



Contribution of Remote Sensing in The Study of The Spatio-Temporal Dynamics of Classified Forests: Case of The Classified Forest of Irobo (Southern Ivory Coast)

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ABSTRACT: This study was carried out in the south of the Ivory Coast as part of our master's thesis. This study aims to highlight the improvement in knowledge on the phenomenon of degradation in the Irobo classified forest and to provide managers with essential elements for the establishment of a sustainable forest management policy. Concretely, it was a question of (1) characterizing the different types of land use of the Irobo classified forest, (2) mapping the vegetation cover of the classified forest of Irobo from the Landsat images of 1988, 2005 and 2020, (3) evaluating the forest dynamics between 1988 and 2020. To this end, the characterization of the types of land use, the mapping of the dynamics and the evaluation of the forest dynamics between 1988 and 2020 were carried out using cartographic methods on the one hand and area calculations on the other. The results indicate that there are nine types of land use. These are forests, reforestation plots, perennial crops, annual crops, fallows, bare soils and habitats. Regarding the assessment of forest dynamics, it appears that forest cover has lost 11,993.3 ha between 1988 and 2020, which means a decrease of 2.07% per year in favour of agricultural holdings (26,838.9 ha in 2020).

KEYWORDS: Classified forest, Forest dynamics, Landsat image, Remote sensing, South Cote d'Ivoire, Irobo.

I. INTRODUCTION

Ensuring the protection of forests, in a context of development backed by the exploitation of natural resources, presents itself as one of the most important challenges of this century. Indeed, despite their importance, forests are continually cut down and degraded. For example, between 1990 and 2015 there was a net loss of approximately 129 million hectares of forest worldwide (FAO, 2015). It is estimated that approximately 7.6 million hectares of forest have disappeared every year since 2010. Furthermore, the greatest losses of forest areas are in the tropics, particularly in South America and Africa (Lewis, 2006). The causes of deforestation are multiple. Shifting cultivation, fuelwood collection, mining, logging, and infrastructure development are the direct causes in tropical areas (Margono *et al.*, 2012).

Deforestation and forest degradation in Côte d'Ivoire are very alarming. Since its independence, the country has based its development on agriculture. With the support of the State, «The success of this country is based on agriculture, «thousands of hectares of forest have vanished in favor of agriculture and forestry. Thus, the cultivated areas, which were approximately 3.0 million hectares in 1970, increased to 7.5 million hectares in 1990 (SODEFOR, 2000). It is estimated that they are more than 12 million hectares today. Extensive slash-and-burn agriculture and poaching lead to bushfires which have also devastated large areas of forest. Thus, estimated at 16 million hectares at the end of the 19th century, the Ivorian forest is currently estimated at 3.4 million hectares (MINEF, 2018). The forest resources of Côte d'Ivoire are



thus subject to strong anthropic pressure, leading to the reduction of their areas and their fragmentation. Also, the diversity and variability of ecosystems, the quantity and quality of available forest resources which constitute considerable potential for the well-being of populations and future generations are reduced every day (Aké - Assi , ; Cissé *et al.* 2020,1998). Unbridled deforestation, unhindered by any regulation, now constitutes a threat to biological resources and to populations (Serageldin, 1993).

In order to promote the sustainability of forest resources and better conserve their biological diversity, Côte d'Ivoire has undertaken, since the colonial period, the creation of a network of protected areas and classified forests (Koné *et al.*, 2012). These areas cover 6,267,730 hectares, or 19% of national territory. These include 234 classified forests, eight (8) national parks and five (5) nature reserves (IUCN/BRAO, 2008).

Classified forests represent areas capable of preserving and supplying the forestry industry with the main species, but also of being sources of supply of harvested products for local populations (Zoro Bi and Kouakou, 2004).

However, the various forest massifs continue to suffer from anthropogenic attacks. As a result, most of the Ivorian classified forests are now classified only in name, although they now; pall house not only large cocoa plantations, but also camps and villages (Traoré, 2018). Current deforestation hotspots are located in classified forests where the annual deforestation rate was 3 % over the period 1990-2000 and 4.2% over the period 2000-2015 (Koné, 2015). There remained 844,938 hectares of classified forests in 2015 compared to 1,585,626 hectares in 2000 and 2,129,729 hectares in 1990 (Koné , 2015).

The Irobo classified forest is not left out of this deforestation. Unfortunately, reliable scientific data on the spatio-temporal dynamics of classified forests are quite rare. Several studies have been conducted using remote sensing by different authors such as N'Guessan (2018) and N'Guessan and N'Da (2005) but very few studies have been conducted using remote sensing tools in the Irobo classified forest. It is in this context that this study entitled " Contribution of remote sensing in the study of the spatio -temporal dynamics of classified forests: case of the classified forest of Irobo au South of Ivory Coast » was initiated. It aims to improve knowledge on the plant dynamics of the Irobo classified forest in relation to human actions, through the use of satellite images. It specifically involves characterizing and mapping the different types of land use in the Irobo classified forest and evaluating forest dynamics between 1988 and 2020.

A. Description of the study area

Created by decree No. 996 of September 29, 1962 of the Water and Forests Service and the Ministry of Agriculture, the Irobo massif is made up of the classified forests of Méné, Bakanou, Cosrou and Bandama. Located in the forested south of Ivory Coast , with an area of approximately 42,000 ha ; it is 25 km from Sikensi, 67 km from Dabou , 80 km from Tiassal é and 105 km from Abidjan . The classified forest of Irobo or Irobo-Méné massif is positioned between the following geographical coordinates: 4 ° 40 ' and 4 ° 50' West longitude and 5 ° 25' and 5 ° 48' North latitude (Zobi and Chessel, 2007). It straddles four departments and two administrative regions: Agné by -Tiassa and Grands Ponts (Figure 1). The FCI is located in the Guinean rainforest sector, with a sub-equatorial climate, hot and humid all year round. Average annual temperatures vary between 26 and 27° C. (Eldin, 1971). The Irobo massif is made up of a typical dense evergreen forest. The overall impression is that of a hygrophilous forest. The vegetation which was a virgin forest (Mangenot, 1955) at *Diopyros mannii*, at *Diospyros spp.*, and to *Eresmospatha macrocarpa* (Guillaumet and Adjanohoun, 1971) is today dominated, on the one hand, by plantations of cacao, deoil palms and other cash crops as well as by fields of various food crops and, on the other hand, by secondary forests with *Musanga cecropioides* (parasolier) or bushy stands at *Chromolaena odorata*. According to the 2014 General Population and Housing Census (RGPH, 2014), the Agnéby -Tiassa region has 606,852 inhabitants, divided between 320,713 men and 286,139 women, for an average annual population growth rate estimated at 1.29%. The population is made up of the Abidji, the Abbey, the Agni, the Adioukrou, the Avikam, the Baoulé, the Dida, mixed with populations from neighboring countries (Burkina Faso, Mali, Guinea). Agriculture, the basis of the country's economy, is the main activity of the local population. Cash crops are mainly cocoa (*Theobroma cacao*), coffee, (*Coffea sp.*) and oil palm. (*Elaeis guineensis*), l'hévéa (*Hevea brasiliensis*) and coconut (*Cocos nucifera*). Banana, cassava, corn, rice, taro and yam constitute the staple foods of these populations (Atta *et al.*, 2016).

