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Aerial photography of traces of human activities around the UNESCO World Heritage site in the Nimba Mountains Biosphere Reserve, Republic of Guinea

Pascal Bilivogui[1], Lanan Wassy Soromou[2], Daouda Konate[1], Ansoumane Sakouvogui[3], Martin Yelkouni[4], Paquilé Molmou[5], Gnan Mamy[6], Maria Loua[7], Gabriel Hoinsoudé Ségniagbeto[8]

[1]Higher Institute of Science and Veterinary Medicine of Dalaba, Republic of Guinea, pascalbilivogui@gmail.com, daoudakonate48@gmail.com
[2]University of Labé, Republic of Guinea, lananwassy@gmail.com
[3]Mamou Higher Institute of Technology, Republic of Guinea, ansoumane2015@gmail.com
[4]Senghor University of Alexandria, Egypt, martin.yelkouni@usenghor.org
[5]Station Scientifique des Monts Nimba, Republic of Guinea paquilemolmou2014@gmail.com
[6]Environmental Research Institute of Bossou, Republic of Guinea, mamygnan2@gmail.com
[7]Université de N'zérékoré, République de Guinée, marialoua22@gmail.com
[8]University of Lomé, Republic of Togo, GSegniagbeto@gmail.com

Corresponding author's contacts: pascalbilivogui@gmail.com

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Abstract

The objective of this study is to identify traces of human activities on the central area (UNESCO Heritage Site) of the Biosphere Reserve of the Nimba Mountains through drone photographs and the cartographic analysis of images from 1990 and 2020. The methodology was: aerial photography of peripheral areas using a MAVIC-4 drone, and cartographic analysis of satellite imagery from 1990 and 2020. The analysis of satellite imagery from 1990 and 2020 show that the land uses of the Biosphere Reserve have increased considerably. The total area under construction fell from 81.66 ha to 303.76 ha, the bare soil from 1226, 28 ha to 3344.11 ha and the agricultural areas from 19.89 ha to 58.98 ha. However, the primary forest decreased from 11,326.05 ha to 4,345.09 ha, recording a loss of 6,980.96 ha or -15.19% of its area. The images taken with the drone at low altitude show traces of anthropogenic activities getting closer and closer to the central area, traces of clearing, and fallow. The degradation is strongly observed in the buffer zone and gradually weakens towards the center.

Keywords: Aerial photography, anthropogenic activities, World Heritage site, Biosphere reserve, Republic of Guinea

Introduction

Population growth and the influx of refugees from neighbouring countries such as Liberia, Côte d'Ivoire and Sierra Leone have increased pressure on the natural resources in the Nimba Mountains biosphere reserve in Guinea, causing the fragmentation of ecological habitats through anthropogenic activities including: shifting agriculture, uncontrolled bush fires and the loss of wildlife through hunting and fishing (IUCN World Heritage Outlook, 2020).

The buffer zone of the Nimba Mountains Biosphere Reserve, once dominated by dense forest is increasingly declining, with the exception of a few isolated sacred sites and forests galleries towards the plain of Gbié in the course of exploitation by burnt crops and bush fires. Currently this area has about 12 villages divided into two sub-prefectures (Bossou and N'Zoo) (IUCN & World Heritage Outlook, 2017). Agriculture accounts for more than 80% of the population of the Nimba Mountains reserve. The shortage of arable land has drastically reduced fallow times from 2 to 5 years. However, deforestation is one of the major means of land use change that occurs over time but has a significant impact on biodiversity loss (Gillet et al., 2016). While the lack of arable land leads to encroachment of central areas of the biosphere reserve. Coffee, cocoa, oil palm and rubber plantations are the industrial crops found in the vicinity of the agglomerations. Rice, cassava, taro, potato and groundnut are the food base of the population, generating income for the populations. Hunting and fishing on the reserve's waterways are the main sources of protein supply for the population. These different activities pose a major threat to the important flora and fauna of the Nimba Mountains. Therefore, the Exceptional Universal Values such as: Bossou's Chimpanzees, Viviparous Toads and Micropotamogale are exposed to habitat degradation (UNESCO & UICN, 2019). To all this is added the mining in the same network.

In addition, the evolution of drone technology is one of the simple and fast methods for statistical evaluation of land use through the acquisition of images at very high resolution. This method allows better monitoring of land use and the control of space evolution over time (Semeki Ngabinzeke et al., 2018). The application of the drone has several advantages including the instant obtaining of good quality images and immediately finding for a quick solution unlike the platforms Classic with low ecological footprint (Nago et al., 2021). Aerial photogrammetry combined with mapping is a solution for environmental monitoring of protected areas (Bourdouxhe, 2017).

