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SPATIO-TEMPORAL DYNAMICS OF FOREST COVER IN THE FOREST ZONE AND ECOLOGICAL ZONE II OF TOGO FOR ASSESSING THE CONSERVATION STATUS OF HABITATS OF NON-HUMAN PRIMATE POPULATIONS

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ABSTRACT

Knowledge of the conservation status of the habitats of animal species such as non-human primates is essential for their sustainable management and conservation. To better analyse the extent of threats and assess the conservation status of non-human primates in Togo's forest zone and ecological zone II, an analysis of forest cover dynamics in these two zones was carried out using digital processing and interpretation of Landsat imagery from 1985, 2000 and 2020. Software such as Envi 5.1 and Qgis version 3.34 were used for this purpose. Analysis of the spatio-temporal dynamics of the forest cover revealed a high rate of deforestation, estimated at 0.7%, reflecting a worrying level of degradation and disturbance of the habitats of all the non-human primates that depend on the ecosystems in the study area. Numerous pressures are thus threatening the survival of non-human primate populations in the study area.Poaching comes first, followed by habitat destruction and disturbance caused by human activities such as agriculture and logging. The community of non-human primates is therefore in real danger of extinction in Togo if appropriate action is not taken in time to preserve them. An effective conservation and sustainable management strategy for the network of protected areas in the study area needs to be updated and implemented.

Keywords: Spatio-temporal Analysis, Primates, Conservation, Fazao-malfakassa National Park and Missahohe Classified Forest.

1. INTRODUCTION

Deforestation is defined as the reduction in forest area in favour of other uses such as agriculture, urbanisation or mining. According to the FAO report (2016) on the state of the world's forests, nearly 80% of global deforestation is caused by agriculture, with the remaining 20% divided between infrastructure construction (roads, dams) first, then mining activities and finally urbanisation. These natural environments, destroyed by human activities, threaten the existence of the species that live there and have serious consequences for the proper functioning of the ecosystem. Deforestation substantially reduces a forest's capacity to provide goods and services (FAO 2002), including for climate change mitigation (Baccini et al., 2017). One of the consequences of these phenomena is the fragmentation and disturbance of the habitats of populations of animal species, such as non-human primates, that depend on forest ecosystems. To assess the state of conservation of the habitats of these species over time and space in the forest zone and ecological zone II of Togo, in addition to socio-economic surveys based on an interview guide, a spatio-temporal study was carried out by processing and interpreting satellite images from the years 85, 2000 and 2020. The diachronic study was carried out to analyse the

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link between deforestation and the conservation status of non-human primate habitats. The methodological approach of diachronic analysis of land use in geomatics was used for this purpose.

2. MATERIALS AND METHODS

2.1 Study site

The study area is defined by two ecological zones of Togo, namely ecological zone II and ecological zone IV, also known as the forest zone of Togo (Figure 1). This study area covers the Kara, Central and Plateaux regions. There are two major protected areas. These are the Fazao-Malfakassa National Park (PNFM) located in ecological zone II and the Missahohe Classified Forest (FCM) located in the forest zone, also known as ecological zone IV.

2.2 Methodology

2.2.1 Acquisition and processing of geomatic data

The images were downloaded from the USGS (United States Geological Survey) Earth Explorer image servers at http://earthexplorer.usgs.gov/. Three Landsat satellite images corresponding to the years 1985 (Landsat 5), 2000 (Landsat 7) and 2020 (Landsat 8) were used for the diachronic analysis, the production of georeferenced databases and the thematic maps. The choice of images for these dates was motivated by their availability, their coverage of the study area (PNFM) and their quality. The period of image acquisition (early January and early March of the years concerned) was chosen in order to have cloud-free images, as these are the months corresponding to the dry seasons when clouds rarely form, and above all to reduce problems linked to changes in the phenology of the vegetation. The period during which the images were taken was also taken into account so that an objective comparison could be made between the different dates. The rest of the image processing and analysis process is illustrated in Figure 2.