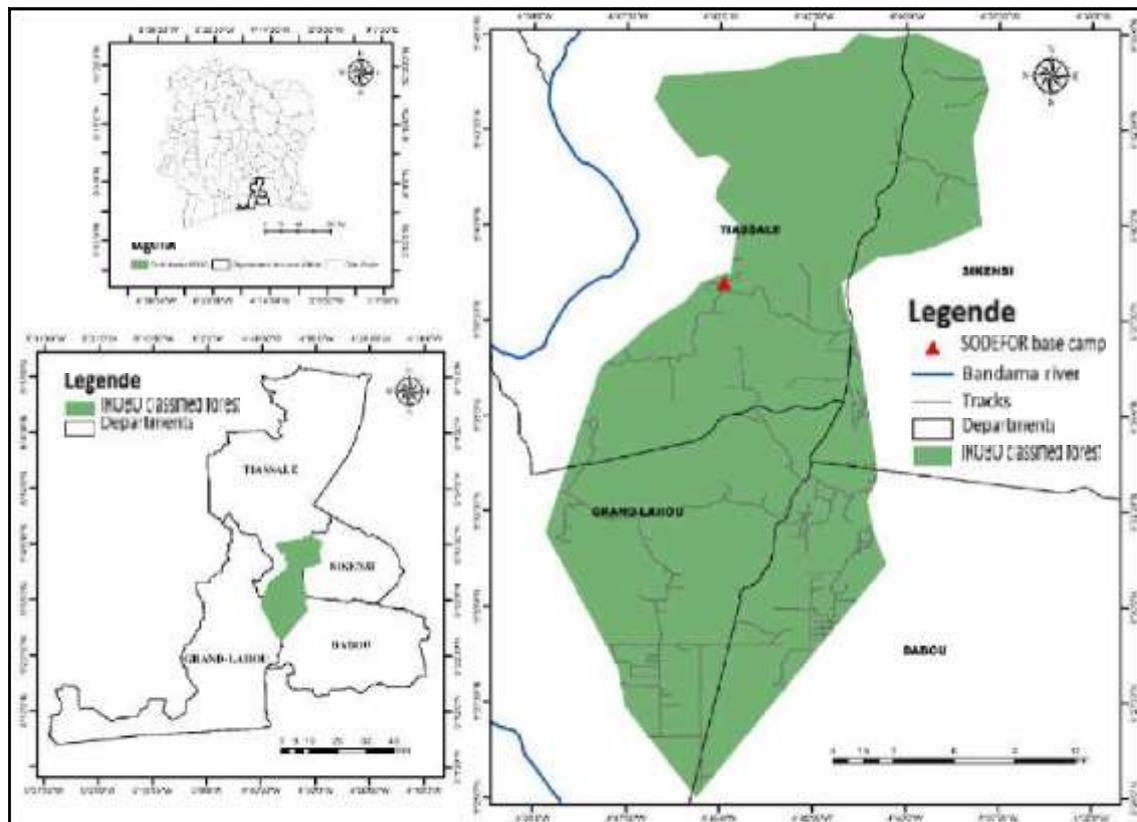


Figure 1. Geographic location of the study area

II. MATERIALS AND METHODS

B. Material

The equipment used in this study consists of technical equipment and remote sensing data. The technical equipment consists mainly of a Garmin GPS receiver (Map64) for recording the coordinates of the different land use types, a digital camera for taking pictures, descriptive sheets for the different land use types, pairs of boots, machetes and a field vehicle.

The optical images used in this study cover les images du satellite Landsat quithe 196-56 scene. Les images sont issues des capteurs Landsat *Thematic Mapper* (TM4) pour l'image from 12/24/1988, *Enhanced Thematic Mapper Plus* (ETM+7) pour celle from 01/05/2005 and *Operational Land Imager* (OLI 8) pour l'image acquise lefrom 01/07/2020. They are all available free of charge on the United States Geological Survey (USGS) website via the link <https://earthexplorer.usgs.gov/>.

It should be remembered that vector files of the Irobo classified forest which were made available by SODEFOR made it possible to extract the study area and carry out the cartographic drafting.

Regarding software, ENVI 5.3 has was used for pre- processing and processing of satellite images, ArcGIS 10.8 for vectorization and geoprocessing and cartographic restitution as well as Microsoft Excel 2016 for calculations (statistical analyses) and creation of graphics.

Methods

The methodology adopted in this study combined satellite image processing and field data collection techniques.

Image pre - processing began with radiometric correction to correct the effects of various artifacts that disrupt radiometric measurement, including sensor defects and atmospheric haze. Then, one atmospheric correction has been applied to improve image readability. To finalize the pre-processing, we extracted our study area using the shapefile of the contour of the classified forest.

Image processing involves the calculation of biophysical indices enabling the overall physical and biological characteristics of the vegetation to be based on the indices :highlighted.

- The Standardized Vegetation Index or *Normalized Difference Vegetation Index* (NDVI)

$$NDVI = (PIR - R) / (PIR + R)$$

- The Brightness Index

$$BI = (R^2 + PIR^2)^{1/2}$$

- **The Normalized Difference Wetness Index**

$$NDWI = (PIR - MIR) / (PIR + MIR)$$

These three indices allowed us to discriminate respectively dense vegetation (forest, reforestation) from those which are not very dense (annual agricultural exploitation, and young fallow) and bare soils (agricultural clearing and habitats); to subdivide plant formations according to their level of ground cover, therefore their density, and to separate the most humid plant formations from those which (N'Da *et al.*, 2008), are the least humid

Colored compositions using raw strips (OLI 5-6-4 and OLI 5-6-7) made it possible to discriminate between different types of land use. To refine the treatments, a Principal Component Analysis (PCA) 1-3-2) was performed on the raw tapes to improve the visual quality of the raw tapes and to maximize the information on the first 3 tapes. These treatments allowed:

- discrimination between different types of land use,
- the selection of sites to visit and orientation on the ground,
- the choice of training plots for classification .

Based on the discriminated land use and the integration of certain data such as localities, tracks, bodies of water, the limits of the Classified Forest, 140 points to visit were identified. The geographic coordinates of the points were taken and integrated into the GPS.

The information collected in the field also made it possible to finalize the digital processing. Indeed, Maximum likelihood-guided classification, which involves identifying spectrally similar areas based on known training sites to extrapolate these signatures to unknown areas, was used to produce the maps. For the 2020 image, the classification was validated using confusion matrices to assess overall accuracy and the Kappa coefficient. A 3x3 median filter was then applied to eliminate isolated pixels and reduce heterogeneity. The classification results were converted from raster to vector format using ArcGIS software.

This classification is a procedure for identifying spectrally similar areas on an image by identifying "training" sites of known targets and then extrapolating these spectral signatures to other domains of unknown targets. The validation of the 2020 image classification was carried out by the production and analysis of confusion matrices, to evaluate the overall performance level of the processing, but also of the land use classes through the overall precision and the Kappa coefficient. Once the classification is validated by the different performance tests above , a 3x3 median filter makes it possible to reduce intra-class heterogeneity by eliminating isolated pixels . The classification results obtained in raster format are *exported* to ArcGIS *software* for conversion to vector format. La même technique a été utilisée pour les images de 1988 et 2005, avec quelques adaptations, à savoir la composition colorée sur les bandes 4/5/7 pour les capteurs TM et ETM+, et l'utilisation sélective des données de terrain de 2020, en ne retenant que les points invariants (les zones restées stables sur toute la période d'étude).