Thus, to effectively remedy the decline of natural landscapes in protected areas, It is necessary to start with a better understanding of the mechanisms of degradation of land-use units and assess its magnitude (Mama et al., 2020). This work requires the use of tools and indicators capable of revealing observable spatio-temporal changes. This study will focus on both a qualitative and quantitative assessment of the vegetation cover and the photography of anthropogenic traces in the immediate vicinity of the heritage site UNESCO World Heritage Nimba Mountains (central area). The main objective of the study is to identify using mapping and photography of the MAVIC-drone4, the degree of disturbance to natural ecosystems around the central zone for better interpretation of changes to facilitate decision-making for sustainable management of biodiversity. The hypothesis to be tested in this study is that anthropogenic activities are the driving force behind the vegetation cover dynamics observed from 1990 to 2020 at the Nimba Mountains.

Methods

Map Analysis

The UNESCO World Heritage Site is the third central area, after that of Déré and the Bossou Hills in the Biosphere Reserve of the Nimba Mountains. It covers an area of 12 540 ha. In this study, a radius of 5 km has been added to the study area itself, with the aim of observing the dynamics of different land uses in 2020 (Figure 1). The map of the study area was uploaded to the WDPA site and added to the map of the Nimba Mountains Biosphere Reserve for correct analysis. Excel was used as a spreadsheet to calculate the area of land use classes.

This area covers the two sub-prefectures Bossou and N'Zoo. Vegetation cover dynamics were studied in this delimited area. Figure 1 shows the space added to the UNESCO World Heritage Site (central area of the Biosphere Reserve of the Nimba Mountains.

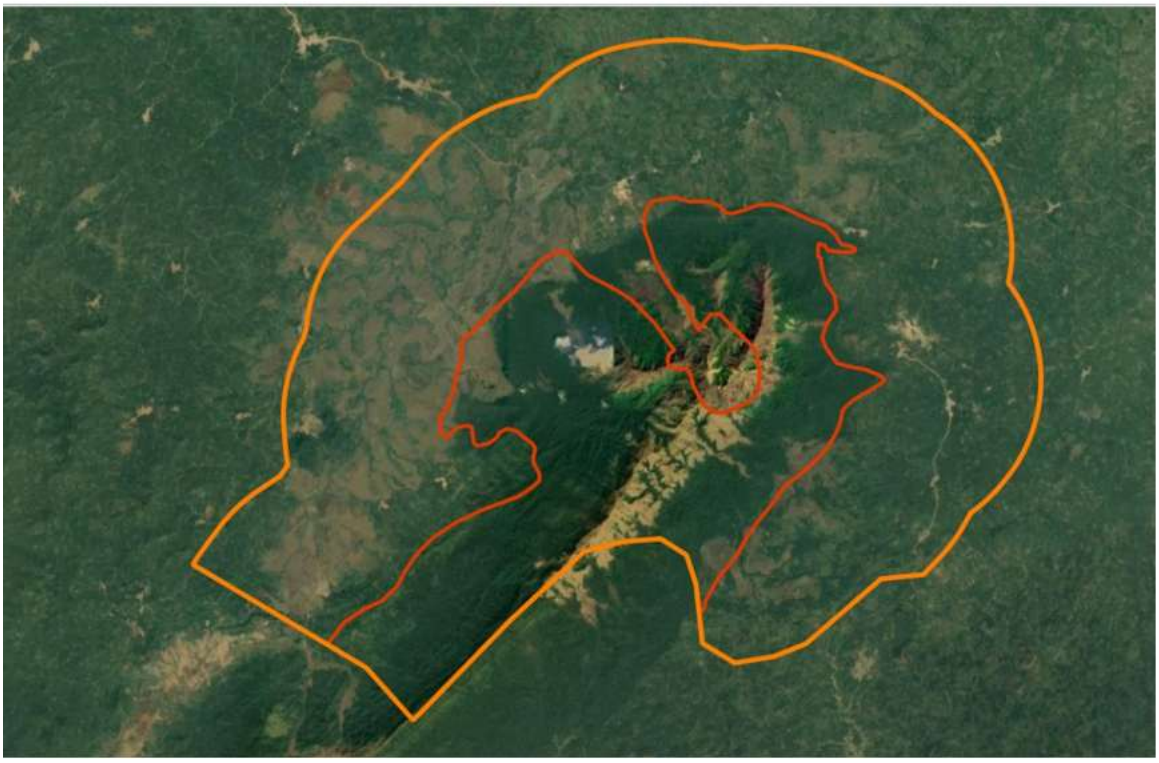

Figure 1: Heritage site and peripheral area subject to cartographic analysis

Landsat images from 1990 and 2020 were then uploaded and classified using the Maximum Likelihood method (QGIS). The analysis of GIS data began with the correction of GPS data collected in the field. This data was projected on OpenStreetMap in order to close the circuits that had not been during the WayTrack process with GPS.