The analysis of land use dynamics was carried out after pre-processing the images acquired, classifying the images using ENVI 5.1 software, validating the classifications and rendering the maps. The pre-processing consisted essentially of choosing the composition of the spectral bands. The study area was then extracted from scenes 193/054 and 193/055 ('Path/Row'). To classify the images, the colour composition was based on channel 4 for infrared, channel 3 for red and channel 2 for green, according to the order of the colours red, green and blue. These are the bands generally used for mapping land use and vegetation cover dynamics. The training plots were identified by visual interpretation using knowledge of the study area and maps produced from high-resolution images (RapidEye and Google Earth). Supervised classification was applied using the 'maximum likelihood' algorithm, given the good knowledge of the study area. Five land-use units (Figure 2) were identified on the satellite images:

- ✓ the association of dense forests and riparian forests (DF), which include dense dry forests (closed stands with trees and shrubs reaching different heights) and riparian forests, which are made up of forest galleries. These are forests located along watercourses which are often narrow;
- ✓ open forests/wooded savannahs (FC): open forests are open stands of small and medium-sized trees whose crowns are more or less contiguous, with the entire forest canopy allowing a large amount of light to pass through;
- ✓ Tree/shrub savannah (TS): a variant of savannah in which trees and shrubs are scattered over grassy mats;

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- ✓ Crops/ fallow land (CU): a highly anthropised formation, either through long-term cultivation or a succession of crops and fallow land. The low density of woody vegetation includes forest fallows where the height of the woody vegetation is less than 5 m. Crops/fallow land correspond to woody vegetation resulting from the clearing of natural forest for shifting cultivation;
- ✓ built-up areas or bare surfaces (BA): these are areas of artificial buildings, dwellings, enclaves, human settlements, footpaths, rocky areas, dry ground and areas with no vegetation.

The training plots identified are representative of the land use classes in the study area. The images were visually interpreted for this purpose. The training plots were evaluated using the contingency matrix, which presents the various confusions between the classes used for classification. The assessment of the quality of the classification was confirmed by field verification using GPS campaigns. A sample of more than 250 observations (stratified) for each land-use map was taken. The classifications were assessed using the confusion matrix by comparing the results of the high-resolution maps of the region and the Google Earth Pro images, with the exception of the 1985 classification, which required a more in-depth analysis of the colour composition and a pixel-by-pixel comparison of the classified images for an objective assessment of the changes between 1985 and 2020.

Once the classification had been validated, the different land-use classes were vectorised, and the results were used to develop a georeferenced database using QGIS 3.10 and to produce thematic maps and various statistics relating to the different land-use classes identified. Comparison of the surface areas of the different land-use units for the periods covered by the classification and calculation of the overall rate and the annual deforestation rate highlighted the dynamics of the vegetation cover between 1985 and 2020 in the study area. The Kappa index obtained, in the confusion matrix, evaluates the agreement between the results obtained and the data collected in the field. According to Landis and Koch (1997), it varies from 0 to 1 and can be interpreted as follows:

- ➢ very low agreement when the rate varies from 0 to 0.20;
- ➢ low agreement when the rate varies from 0.21 to 0.40;
- ➢ moderate agreement when the rate varies from 0.41 to 0.60;
- ➢ a high level of agreement when the rate varies from 0.61 to 0.80;
- ➢ almost perfect agreement when the rate varies from 0.81 to 1.

The results of the diachronic study have made it possible to analyse and assess the transformations and changes that have taken place over the period under consideration. In fact, the rate of change is the statistical indicator that was used to assess the changes that occurred in each occupation class between 1985 and 2010. To calculate the rate of change (annual rate of change: Tg) in the areas of the different land cover classes between 1985 and 2020, the formula suggested by the FAO was used. It is as follows

$$Tg = (S2-S1)/S1x\ 100$$

S1 being the surface area of a surface unit class at date t1;
S2 being the area of the same surface unit class at date t2.

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The negative values obtained highlight the loss of a class between two periods. Positive values indicate an increase in area between two dates, and values tending towards zero indicate relative stability of the class concerned between two periods. The annual deforestation rate corresponds to the ratio between the area cleared over a period, divided by the initial forest area and by the number of years in the period (Menon et al., 1997). However, shortcomings have been identified, based on the fact that changes in forest loss cannot be obtained using this simple ratio (Puyravaud et al., 2003). Hence the interest in using the standardised formula of Puyravaud et al. (2002) to determine the annual deforestation rate:

$$T_{xdef} = -\frac{1}{t_2 - t_1}.x.\ln\left(\frac{A_2}{A_1}\right)$$

with:

- T_{xdef} is the rate of deforestation in % and
- t1 and t2: the initial and final years considered for the calculation
- A1 and A2: the forest areas corresponding to years t1 and t2.