The assessment of changes occurring over the entire study period was made by producing and analyzing transition matrices between maps of two dates (Girard and Girard, 1999). This assessment, which was carried out using ArcGIS 10.8 software, was used to analyze different types of land use between 1988 and 2005, between 2005 and 2020 and between 1988 and 2020. The overall rate of change is obtained from the following mathematical formula: $Tg = [(S_2 - S_1) / S_1] \times 100$

Where:

Tg = Overall rate of change (%)

S₁ = Area of the class at date t₁ (initial date);

S₂ = Area of the class at date t₂ (final date), and t₂ > t₁



III. RESULTS AND DISCUSSION

C. Results

Different types of land use in the Irobo classified forest

The mission carried out in the Irobo classified forest allowed us to identify nine (9) types of land use which are: areas of deforestation; secondary forests; perennial cocoa crops, annual crop mosaics young cocoa; perennial crops (rubber and oil palm); degraded forest mosaics /old fallow; young fallow; young perennial crops (rubber and oil palm) and bare soils and habitats.

Map of vegetation cover in the Irobo classified forest Mapping performance

The overall accuracies of the different classifications for the 1988, 2005 and 2020 images are respectively 91.01%; 87.26% and 88.55% (Tables 1, 2 et 3). The most significant confusions, for these classifications, are observed between the classes of relatively well-preserved secondary forests and reforestation. Other confusions, although minor, were observed between the young perennial rubber / oil palm crop class and the young perennial cocoa crop class, then the bare soil / Habitats class and the young perennial cocoa crop, young perennial rubber / oil palm crop and young fallow land classes. Except for these cases, all other land use types are relatively well discriminated.

Table 1 : Confusion matrix of 1988 Landsat TM image classification Overall accuracy = 91.0163%; Kappa coefficient = 0.8829

Classes	REB	FS	CPC	MCAJC	CPHP	MGDVJ	JJAC	JCPHP	SNH
REB	93,77	0,31	3,00	0,36	2,30	1,80	0,01	0,01	0
FS	0,24	98,81	4,84	0	0	0,14	0	0	0
CPC	2,32	0,69	86,92	2,27	0,15	0,07	0	0,21	0,04
MCAJC	1,13	0,02	0,70	85,24	0,46	0,02	0	0,26	1,04
CPHP	0,01	0	0	0	81,30	0	0	0	0,16
VJAC	2,10	0,16	3,24	0,42	5,80	97,81	0,01	0,08	0,18
JJAC	0,13	0	0,63	0,00	6,12	0,09	89,19	0	3,89
JCPHP	0,28	0	0	10,79	3,66	0,00	0	97,52	0,52
SNH	0,04	0,01	0,68	0,92	0,20	0,07	10,80	1,92	94,18
TOTAL	100	100	100	100	100	100	100	100	100

Table 2 : Confusion matrix of the classification of the 2005 Landsat ETM+ image Overall accuracy = 87.2688% ; Kappa coefficient = 0.8407

Classes	REB	FS	CPC	MCAJC	CPHP	MGDVJ	JJAC	JCPHP	SNH
REB	88,52	2,73	0,07	0,18	4,72	0,92	0,09	0,08	0,10
FS	0,98	91,67	0,56	0,17	0,40	2,06	0,01	0,03	0,44
CPC	1,54	0,31	93,25	1,84	0,10	1,36	1,84	1,12	0,50
MCAJC	0,85	0,58	5,29	96,39	3,91	5,85	4,32	12,67	5,27
CPHP	0,90	0,15	0,02	0,02	84,83	0,37	0	0,01	0
MGDVJ	7,13	4,56	0,25	0,61	4,53	88,38	0,00	0,15	0,17
JJAC	0,07	0	0,32	0,43	0,29	0,73	93,28	5,50	4,53
JCPHP	0,00	0	0,24	0,31	0,86	0,32	0,46	77,25	0,82
SNH	0,00	0	0,00	0,06	0,36	0,00	0	3,19	88,17
TOTAL	100	100	100	100	100	100	100	100	100



Table 3 : Confusion matrix of Landsat-8 image classification (2020) Overall accuracy = (801248/904785) 88.5567%; Kappa coefficient = 0.8633

Classes	REB	FS	CPC	MCAJC	CPHP	MFDVJ	JJAC	JCPHP	SNH
REB	88,52	2,73	0,07	0,18	4,72	0,92	0,09	0,08	0,10
FS	0,98	91,67	0,56	0,17	0,40	2,06	0,01	0,03	0,44
CPC	1,54	0,31	93,25	1,84	0,10	1,36	1,84	1,12	0,50
MCAJC	0,85	0,58	5,29	96,39	3,91	5,85	4,32	12,67	5,27
CPHP	0,90	0,15	0,02	0,02	84,83	0,37	0	0,01	0
MFDVJ	7,13	4,56	0,25	0,61	4,53	88,38	0,00	0,15	0,17
JJAC	0,07	0	0,32	0,43	0,29	0,73	93,28	5,50	4,53
JCPHP	0,00	0	0,24	0,31	0,86	0,32	0,46	77,25	0,82
SNH	0,00	0	0,00	0,06	0,36	0,00	0	3,19	88,17
TOTAL	100	100	100	100	100	100	100	100	100

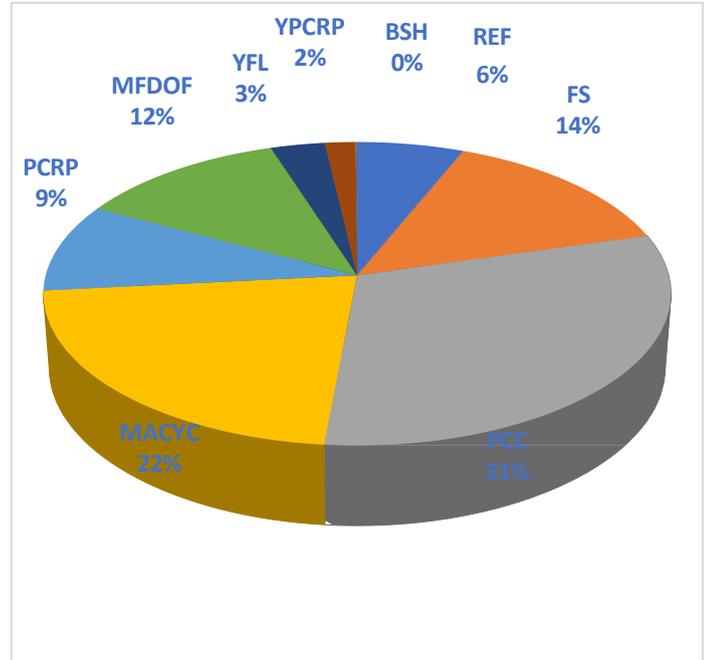
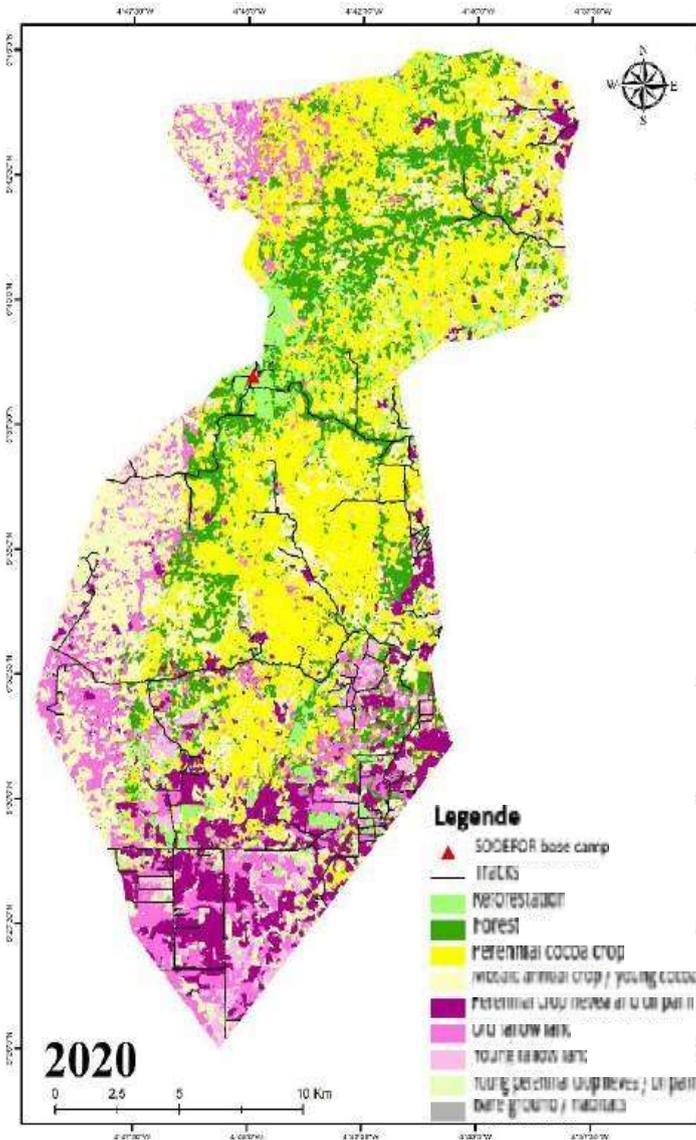
REB = reforestation; FS = secondary forest; CPC = perennial cocoa crop, MCAJC = mosaic annual young cocoa crop; CPHP = perennial rubber and oil palm crop; MFDVJ = degraded forest mosaic old fallow; JJAC = young fallow; JCPHP = young perennial rubber and oil palm crop and SNH = bare soils and habitats.