Acquisition of Images Through the Drone

In this part, the DJI 4 drone made it possible to photograph the surroundings of the study area for the detection of possible presence of traces of anthropogenic activities in the vicinity or inside the central area, notably: traces of human activities were photographed, camps, fields, fallows and tracks.

Six (6) take-off points made it possible to fly over the entire mountain range on the Guinean side, including three take-off points on the southwest side in the sub-prefecture of N'Zoo and three others on the northeast side in the sub-prefecture of Bossou. Overflight stations on the southwest side began at Gbié, for observation from the border with Côte d'Ivoire to Kéoulenta.

The second station was at Kéoulenta which allowed to observe the length of the chain of this face of the mountain for the taking of photos and the evaluation of the effects of the anthropogenic activities. And finally, the third station in Foromopa for in the direction of mining excavation. Three other stations including: the plane of Séringbara, Nyon and the checkpoint in Thio have covered the whole chain. The geographical coordinates of the take-off points are shown in Table 1.

Table 1: Aircraft coordinates, altitudes and distances flown by the drone

Stations	Coordinates	Drone altitude	Distance travelled to the site
Gbié	07.67157° N 008. 31492° W 467 m	119 m	574 m
Kéoulenta	07.70996° N 008.33259° W 505 m	133 m	359 m
Foromota	07.71645° N 008.37328° W 529 m	148 m	338 m
Séringbara plain	07.66900° N 008.44883° W 560 m	120 m	500 m
Nyon	07.63275° N 008.46125° W 528 m	120 m	335 m
Ecoguard station Nyon	07.60829° N 008.47778° W 486 m	122 m	420 m

Material

Study Area

The Nimba Mountains Biosphere Reserve is located in the extreme southeast of the Republic of Guinea, on the border with Côte d'Ivoire and Liberia, between latitude 7°25 and 7°35' North and longitude 8°20' - 8°30 West (Lamotte et al., 2003). It covers a total area of 145,200 hectares and is crossed by the national road No. 2 which connects Lola to Danané (Côte d'Ivoire) and the national road No. 19 (Lola-Yekepa (Liberia). It is home to 50% of the long chain of Nimba shared between the three countries.

The RBMN was declared an Integral Nature Reserve in 1944 and then a Biosphere Reserve in 1980 (UICN/PACO, 2008), it underwent the classic Man and Biodiversity (MAB) model in order to conserve biological resources of global importance. The peculiarity of the RBMN is that it is composed of three central areas of small areas covering the main habitats of the values of the reserve.

It consists of a buffer zone characterized by the presence of increasing populations, human activities and a vast transition area of 88,280 hectares. It is limited by a buffer zone of 35,140 hectares.
The three core areas of different areas are:

a. Bossou Chimpanzee Hills, 320 hectares in size;
b. the Déré Forest, covering 8,920 hectares;
c. UNESCO World Heritage Site of 12,540 hectares.

The Nimba Mountains have one of the highest rainfall in West Africa with an annual total of between 2000 and 3000 mm per year (Conde, 2019). They benefit from a hydrographic network that includes more than fifty streams of a torrential nature. These rivers take their sources on the slopes of the mountain range and flow into ravines sometimes in falls or waterfalls. They are home to nearly 85% of Guinea's biodiversity, including 200 endemic species. The very rich entomological fauna favors the presence of many insectivores with more than ten species of Crocidura, seven species of chiroptera and an exceptional amphibian *Nectophynoides occidentalis* (viviparous toad) (UICN/PACO, 2008).

The World Heritage site (12,540 hectares), representing the Guinean part of the Nimba Mountains is our study area. It is located in the prefecture of Lola, shared between two sub-prefectures. The sub-prefecture of N'Zoo in the northeast and Bossou in the west.

The Nimba Mountain Range has more than 2,400 plant species. This makes it the richest and most documented botanical site in West Africa. It contains at least 40 threatened species and several endemic species, such as *Osbeckia porteresii* and *Sporobolus pauciflorus.* It is also home to disjunct and restricted species such as *Justicia jamisonii* (Couch et al., 2018).

The western part of the chain is exposed to humid winds and the forests of the slopes meet at the level of the ridge which carries on small plateaus with afforestation of less height. Its entities are structured as follows from bottom to top:

a. the forests of the plain and the low slopes; the savannahs of the plain, traversed by forest galleries that extend the previous forests.
b. the mountain forest at *Parinari excelsa* which dominates above 1000 m;
c. grassy formations of the upper regions with floristic variants related to altitude and often bedrock.

The biogeographic originality of Nimba is mainly due to the grassy vegetation of the upper regions (Lamotte & Roy, 1998). Today, although it is recognized as a Biosphere Reserve and a World Heritage Site, its distribution area is threatened.

The Nimba massif was long surrounded by some villages among which: Thio, Nyon and Séringbara on the north-west side, populated by the Manons; Ziguépo, Kéoulenta, N'Zoo, Gbié and Guéguépo to the northeast, populated by the Kônôs ((Lamotte, 1949).