In addition, the spatio-temporal study of the study area carried out through the processing and interpretation of satellite images from the years 1985, 2000 and 2020 made it possible to analyse the spatial distribution of non-human primate habitats and to assess the level of disturbance to their habitat in the study area.

3. RESULTS AND DISCUSSION

3.1 Validation of classification results

The confusion matrices obtained (Tables 1, 2 and 3) indicate the reliability of the classifications for the three periods. Overall accuracy was good, at 95.56%, 88.27% and 88.30% respectively for the 1985, 2000 and 2020 classifications, despite some confusion. The Kappa coefficient was 0.91 for the 1985 classification, 0.82 for the 2000 classification and 0.85 for the 2020 classification. This suggests a good match between the results of the classifications and the information extracted from the images. In fact, according to the interpretation grid proposed by Landis and Koch (1977), when the value of the Kappa coefficient obtained is < 0, there is strong disagreement; between 0.00 - 0.20: very poor agreement; 0.21 - 0.40: poor agreement; 0.41-0.60: average agreement; 0.61 - 0.80: satisfactory agreement 0.81-1.00: excellent agreement. The classification operations carried out for land use studies, with Kappa coefficients of between 0.50 and 0.75, are valid and the results can be used reliably (Pontius, 2000). It is therefore concluded that the various land-use units derived from the classifications are reliable and can be used to analyse the conservation status of the various habitats in the study area.

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Table 1. Confusion matrix for the 1985 classification

	VALIDATION ZONE (Field)					
		C_FR	C_FC	C_FD	C_SAVAA	C_CU	BA
CLASSIFICATION (1985)	FR	202	631	592	0	0	0
	FC	29	6576	7	0	0	0
	FD	9	209	3293	0	0	0
	SAVAA	0	0	0	2105	0	0
	CU	0	0	0	15	47	0
	BA	0	165	6	0	0	206
	Total	240	7581	3898	2120	47	206

Overall accuracy = (43865/45893) 95. 56%
Kappa Coefficient = 0.9130
FD: Dense forest, *FR: R*iparian forest, *FC:* Open forest or wooded savannah, *SAVAA:* Wooded/shrubby savannah, *CU:* Crop/fallow, *BA:* Building/bare surface.

Table 2. Confusion matrix for the 2000 classification

	VALIDATION ZONE (Field)						
		C_FD	C_FR	C_FC	C_SAAV	C_CU	C_BATI
CLASSIFICATION (2000)	FD	1633	1	0	0	0	0
	FR	0	153	93	0	0	0
	FC	0	18	1618	0	0	0
	SAVAA	0	0	2	201	0	0
	CU	0	0	0	3	276	29
	BATI	0	0	0	2	16	52
	Total	1633	172	1713	206	292	81

Overall accuracy = (3629/4111)) 88.27%
Kappa Coefficient= 0.82

Table 3. Confusion matrix for the 2020 classification

	ZONE DE VALIDATION (Terrain)						
		C_FD	C_FR	C_FC	C_SAVAA	C_CU	BATI
CLASSIFICATION (2020)	FD	1248	4	2	0	0	0
	FR	302	369	93	0	0	0
	FC	1	20	946	6	0	0
	SAVAA	0	0	0	3531	0	0
	CU	0	0	0	0	35	0
	BATI	4	0	0	12	0	79
		1555	393	1041	3549	35	79

Overall accuracy = (9998/11409) 88 %
Kappa Coefficient= 0.85

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3.2 Land cover dynamics in the study area (1985-2020)

Five land cover classes were identified on Landsat satellite imagery. These are Dense Forest/Riparian Forest (DFR), Open Forest (OF), Arboreal/Shrubby Savannah (AS), Crop/Fallow (CF) and Built/Bare Land (BL). Dense forests and riparian forests were subsequently combined because of the similarity of their spectral signature and the confusion they are subject to during classification. The same applies to human settlements and bare surfaces. Figure 4 shows the evolution over the years of fallow crops and buildings/bare land to the detriment of the forest strata represented by dense/riparian forests, open forests and wooded/shrubby savannahs. Table 4 presents detailed statistics for the various land-use units. Analysis of the dynamics was supported by change detection.

