation of sustainable management practices has contributed to the recovery of vegetation between the years 2000 and 2015. The involvement of the forest administration and the authorities of the Dimako commune through monitoring in and around this forest massif in collaboration with the local population have slowed down colonization. Forest management is undoubtedly a tool for sustainable forest management because it strikes a balance between the removal and renewal of goods and services from the forest.

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