Updated map (2020)

updated map of the study area was produced using the Landsat-8 image from 07-01-2020 . The (figure 2) distribution of these land use units is such that practically the entire southern area of the classified forest is covered with perennial crops, including rubber trees and oil palms. It can be seen that annual crops consisting mainly of cassava (*Manihot esculenta*) and banana trees (*Musa sp.*) are very few and are grown in association with cocoa trees. The latter are found almost everywhere in the study area. There has been reforestation almost everywhere in the FCI but this is more visible in the extreme west of the central part of the classified forest. The relatively well - preserved secondary forests are located along the main tracks running through the Irobo classified forest and scattered in the northern part of the latter in the form of forest islands. It is noted that the mosaics of degraded / old fallow forests are concentrated in the northwestern and southwestern parts of the classified forest. The largest areas are occupied by the classes "mosaic annual and young cocoa crops" (22%) and "perennial cocoa crops " (31%) (Tableau 4).

Table 4: Areas (in ha) and proportions (in %) of land use classes from the Landsat-8 image (2020)

CLASSES	AREAS	PROPORTIONS
REB	2,596.00	6.19
FS	6,044.75	14.41
CPC	12,953.49	30.89
MCAJC	9,188.01	21.91
CPPH	3,958.10	9.44
MFDVJ	5,099.59	12.16
JJAC	1,323.54	3.16
JCPHP	739.30	1.76
SNH	37.08	0.09
	41,939.86	100



REF= reforestation ; FS= secondary forest ; PCC= perennial cocoa crop, MACYC= mosaic annual crop young cocoa; PCRCP= perennial crops: rubber trees and oil palms; MFDOF = mosaic forest degraded old fallow land ; YFL= young fallow land ; YPCRP= young perennial crops: rubber trees and oil palms ; BSH= bare soils and habitats.

A-Land use categories by area (2020)

A-Land use map of Irobo classified forest (2020)

Figure 2: Updated land cover map and spatial distribution of FCI biotopes from the 2020 Landsat-8 image

Historical maps (1988 and 2005)

Historical maps of the study area were produced using Landsat TM images from 24-12-1988 and ETM+ from 05-01-2005. We obtained nine (9) land use classes with the images from 1988 and 2005 (Figure 3).

In 1988, the largest areas were occupied by secondary forests and reforestation, with a coverage of 43% and 22% of the Irobo classified forest, respectively. These forests were concentrated in the central part and scattered in some places in the northern part of the classified forest. As for reforestation, they were concentrated in the northern part of the forest. In 2005, the classes "mosaic annual young cocoa crop" and «secondary forest» occupied the largest areas with respectively 45% and 20% of the classified forest. The mosaics of annual young cocoa crops occupied the southern zone and the extreme north of the classified forest. The secondary forests, for their part, were located in the central part of the FCI (Tables 5 and 6).



Table 5: Spatial distribution of the areas of OCS classes in 1988

CLASSES	AREAS (in ha)	PROPORTIONS (in %)
REB	9017.14	21.50
FS	18038.05	43.01
CPC	2899.11	6.9 1
MCAJC	3964.13	9.45
CPPH	2590.22	6, 19
VJAC	2866.55	6.8 3
JJAC	553.95	1, 32
JCPHP	1761.73	4.2
SNH	248.98	0.59
TOTAL	41,939.86	100

Table 6: Spatial distribution of OCS class areas in 2005

	CLASSES	AREAS (in ha)	PROPORTIONS (in %)	
	REB	1760.88	4.20	REB =
reforestation; forest; CPC =	FS	8560.33	20.41	FS = secondary perennial
cocoa crop, mosaic annual crop; CPHP =	MJCAPC	1171.48	2.79	MCAJC = young cocoa
rubber and oil MFDVJ =	MCAJC	18807.49	44.84	perennial palm crop; degraded forest
mosaic old = young	CPPH	4986.92	11.90	fallow; JJAC
JCPHP =	VJAC	4580.79	10.92	fallow; young rubber and oil
perennia	JJAC	1499.99	3.58	
palm crop and soils and	JCPHP	490.34	1.17	SNH = bare habitats.
	SNH	81.64	0.19	
	TOTAL	41,939.86	100	