Today, the RBMN has three sub-prefectures including: Tounkarata surrounding the central area of Déré, N'Zoo and Bossou that surround the World Heritage site and the chimpanzee hills of Bossou. The sub-prefecture of N'Zoo, located in the buffer zone of the RBMN to the east of the site, covers an area of 375 km² with a population of 22,330 including 12,990 women, with a density of 59.54 hbts/ Km² It occupies the northern part with nine (9) districts including: N'Zoo 1, N'Zoo 2, Doromou; Bourata; Gonomanonta; Gbakoré; Kéoulenta; Pôro and Gaah. These districts are divided into 25 villages (Mairie, 2020).

The sub-prefecture of Bossou occupying the northwest side of the site, is located 18 km from Lola. It covers an area of 236 km² with a population of 14,057 inhabitants: a density of 52 hbts/ km². The sub-prefecture of Bossou occupying the northwest side of the site, is located 18 km from Lola. It covers an area of 236 km² with a population of 14,057 inhabitants: a density of 52 hbts/ km².

Results

The treatment of the classification of Landsat images allowed the observation of the evolution of the land use classes of the Heritage Site over time (1990 and 2020). The spatial variations over time are presented in the following pages.

Land Use in 1990

The analysis of land use classes in 1990 consisted in knowing the state of the study area and allows to determine the impacts of human activities from this date. As part of this study, the description of the various changes was carried out to compare the areas processed in past years. Figure 2 shows the land cover map for 1990.

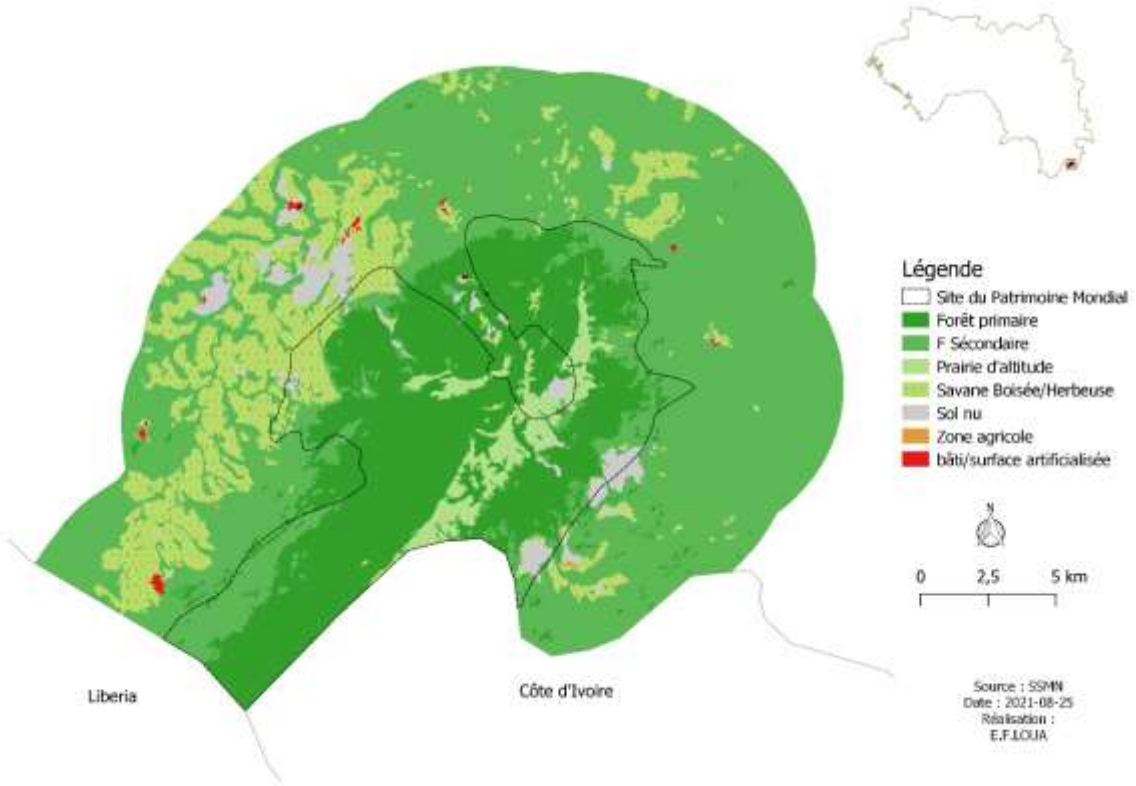

Figure 2: Land use classes of the World Heritage Site and its periphery in 1990

Table 2 Land cover classes

Land cover classes	**1990**	
	Area (ha)	**Percentage (%)**
Built	81.66	0,17%
Primary forest	11326.05	24,65%
Secondary forest	25285.1	54,96%
Mountain meadow	1247.02	2,71%
Woodland/Grassy Savannah	6814.12	14,81%
Bare soil	1226.28	2,66%
Agricultural zone	19.89	0,04%
Total	**46000,12**	**100,00%**

Table 2 shows that in 1990 the secondary forest is the most dominant with 54.96% of the total area analysed. It is followed by the primary forest which covered 24.65%, then the wooded and grassy savannah (14.81%), the high-altitude meadow (2.71%), the bare ground (2.66%) and finally the human dwellings and the agricultural zone respectively: (0.17%) and (0.04%).