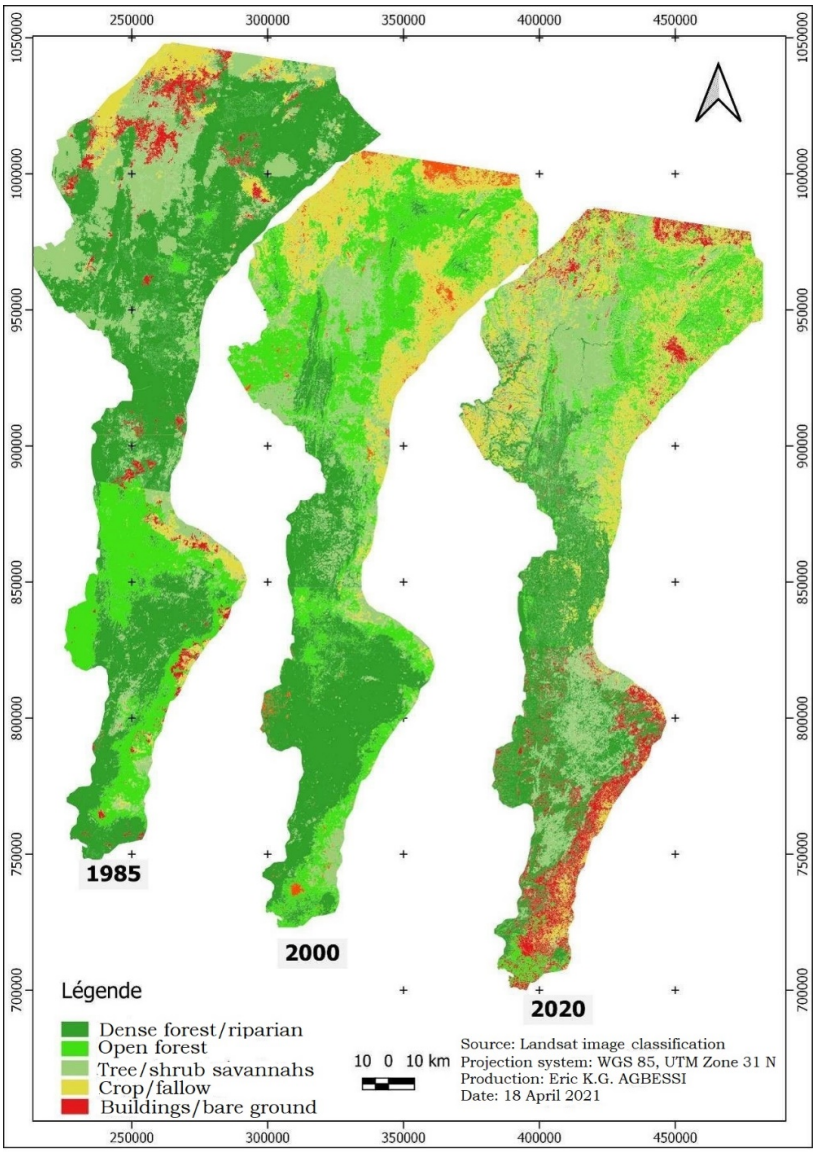

Figure 1. Comparison of land use units in 1985, 2000 and 2020

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Tableau 4. Dynamique de l'occupation du sol dans les zones écologiques II et IV du Togo.

N°	Unité d'occupation	1985		2000		2020		Dynamique en %		
		Sup (ha)	%	Sup (ha)	%	Sup (ha)	%	1985-2000	2000-2020	1985-2020
1	Dense forest/Riparian (FDR)	777 070	52.98	443 404	30.23	420 127	29	- 42.94	- 5.25	- 45.93
2	Open forest or wooded savannah (FCSB)	215 723	14.71	486 531	3.,17	275 574	19	+125.53	- 43.36	+27.74
3	Wooded/shrubby savannah (SAA)	309 167	21.08	216 094	14.73	309 866	21	-30.10	+43.39	+0.23
4	Crop/fallow (CUJ)	89 152	6.079	278 660	19	292 847	20	+212.57	+5.09	+228.48
5	Building/bare surface (BSN)	75 552	5.151	41 974	3	168 249	11	- 44.44	+300.84	+122.69
Total		1 466 663	100	1 466 663	100	1 466 663	100			

3.3 Mapping habitat conservation status and fragmentation factors for different primate groups

The spatio-temporal study of the study area was carried out by processing and interpreting satellite images from 1985, 2000 and 2020 in order to assess the level of disturbance to primate habitats in the study area. Figure 4 shows that the 1985 land cover map is dominated by green colours (chosen deliberately), which are representative of dense, riparian forests (dark green) and open forests (light green), to the detriment of yellow and red colours, which are respectively representative of crops/ fallow land and buildings, which are poorly represented. These greens are more localised in the central region, which contains the largest protected area (Fazao-Malfakassa National Park). The trend begins to reverse from the year 2000 onwards, becoming more pronounced in 2020, when we see a change in cultivated areas (yellow) and human settlements (red).