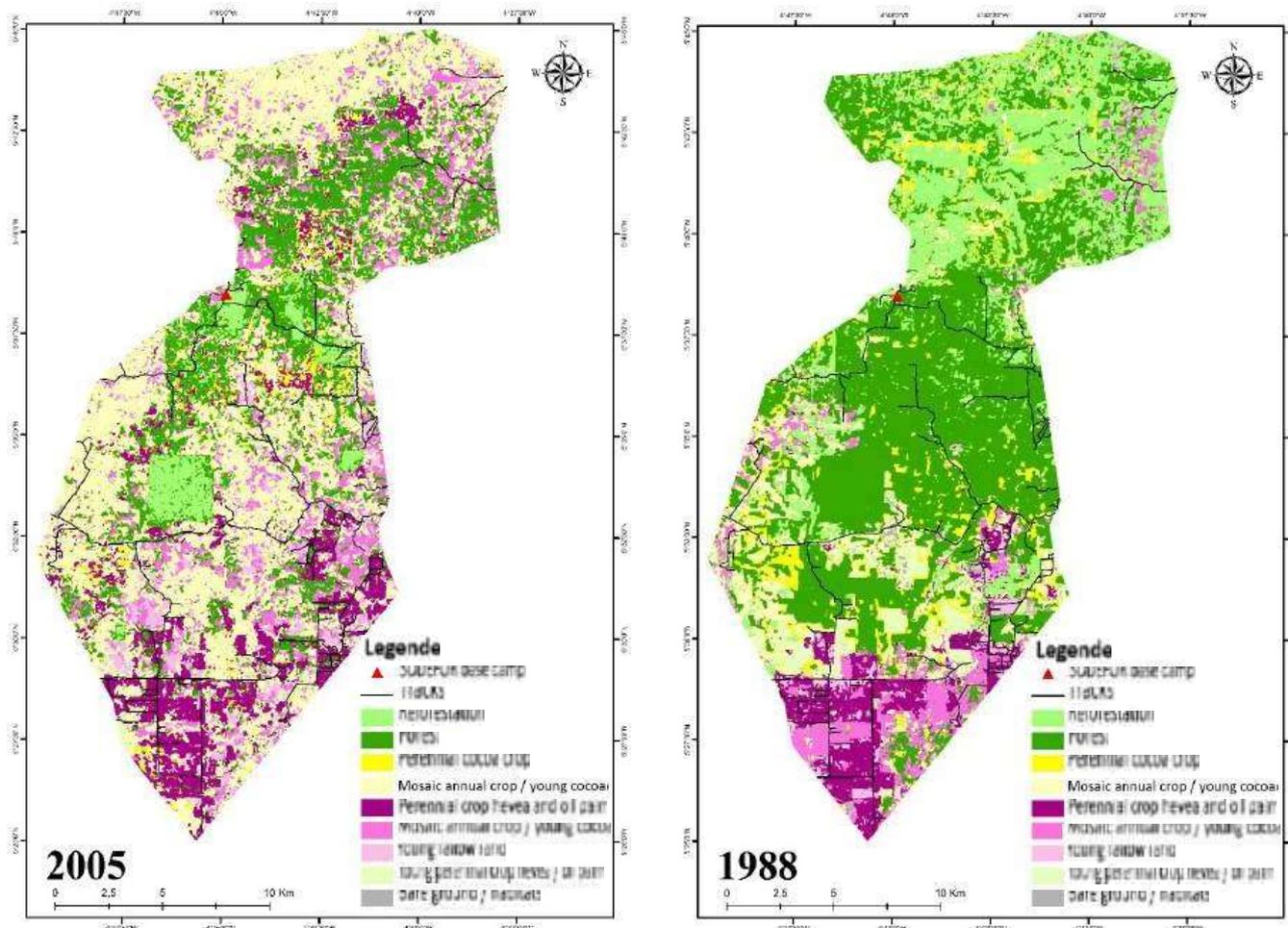


Figure 3: FCI land cover maps based on 2005 Landsat-ETM+ and 1988 Landsat TM imagery

Mapping the spatio-temporal dynamics of land use in the Irobo classified forest using Landsat images from 1988, 2005 and 2020

The map showing the dynamics of land use types in the Irobo classified forest, taking into account the years 1988, 2005, and 2020, is the result of juxtaposing the land use maps for each of these years.

From 1988 to 2020, we have an interval of thirty-two (32) years and a year step of at least 15 years between two dates. From 1988 to 2020, we have an interval of thirty-two (32) years and a gap of at least 15 years between two dates. The evolution of the different types of land use from 1988 to 2020 is recorded in Table II and summarized in the graph in Figure 15. Analysis of Figure 15 shows that the evolution of land use types is very uneven, and we observe two trends in their evolution from 1988 to 2020: an increase and a decrease in area. The increase in area is notable in the categories “perennial cocoa cultivation,” “mosaic of young annual cocoa cultivation,” “perennial rubber and oil palm cultivation,” “mosaic of degraded forest/old fallow land,” and “young fallow land.” The “perennial cocoa cultivation” category, which covered an area of 2,899.11 ha in 1988, increased to 12,953.49 ha in 2020. The class “mosaic” that annual culture young cocoa goes from 3964.13 ha to 9188.01 ha with an area which was 18807.49 ha in 2005. The third class, which concerns rubber and oil palm crops, has gone from 2590.22 ha to 3958.1 ha. The “degraded forest mosaic / old fallow” class presents 5099.59 ha in 2020 while it covered 2866.55 ha in 1988. As for the last class of this trend, the “young fallow” class which covered 559.95 ha, increases to 1323.54 ha today. The second trend includes the following classes: “reforestation”, “secondary forest”, “young perennial rubber and oil palm cultivation” and “bare soils and habitats”. With areas respective areas of 9017.14 ha, 18038.05 ha, 1761.73 ha and 248.98 ha in 1988, they cover respectively in 2020; 2596 ha, 6044.75 ha 739.3 ha and 37.08 ha.