The analysis of these data shows that at that time, there were already some communities around the chain, but at a low percentage and that at that time the activities did not hinder the conservation of biodiversity. A significant part could also be attributed to the role played by the various services in maintaining and sustaining the biosphere.

Land use in 2020

The analysis of the dynamics of land use classes in 2020 aimed to assess the changes that occurred in the study area through anthropogenic activities such as: agriculture, extension of villages or mining, caused by man after 30 years. It allowed to know the increased or decreased area of each land use class. The total area of the study area remained the same to observe the losses or gains. Figure 3 shows the vegetation cover in 2020.

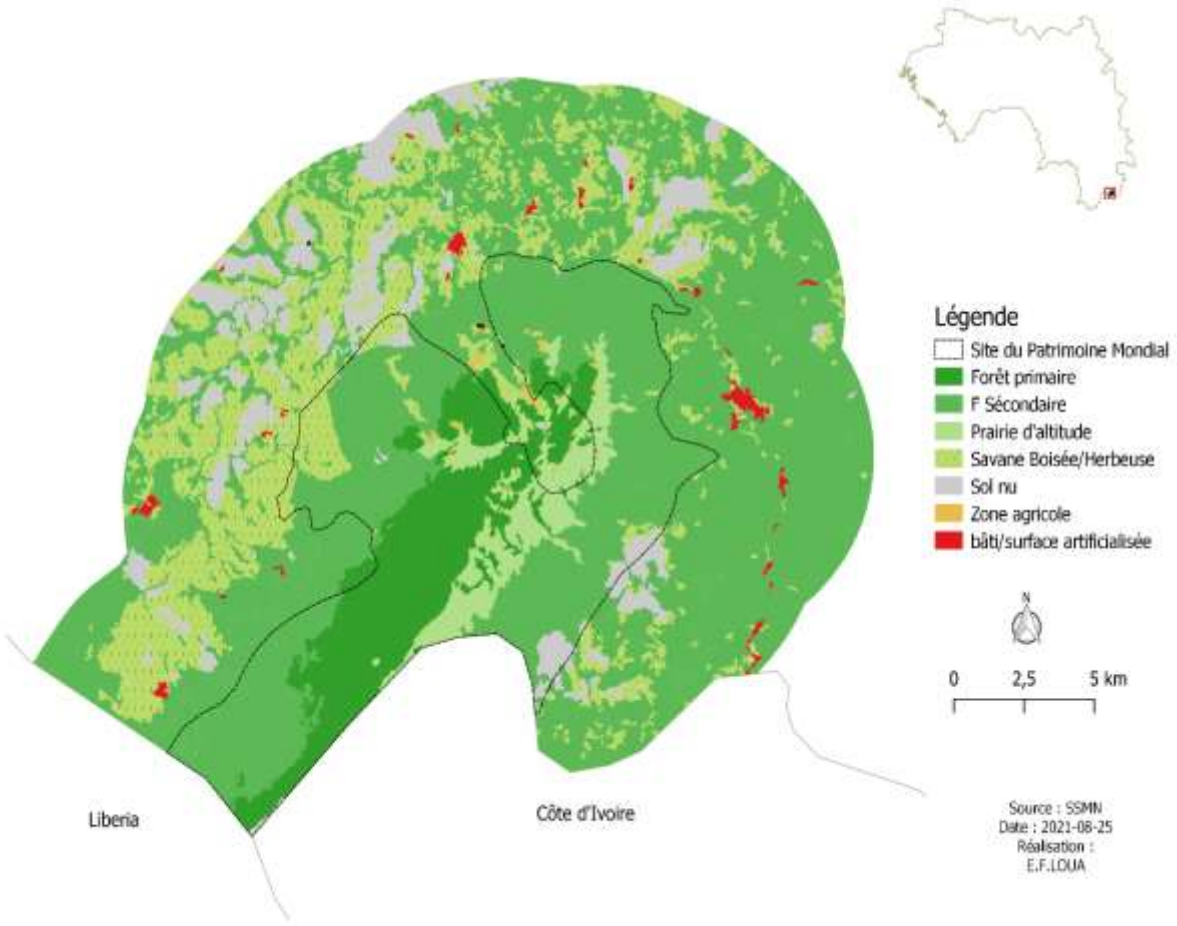

Figure 3: Land cover in 2020

The mapping of the Site through remote sensing shows a change in all land use classes. The observation shows a reduction of the primary forest giving way to the secondary forest and the different agricultural practices to which is added the built and the artificialized surface. The different areas obtained are shown in Table 3.