Table 4 (above) shows the precise dynamics that occurred during the three periods considered in the study. The changes that occurred within the different land use classes can be described as regression or progression. According to the statistical analysis of the 1985 classification, the reference date for the study, the forest zone (ecological zone IV) and ecological zone II are characterised by vegetation that is fairly marked by dense and riparian forests (777,070 ha), open forests/wooded savannahs (215,723 ha), which occupy 52.98% and 14.71% of the total surface area of the study zone respectively. Tree/shrub savannahs occupy an area of 309,167 ha, or 21.08%. Crops/ fallow land (89,152 ha) and built-up/bare land (75,552 ha) are the least represented classes, at 6.079% and 5.151% respectively (Figure 5).

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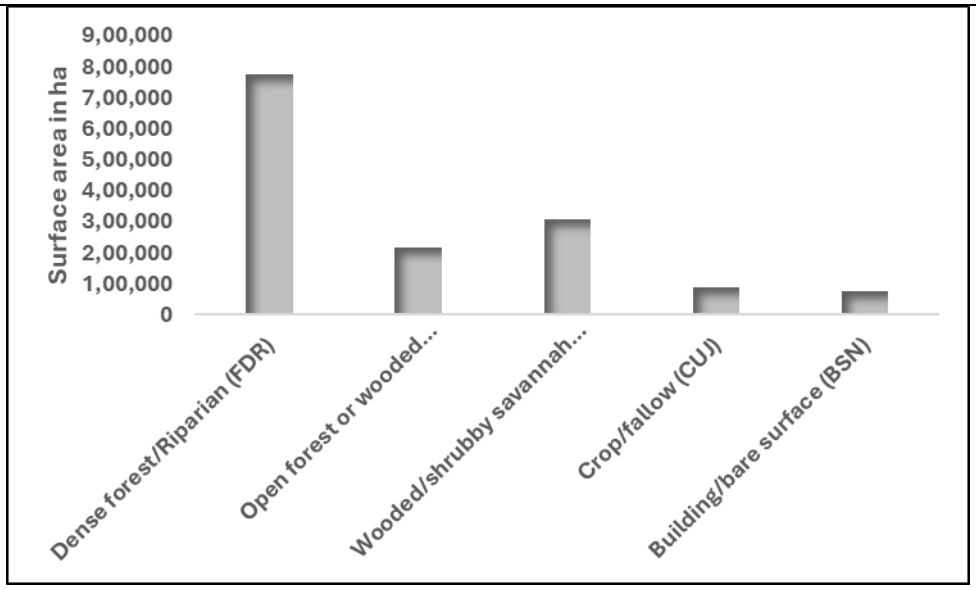

Figure 2. Surface area of the different land-use units of 1985

During the 1985 period, there was little pressure on resources because of the low population density in the forest zone and in Togo's Ecological Zone II, as was the case throughout the country. This situation, which was favourable to the conservation of biodiversity, can also be explained by the effectiveness of the forestry administration's control at the time. The management of protected areas at the time was very rigorous, and the penalties imposed on offenders were severe and highly dissuasive. Human settlements and bare land accounted for only 5.151%. Crops and fallow land occupied around 6% of the total surface area of the study area. At that time (1985), the national population was estimated at 3.253 million, and the population centres were more or less grouped together.