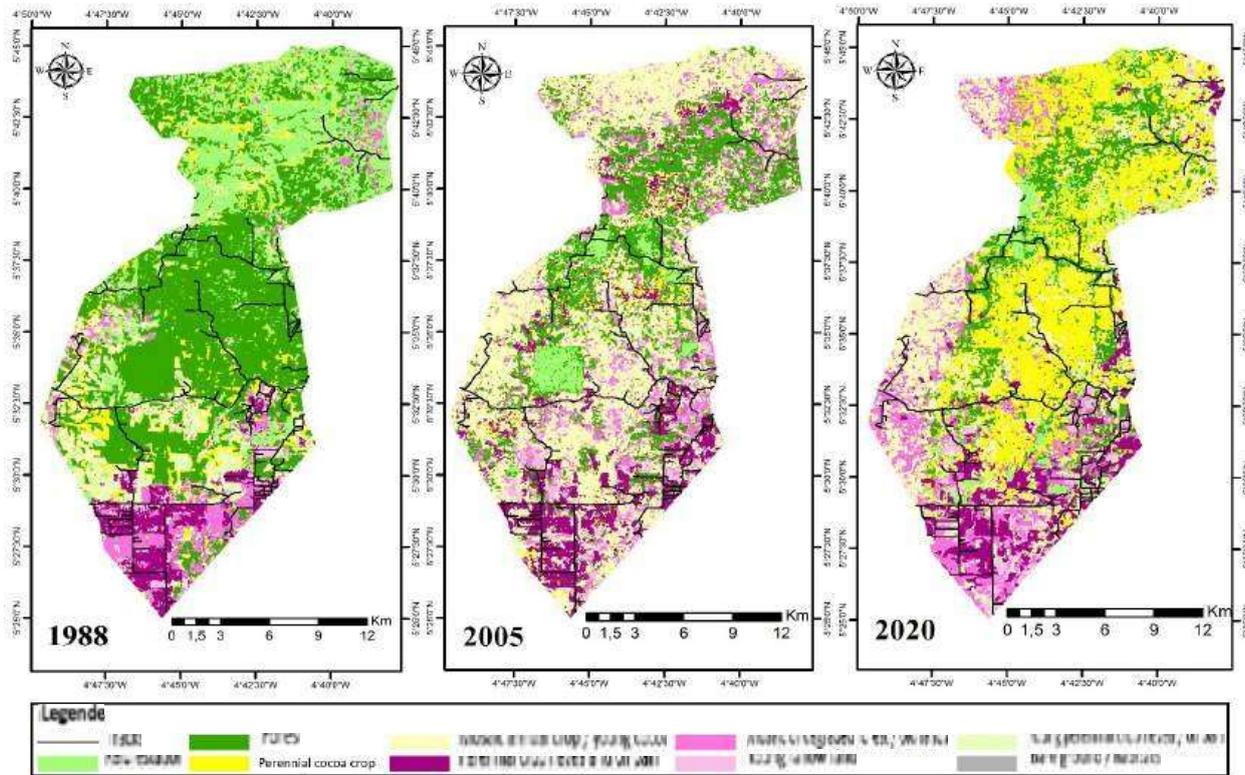
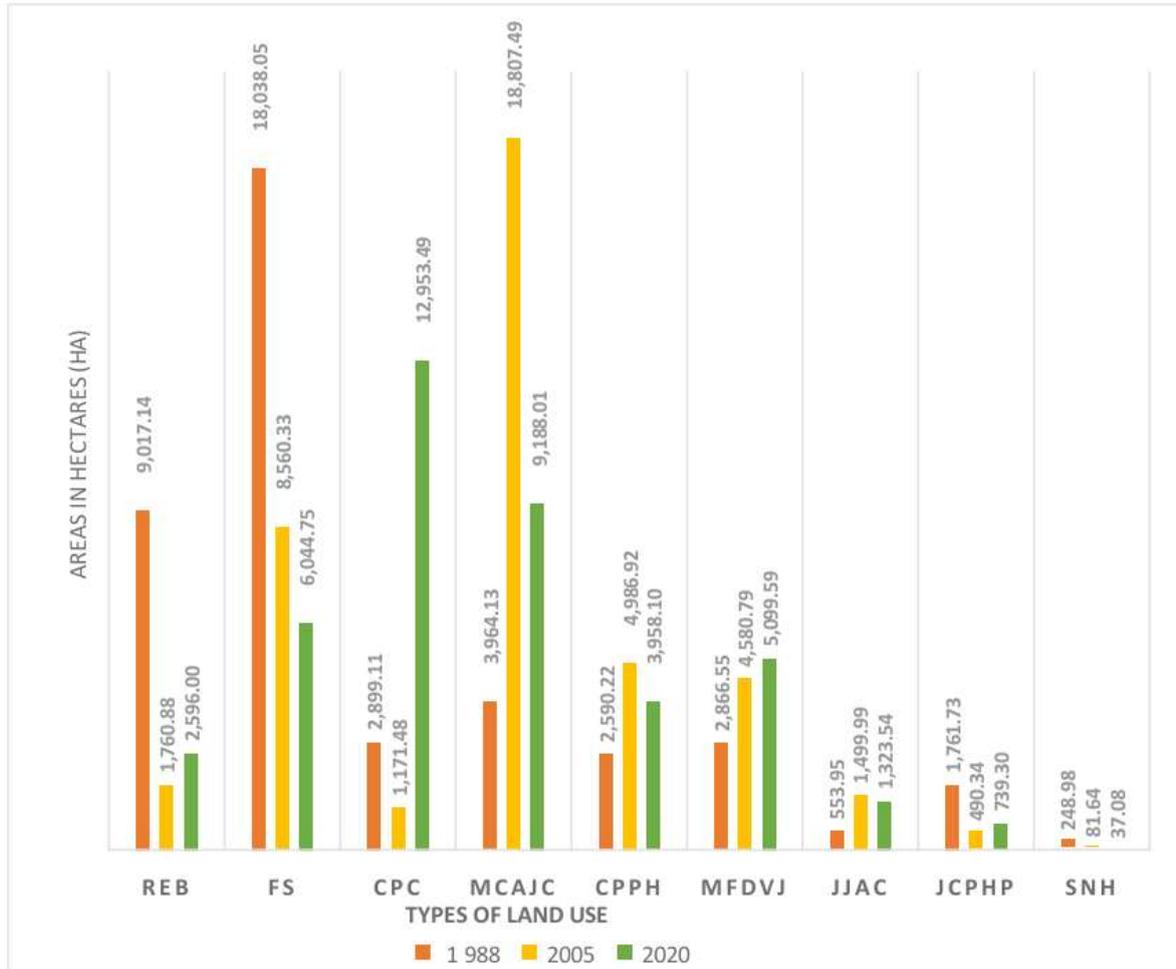


Figure 4: Land use dynamics in the Irobo Forest Reserve in 1988, 2005, and 2020 based on Landsat images

Table 7 : Changes in the areas of the different land use classes from 1988 to 2020

Classes	Areas in ha		
	1988	2005	2020
REB	9017.14	1760.88	2596
FS	18038.05	8560.33	6044.75
CPC	2899.11	1171.48	12953.49
MCAJC	3964.13	18807.49	9188.01
CPPH	2590.22	4986.92	3958.1
MFDVJ	2866.55	4580.79	5099.59
JJAC	553.95	1499.99	1323.54
JCPHP	1761.73	490.34	739.3
SNH	248.98	81.64	37.08
TOTAL	41939.86	41939.86	41939.86



REB = reforestation; **FS** = secondary forest; **CPC** = perennial cocoa crop, **MCAJC** = mosaic annual young cocoa crop; **CPHP** = perennial rubber and oil palm crop; **MFDVJ** = degraded forest mosaic old fallow; **JJAC** = young fallow; **JCPHP** = young perennial rubber and oil palm crop and **SNH** = bare soils and habitats.

Figure 5: Spatio-temporal evolution of the areas (ha) of land use types from 1988 to 2020

Impact of anthropogenic pressures on land use changes

Rate of change in land use types

The global rate of change made it possible to estimate the overall increase (proportion of gain or loss) in the areas of the different land use classes. Following the analysis of Figure 16 showing the global rate of change over the entire study period (from 1988 to 2020), we note that:

- The reforestation classes (**REB**); Secondary forest (**FS**); young perennial rubber and oil palm crops (**JCPHP**) and bare soils and habitats (**SNH**) experienced a regression during this period.
- THE classes perennial cocoa crop (**CPC**) ; mosaic young annual cocoa crop (**MCAJC**) ; perennial rubber and oil palm crop (**CPHP**) ; mosaic degraded forest/old fallow (**MFDVJ**) and young fallow (**JJAC**) have seen an increase (increased in area) from 1988 to 2020.