Table 3: Area of land cover classes in 2020

Land use class	**2020**	
	Area (ha)	**Percentage (%)**
Built	303.76	0,66%
Primary forest	4345.09	9,43%
Secondary forest	27032.5	58,72%
Mountain meadow	1575,43	3,42%
Woodland/Grassy Savannah	9340.11	20,28%
Bare soil	3344.73	7,26%
Agricultural zone	58.98	0,13%
Total	**46000,6**	**100%**

Table 3 shows the changes in area of land use classes. In descending order, we observe the secondary forest which occupies the largest area (58.72%), followed now by the wooded and grassy savannah (20.28%), the primary forest (9.43%), the bare ground (7.26%), the altitude meadow (3.43%), finally the built up (0.66%) and the agricultural area (0.13%).

The analysis of these percentages shows a clear increase in the area of secondary forest, buildings and agricultural area. This would be a consequence of the anarchic exploitation of these natural resources and the invasion of the buffer zone by the population. Human presence in the buffer zone is the cause of degradation of this area. Compared to the 1990 map, the 2020 map shows a sharp decrease in primary forest and a slight increase in secondary forest in the study area.

Evolution of plant formation over the period 1990-2020

The World Heritage site and its surrounding areas have undergone major changes in the size of land-use classes. The areas and percentages indicate a decline in the primary forest, or -15.19% of its area, or 6,980.96 ha. However, secondary forest (3.76%), wooded and grassy savannah (5.47%), bare soil (4.6%), agricultural area (0.09%), built-up (0.49%) and high-altitude grassland (0.79%) have seen an increase in their areas. This change in vegetation cover has had direct impacts on ecosystems that support endemic species such as wetlands (rivers and ponds) where micropotamogals live. On the ground, buildings are increasing in proportion to population growth. Savannah and fallow cover almost the entire buffer zone. The road network of the reserve allowed easy access to the reserve resource. The failure to take into account environmental impact studies of road and mining projects are the main cause of the exposure of the biodiversity of the heritage site to unsustainable exploitation.

Table 6 presents the result of the evolution of the different land use classes of the Heritage Site and its peripheral area between 1990 and 2020 while Fig. 11 compares the land use classes of the same years.