This has favoured the conservation of forest massifs (potential wildlife habitats), which have been spared fragmentation. In addition, the good rainfall during this period contributed to the positive dynamics of the plant cover. These ecosystems, which constitute habitats for animal biodiversity, were well preserved at the time thanks to the low level of human pressure. The majority of the best-preserved areas are in the rugged terrain and, above all, in the protected areas. There are twelve (12) protected areas in the study area, the most important of which include: The Fazao-Malfakassa National Park (PNFM) in the Central region, which straddles the prefectures of Sotouboua, Tchaoudjo, Plaine de Mô and Bassar, and the Missahohe Classified Forest (FCM) in the Plateaux region, located entirely in the prefecture of Kloto, the Deux Bena (DB) in the Plateaux region, more specifically in the prefecture of Wawa, the Forêt Classée d'Assoukoko (FCA) in the prefecture of Blitta in the Central region and the Forêt Classée d'Alédjo in the Kara region, located in the prefecture of Assoli. Apart from a few beaches in burnt areas, the forest cover does not appear to have undergone any significant disturbance likely to lead to the degradation or loss of habitats for fauna in general and primates in particular. The varieties of coffee and cocoa introduced into the study area since the German era, and which experienced an unprecedented boom from 1940 onwards requiring shade, also militated in favour of the conservation of the plant cover and, in turn, of wildlife habitats, including those of non-

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human primates. In its natural habitat, the coffee tree is found in shaded or semi-shaded areas. (Tchamiè, 2000). In 2000, according to Table 4 (above), anthropogenic pressures on forest resources began to be felt (Photo 1).

Photo 1. *Ensachage de charbon de bois dans le PNFM (2021)*

Although the vegetation cover seems to be noticeable, the fact remains that it has lost its quality with the regression of dense and riparian forests in favour of open forests and wooded/shrubby savannahs and above all crops/fallow plantations, which reflect degradation and deforestation in places. This conversion can also be seen within the protected areas of the study zone, and is largely explained not only by the substantial increase in population, but also by the invasion of these protected areas following the socio-political unrest in Togo in the 1990s, which led to the displacement of a large proportion of the population to these previously well-protected areas, and to the abusive and illegal exploitation of forest resources. As a result, dense forests and riparian forests fell from 777,070 ha (52.98%) in 1985 to 443,404 ha (30.23%) in 2000. This corresponds to a decline of 42.94% (Figure 6). Over the same period, open forests and wooded savannahs (486 531 ha) increased by 270 808 ha from their initial estimated area in 1985 (215 723 ha), for a growth rate of 125.53%, thus explaining the loss of dense forests and riparian forests in 2000, estimated at 333 665 ha. Tree and shrub savannahs fell from 309,167 ha (21%) in 1985 to 216,094 ha (15%) in 2000, probably to the benefit of crops and fallow land, which increased by 189,508 ha, i.e. a growth rate of 212.57%. The degree of conversion thus observed would significantly affect the state of wildlife habitats, including those of primates. The corollary of this is the disappearance of several habitats and, by extension, the disappearance of certain groups of primates that have not been able to adapt or escape from the vulnerability to which the threat, disturbance and even disappearance of their habitat have exposed them. Similar results relating

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to the regression of forest areas were obtained by Kpedenou (2017), who assessed the quantification of changes in land use in the prefecture of Yoto (south-east Togo) using Landsat satellite imagery.

The same regressive trend in forest strata has characterised the results of the analysis of the dynamics of the forest cover of the PNFM between 1997 and 2017 by MERF (2020) and specifies that forest and savannah formations, more dominant towards the west of the PNFM, constitute the main types of land cover in the park. The area of open forest and wooded savannah has gradually shrunk from 49,915.80 ha in 1987 to 44,973.72 ha in 1997, a loss of 4,942.08 ha. The area lost to these same formations has also fallen sharply over the last 20 years (1997-2017), by 113,093.64 ha.