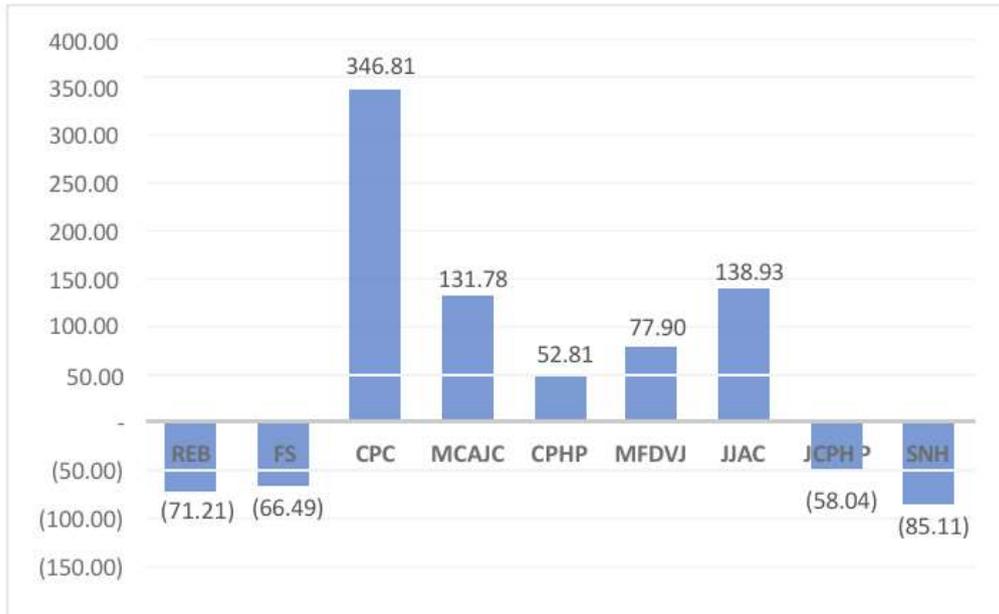


Figure 6: Overall rate of change (%) made in the FCI from 1998 to 2020

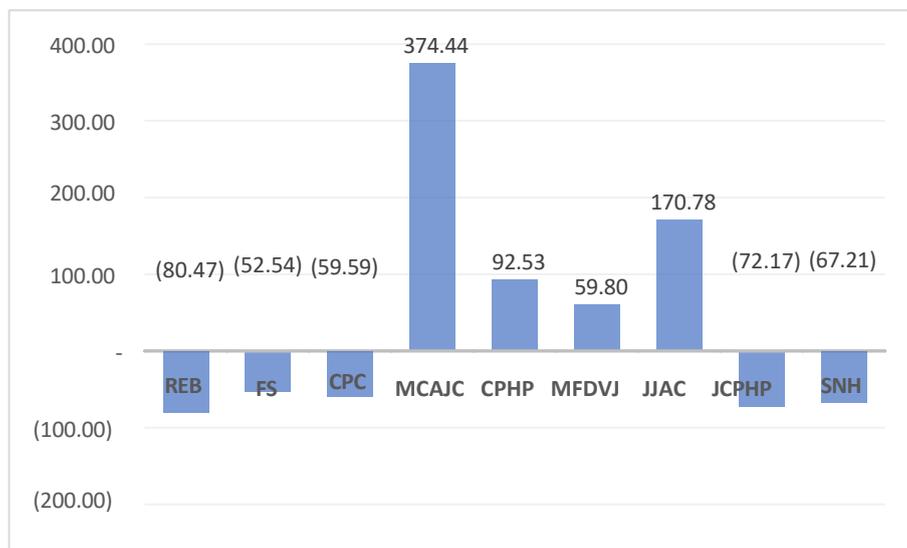


Figure 7: Rate of change (%) in the study area between 1988 and 2005

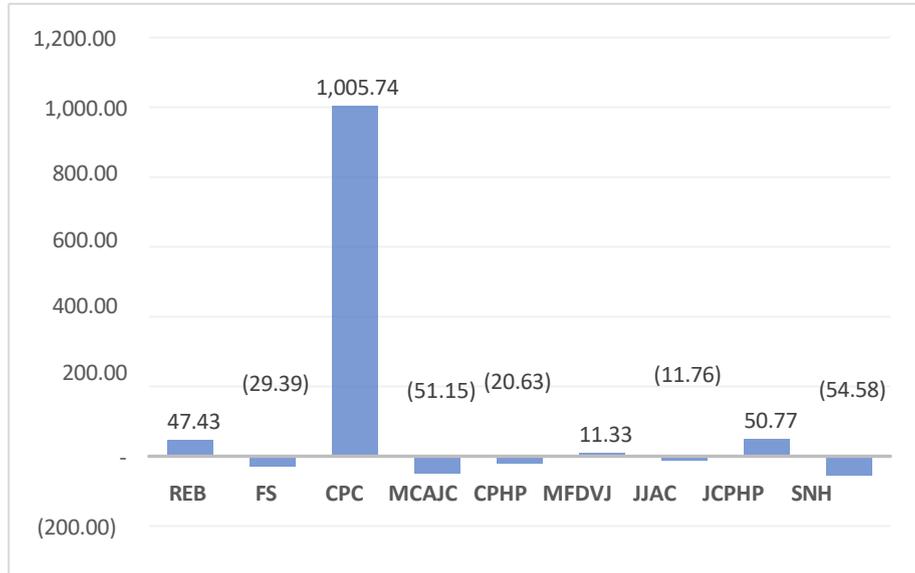


Figure 8: Rate of change (%) made in the study area between 2005 and 2020

Quantitative assessment of the dynamics of agricultural pressures using the transition matrix

The changes that occurred over the entire period etudes (figure 19) were highlighted by the transition matrices (figures 20; 21 and 22). Natural plant formations (secondary forest) are decreasing to give way to artificial plant formations (crops). From 1988 to 2005, 76.63% of forests became fallow land, annual and perennial crops. Over the period from 2005 to 2020, 70.85% of natural plant formations mutated into artificial plant formations. In short, over the entire period of our study, we witnessed an overall mutation of 83.07% of forests into artificial plant formations.

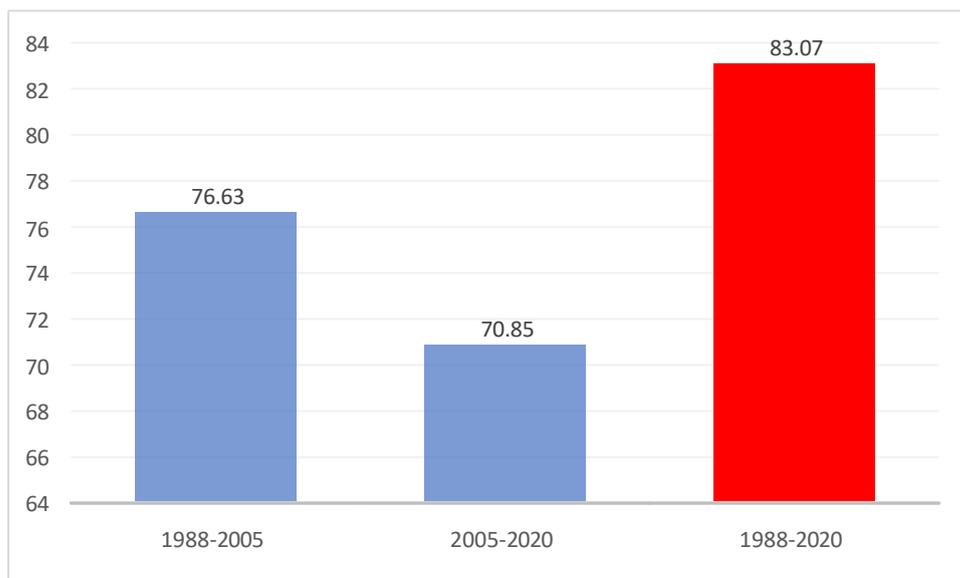


Figure 19: Changes made in the Irobo classified forest from 1988 to 2020



Table 8: Transitions made in percentage (%) from 1988 to 2005

		OCS 1988								
		REB	FS	CPC	MCAJC	CPHP	MFDVJ	JJAC	JCPHP	SNH
O CS 20 05	REB	1.66	5.11	0.53	0.82	0.12	0.18	0.17	0.55	0.19
	FS	21.23	23.22	11.68	2.44	10.98	11.70	0.81	3.59	12.60
	CPC	3.42	7.50	4.40	19.63	6.41	2.10	2.99	1.63	3.20
	MCAJC	42.01	31,33	8.34	46.76	6.03	42.81	20.04	7.92	28,33
	CPHP	8.92	7.46	10.39	10.03	24.94	14.33	55,55	35.85	7.54
	MFDVJ	19,22	18,77	59,14	13,45	39,58	16,68	14,96	39,86	6,60
	JJAC	2,53	4,92	4,09	4,52	7,35	7,15	4,13	7,54	2,55
	JCPHP	0,85	1,53	1,08	1,86	4,22	4,52	1,21	2,72	31,58
	SNH	0,17	0.15	0.35	0.50	0.39	0.54	0.13	0.33	7.41
	Grand total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 9: Transitions made in percentage (%) from 2005 to 2020