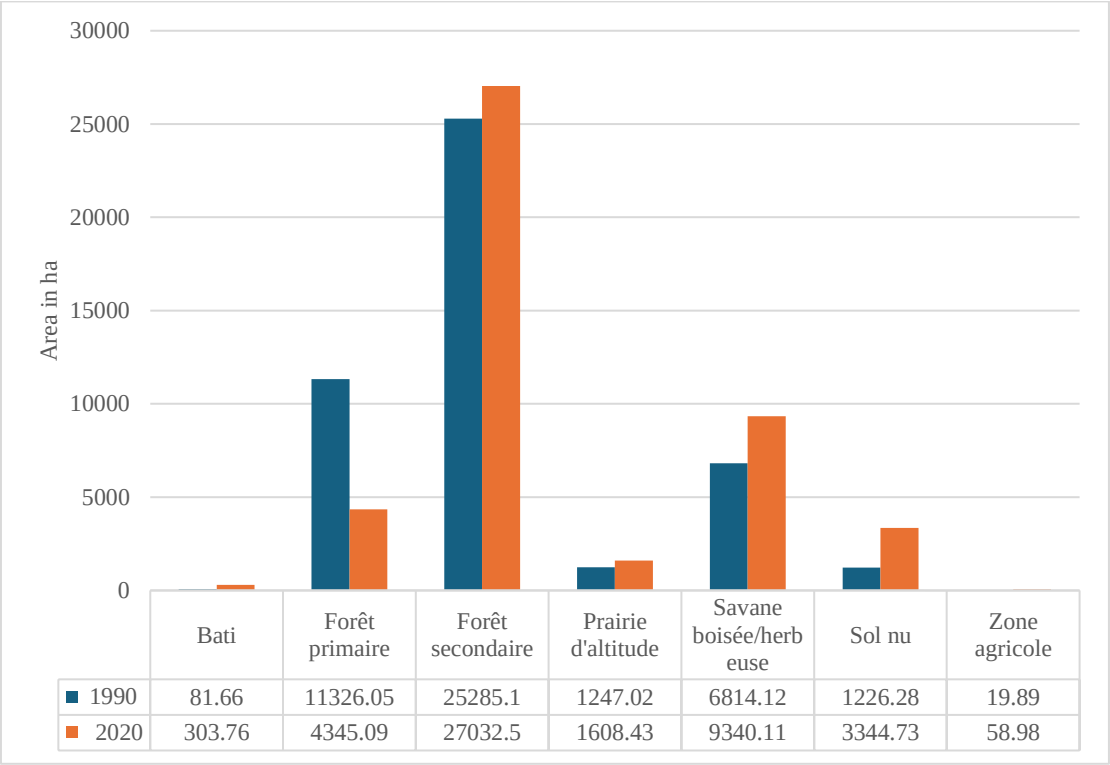

Figure 4: Comparison of land use classes in 1990 and 2020

Figure 4 shows the combined situation for the two years 1990 and 2020. On the abscissa of the graph the land use classes and the ordered area in ha. This comparison explains the different variations that occurred from 1990 to 2020.

There is a decrease in the primary forest and a slight increase in the secondary forest over time and the built environment accompanied by the area of bare ground whose factor remains the influx of the population in the buffer zone.

Table 4: Evolution of plant formation dynamics

Land cover classes	**1990**		**2020**		
	S (ha)	**P (%)**	**S (ha)**	**P (%)**	**Résultat (%)**
Built	81.66	0,17%	303.76	0,66%	0,49%
Primary forest	11326.05	24,65%	4345.09	9,43%	-15,19%
Secondary forest	25285.1	54,96%	27032.5	58,72%	3,76%
Mountain meadow	1247.02	2,71%	1575,43	3,43%	0,79%
Woodland/Grassy Savannah	6814.12	14,81%	9340.11	20,28%	5,47%
Bare soil	1226.28	2,66%	3344.73	7,26%	4,6%
Agricultural zone	19.89	0,04%	58.98	0,13%	0,09%
Total	**46000,12**	**100%**	**46000,6**	**100%**	**-**

S = area ; **P** = percentage

The results presented in Table 4, show a change in the areas around and in the site due to several factors, of which humans are believed to be at the origin. These anthropogenic activities are mainly represented by agriculture, bush fires, mining and road works. Figure 5 shows the observed losses on the vegetation cover of the study area.

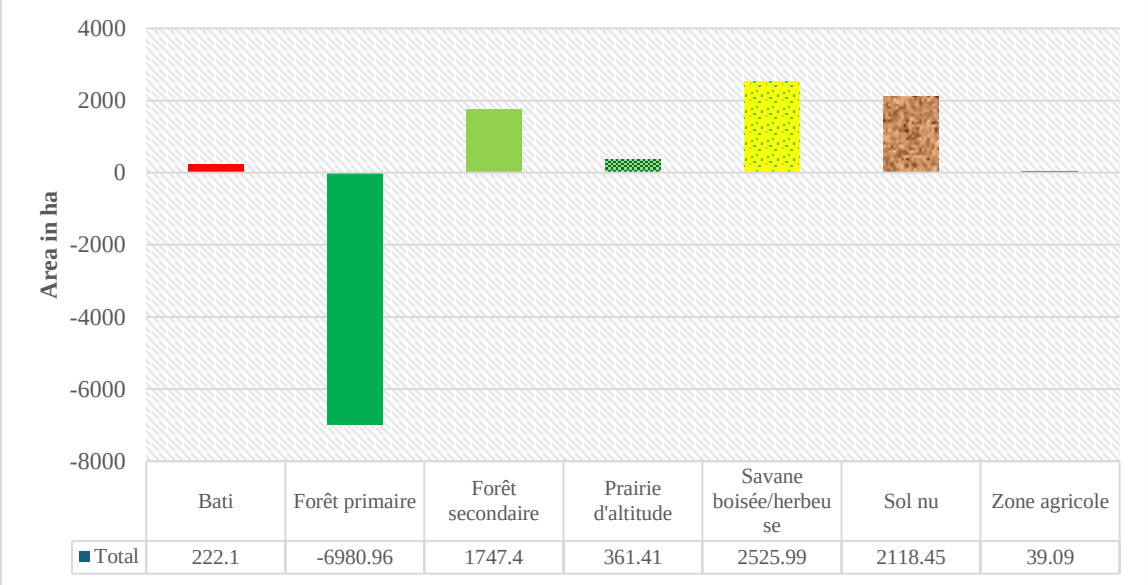

Figure 5: Land cover losses and gains between 1990 and 2020

In this figure, we see losses and gains in areas according to the different components. Primary forest lost (-6980.96 ha). In contrast to the savannah (2525.99 ha), the agricultural area (39.09 ha), the secondary forest (1747.4 ha), the human settlements (222.1 ha), the bare ground (2118.45 ha) and the grassland have increased in size. The analysis of this figure shows that the area lost by the primary forest, was shared between the other classes of occupation with a difference of 33.48 ha. The photograph of the spaces located between the human dwellings and the Site, shows human activities as a source of degradation of plant covers.