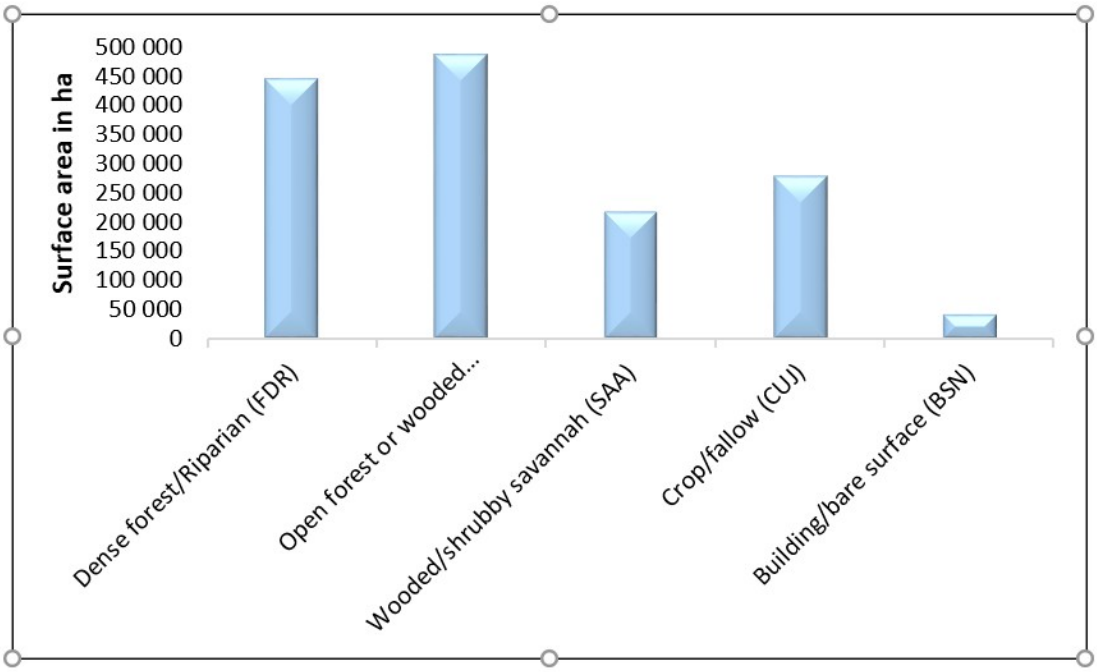

Figure 3. Surface area of the different land-use units of 2000

Analyses for 2020 reveal a drastic decline in dense and riparian forests (Figure 7). The losses of dense and riparian forests observed from 2000 onwards have unfortunately continued in 2020. They will fall from 777 070 ha (53%) in 1985 to 42 0127 ha in 2020 (29%), i.e. a dynamic of -45.93. Open forests and wooded savannahs have increased slightly, from 215 723 ha (14.71%) in 1985 to 275 574 ha (19%). This is also the case for tree and shrub savannahs, which declined slightly in 2000 before showing a slight gain of 699 ha, rising from 309,167 ha (21.08%) in 1985 to 309,866 (30.10%) in 2020, for a dynamic of +0.23%. The fall in the surface area of dense and riparian forests can be explained by their significant conversion to crops and fallow land, estimated at only 89,152 ha (6.079%) in 1985, rising to 278,660 ha (19%) before reaching 292,847 ha (20%) in 2020. This represents a growth rate of more than 228%. The increase in crops and fallow land is correlated with the expansion of built-up and bare land. The latter, which was around 5% in 1985, is estimated to have risen to over 44% thirty-five (35) years later. This indicates significant deforestation in favour of human settlements and fallow crops, which are not likely to preserve the habitats of animals, particularly primates that exploit the forest

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strata. These non-human primates are thus deprived of their habitat and are forced to move to other ecosystems or try to adapt and adapt to savannahs and fallow land that do not offer all the guarantees and acceptable conditions for survival. Africa's tropical forests are shrinking rapidly due to the expansion of cultivated land and commercial timber exploitation (Barnes, 1990; Laporte et al., 2007; FAO, 2010).