		OCS 2005								
		REB	FS	CPC	MCAJC	CPHP	MFDVJ	J AC	JCPHP	SNH
O CS 20 20	REB	10,81	6,47	4,61	4,73	5,97	8,52	12,14	8,00	7,40
	FS	37,72	29,13	9,22	8,23	10,10	12,26	4,78	2,68	1,81
	MCAJC	28,87	32,28	40,15	37,15	10,90	30,57	13,14	9,44	11,43
	CPC	20,60	19,74	15,86	24,61	11,87	26,16	28,38	7,01	18,95
	CPHP	0,32	1,75	6,26	7,17	30,83	6,74	24,22	44,59	6,93
	MFDVJ	1,34	8,55	20,08	13,38	18,93	11,43	9,16	15,88	2,94
	JJAC	0,17	1,59	1.68	2.64	7.98	3.36	6.15	3.36	14.71
	JCPHP	0.15	0.46	2.03	2.02	3.24	0.94	1.95	8.30	27.47
	SNH	0.01	0.02	0.12	0.06	0.18	0.03	0.09	0.73	8.36
	Grand total	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 10: Transitions made in percentage (%) from 1988 to 2020

		OCS 1988								
		REB	FS	CPC	MCAJC	CPHP	MFDVJ	JJAC	JCPHP	SNH
O CS 20 20	REB	8.36	8.02	5.52	6.87	11.04	5.95	10.78	8.90	5.59
	FS	17.37	16,87	15,59	14,79	4,79	5,92	2,66	10,82	7,16
	MCAJC	31,24	24,48	27,82	17,77	4,19	15,12	2,76	12,15	9,65
	JCPC	25,26	27,77	13,86	26,73	17,50	26,97	12,88	19,55	14,67
	CPHP	4,44	6,95	8,50	9,73	15,84	15,19	32,78	17,40	18,87
	MFDVJ	9,88	11,15	25,24	16,65	25,32	19,90	23,08	24,84	26,71
	JJAC	2,24	2,78	1,73	4,02	12,80	6,13	11,33	4,63	3,05
	JCPHP	1,15	1,92	1,66	3,33	7,69	4,63	3,62	1,50	11,30
	SNH	0.06	0.06	0.09	0.11	0.81	0.20	0.11	0.22	2.99
	Grand total	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00



D. Discussion

Mapping and spatio-temporal dynamics of land use

The treatments allowed us to discriminate nine (9) land use classes. This number of classes is significantly higher than that of the **SODEFOR mapping (2019)** which identified four (4) land cover classes from Landsat images. The fact that **SODEFOR** worked with Landsat images could be a probable source of explanation for this low number of classes. Also, only one reforestation class was obtained while there were several reforested species. This is explained by the fact that, apart from *Gmelina arborea*, the other species showed very great confusion with the secondary forest class.

Overall accuracies of 88.55%; 87.26% and 91.01% respectively for the images of 2020; 2005 and 1988 were obtained. These accuracies are close to those of some authors who have worked in classified forests impacted by human activities. **N'Guessan (2018)** obtained accuracies ranging from 90.70 to 92.19% during his work in the classified forest of Agbo1. **N'Guessan and N'Da (2005)** obtained an overall accuracy of 87% from a Landsat image covering the Bouaflé classified forest. According to **Girard and Girard (1999)** and **Congalton (1991)**, any overall accuracy above 80% allows the classification results to be validated. Since our accuracies are above 80%, our maps can therefore be validated.

The overall analysis of the dynamics of the transitions carried out showed that natural plant formations have lost area in favor of perennial crops. Agriculture is the main cause of the loss of areas of natural plant formations. This is explained by the fact that the population growth leads the populations living in the vicinity of the FCI to search for new land suitable for agriculture. Hence the conversion of plant formations into artificial plant formations. It should be noted that the poor conservation of the FCI is due to multiple factors, including the insufficient number of agents assigned to its surveillance, the lack of resources made available to them, not to mention the political and military crisis that Côte d'Ivoire experienced in the 2000s.

Impact of anthropogenic pressures on land use changes

During the period covered by our study (from 1988 to 2020), all types of land use underwent a change. Between 1988 and 2005, the areas of the "mosaic annual young cocoa crop" and "perennial rubber and oil palm crop" classes, as well as the "fallow" classes, increased. The expansion of agricultural activities, largely dominated by perennial crops, can be explained by the attractive cost of cocoa and rubber around the 2000s. Added to this is population growth, which is pushing people to look for new land suitable for agriculture. They then enter the FCI perimeter, destroying the forest to install their plantations. It is rightly so that **N'Da and al. (2008)** stated that deforestation is strongly linked to population growth. Also, part of the FCI (southern part) was granted to the company PALMINDUSTRIE for industrial exploitation. As a result, this would have constituted a gateway for infiltrations into the perimeter of the classified forest. The insufficient number of agents assigned to the surveillance of the FCI, coupled with the lack of resources, do not allow for an effective fight against these intrusions. The political-military crisis of the 2000s is also a significant element in the changes made within the FCI. This crisis favored the massive intrusion of populations in search of spaces suitable for agriculture and illegal loggers in search of species prized in the FCI. Furthermore, the classified forests were not subject to rigorous surveillance during this period, during which SODEFOR agents did not often have access to the classified forests. In fact, the 2005 image allows us to note a decline in forest areas, going from 18,038.05 ha in 1988 to 8,560.33 ha, i.e. a loss of more than 9,000 ha, almost entirely to the benefit of perennial crops.

The period 2005-2020 is marked by the expansion of the "perennial cocoa crop" class and a slight decline in the "mosaic annual young cocoa crop" and "perennial rubber and oil palm crop" classes. This decrease in the areas of these classes could be explained by the fact that the farms present during the first period (1988-2005) would have reached maturity and therefore in production. The need to exploit natural plant formations at the initial rate does not arise.

IV. CONCLUSION AND PERSPECTIVES

At the end of this study we note that the methodological approach allowed us to discriminate nine (9) land use classes which are reforestation, secondary forests, mosaics of annual young cocoa crops, young perennial cocoa crops, perennial rubber and oil palm crops, mosaics of degraded forests/old fallow land, young fallow land, young perennial rubber and oil palm crops and bare soils and habitats.

The various maps were produced with cartographic accuracies ranging from 87.26 to 91.01%. Interpretation of the 1988, 2005 and 2020 maps shows that forests have experienced a loss of area. Thus, forest cover lost 11,993.3 ha between 1988 and 2020, a decline of 2.07% per year in favor of farms (26,838.9 ha in 2020).



Anthropogenic pressures from industrial and family farms are the primary causes of the significant deforestation of the study site. While industrial farming remained confined to the south of the classified forest, family cocoa farms spread rapidly throughout the site from the 2000s onwards.

In view of this study, we envisage:

- Using drones for discriminating the degraded forest class and the old fallow class;
- Test the ability of drone data to discriminate between the different reforestations in this classified forest;
- Take inventory of the flora of the 6,000 hectares of forest relics that still exist in this area.

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