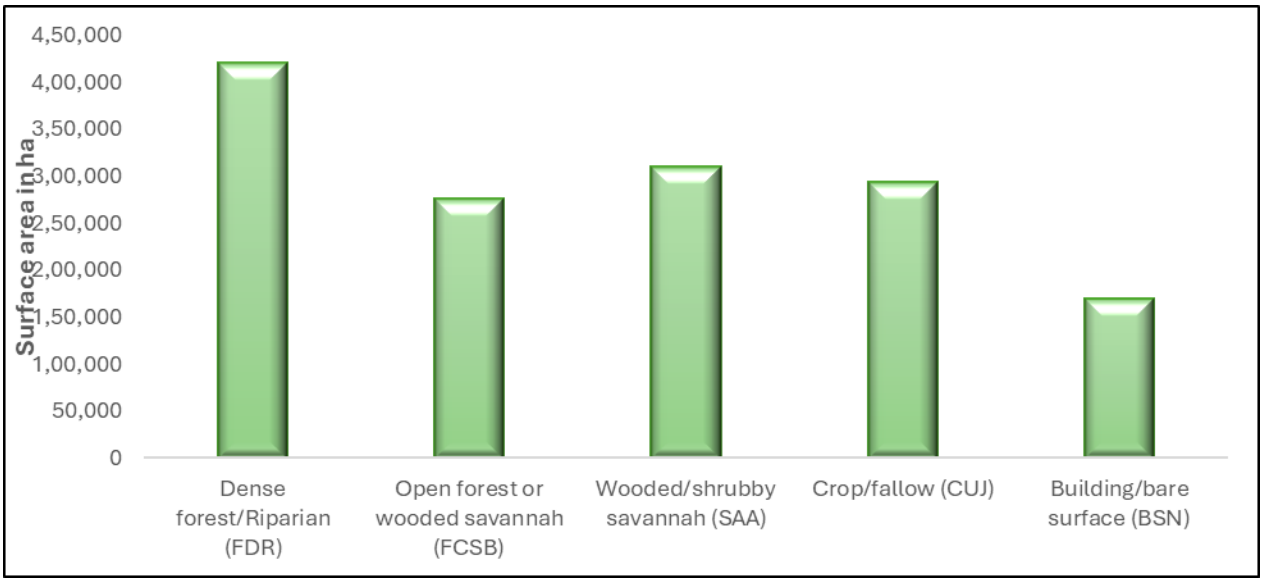

Figure 4. Surface area of the different land-use units of 2020

Similar results have also been obtained by other researchers in Togo and neighbouring countries under almost identical conditions. This is the case of Agbanou (2018) in Benin, whose diachronic analysis results show that between 1987 and 2016, the landscape initially dominated by open forests and wooded savannahs (38.81%) and tree and shrub savannahs (25.82%) in 1987 was replaced by other land-use categories, the most important of which were tree and shrub savannahs (40.53%) and crop and fallow mosaics (50.61%) in 2016. Anthropogenic activities and climatic disturbances are the main determinants of these land cover dynamics. The results of the interpretation of Landsat images of part of the study area (Adélé plateau in the Central region) according to Boukpessi (2019) indicate that in the space of 20 years (between 1999 and 2019), the 'forest' and 'savannah' classes have lost more than half their surface area, dropping from 40.2% to 19% and 40.6% to 15.7% of the surface area of the study area respectively. On the other hand, the surface area of 'fields and fallow land' increased by a factor of 12, from 3,206.3 ha to 39,589 ha, and that of 'buildings/bare ground' almost doubled, from 18,471.6 ha to 33,799 ha. Les mêmes constats ont été faits par N'Guessan (2019) en Côte d'Ivoire où la période allant de 2002 - 2017 est marquée par une plus forte régression des zones de végétations de forêts de la Forêt Classée d'AGBO 1. Ainsi, en cinq ans environ, ladite forêt a perdu 48,29% de sa superficie initiale.

Dans le cadre de la présente étude, le résultat de l'application numérique de la formule de Puyravaud (2002) donne un taux de déforestation : (T_{xdef}) de 0,70 %. Avec t_1 = 1985, et t_2 =2020 ; et A_1 = 1301 960 ha, A_2 = 1 005 567 ha.The annual rate of deforestation in the study area is therefore equal to 0.70%, corresponding to a forest area of around 911,372 ha that would be

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destroyed and probably converted to agricultural land between 1985 and 2020. This reflects the intensity of human pressure on woody forest ecosystems, which are potential habitats for non-human primates. It is clear that the two main direct causes of deforestation are excessive felling to meet people's energy needs and demand for timber, and agricultural expansion (Ariori and Ozer, 2005). As a result, primate habitats have been severely degraded and are not conducive to their sustainable conservation.

4. CONCLUSION

In the light of the above, it is clear that the natural environment of the study area has been greatly modified by human activities, amplified by the ever-increasing population and abusive logging. The impact of habitat fragmentation is therefore perceptible. This transformation of the forest ecosystem into agricultural areas in most cases, in addition to poaching, would justify the disappearance of species such as Pan troglodytes (the chimpanzee) throughout the national territory and the reduction in the numbers of most non-human primates counted in protected areas and associated ecosystems. This has forced a spatial redistribution of non-human primates, with serious impacts on their population dynamics. Only those populations that have been able to adapt are still able to survive in highly anthropised environments, generally finding refuge in adjacent rugged areas. Vulnerable groups have disappeared from their sites, which are easily accessible to humans. Urgent action needs to be taken to reduce human disturbance to the habitats of animal species in general and non-human primates in particular.

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