Evolution of Anthropogenic Activities around the Heritage Site of the Biosphere Reserve of the Nimba Mountains

Population growth in villages around the Nimba Mountains, increased pressure on the resources available in the buffer zone of the reserve, to which are added the recurrent land problems in the villages which are summed up by the lack of arable space. Currently, the untapped resource in the reserve is concentrated in the central area although poaching and exploitation of wood and non-timber products occur. The low-altitude overflight of the drone highlighted the recent state of field activities reported in the 2020 land use map.

Degradation of the South-east Side of the Site

Drone imagery has shown an alarming state of ecosystems in general. The traces of human activities are readable on the maps and are closer and closer to the Nimba chain. The primary forest that existed in the peripheral areas of the World Heritage Site is in the process of complete modification. Hence the increase in the area covered by fallow. The waterways in the shallows are in full swing and contribute to agricultural production activity. We notice traces of clearing on the edges of rivers and crops on the hillsides and fallow (fig. 6). These activities are the main sources of deforestation and degradation of aquatic wildlife habitats in the Micropotamogal Reserve in particular.

The field observation reveals several anthropogenic activities within the core area in addition to the villages located very close to the boundary of the area of the following facilities:

- 5 hunting camps;
- 3 newly burned fields;
- 31 plantations;
- 5 lowlands all sprayed with total herbicide;
- 12 rivers affected by rice farming.

Figure 6 shows traces of anthropogenic activities between agglomerations and the boundaries of the central area.

Figure 6: Traces of human activities in the vicinity of the Site (South-East Side) *Gbié/N'Zoo*

Figure 7: Traces of human activities in the vicinity of the Site (South-East Side) *Gbié/N'Zoo*

Figure 8: Traces of human activities in the vicinity of the Site (South-East Side) *Gbié/N’Zoo*

Figure 9 : Traces of human activities in the vicinity of the Site (South-East Side) *Gbié/N’Zoo*

Figure 10: Photo taken at N'Zoo Centre (South-East Side)

Degradation of the northwest side of the site

The degradation of vegetation cover on the north side of the reserve is more severe than in the south. The boundary between the core area and the buffer zone does not exist in some places. There are important river systems with hills with wooded peaks under the influence of agricultural pressure around. The analysis of the images obtained on this side shows traces of human activities. Waterways are also affected by degradation. Villages and shifting crops are spreading near the core area. According to our own observations, some ecoguard stations for the control of village activities are uninhabited and in a state of disrepair. The decrease in the level of monitoring of activities is due to the lack of monitoring equipment, funding, willingness of officials and the Government of Guinea to conserve the heritage of the Nimba Mountains in the long term. This indicates the irregularity of environmental monitoring activities and the consideration of the consequences of certain activities on the environment. The census of human facilities shows:

- 2 cattle camps for grazing;
- 12 burned fields ;
- 34 plantations in the vicinity of the central area ;
- 2 traces of encroachment for agricultural purposes.

15 rivers have been identified in this part. In this part, almost all of the shallows were sprayed with pesticides including herbicides. Figure 7 shows an aerial image of the hills being degraded with smoke that indicates human presence.

Figure 11 : Photo taken at Foromota/Ziéla (South-East Side)

Figure 12 : Photo taken at Foromota/Ziéla (South-East Side)

Figure 13: Champ agricole proche du site dans la zone de Ziguépo

Figure 14 : Photo of the Seringbara plain (northwest side)

Figure 15 : Cattle encountered in the plain of Séringbara (northwest side)

Figure 16 : Traces of human activities in the area of Nyon/Bossou

Figure 17 : Degradation of the hills in the area near the RBMN World Heritage Site

Discussion

The results obtained after the mapping analysis of the Heritage Site show a regression of the area of the primary forest from 11 326.05 ha to 4 345.05 ha in 40 years, a loss of -15.19%. The causes of this decrease in area are the unsustainable agricultural system practiced by the population bordering the reserve. These results are consistent with the one found by (Conde, 2019), who did the same studies in the Nimba Mountains on the Hills to the chimpanzees of Bossou and observed a regression of 18.06% of the primary forest in 2018.

The resulting increase in population densities in new regions leads to increased pressures on natural resources and environmental degradation. With human concentrations already in excess of 400 per km^2 (UICN & PNUE, 2015), this is one of the threats to biodiversity at the heritage site.The rivers of the Nimba Mountains are affected by human activities carried out in watersheds. The consequences of fires can be direct such as ammonia deposition from smoke or indirect due to abrupt loss of vegetation that can disrupt the nutrient cycle (Poilecot & Loua, 2009). These different modifications can lead to variation in the ephafo-climatic conditions of plants, invertebrates and probably aquatic fauna (Yumba et al., 2016). The photos taken by the drone in the different stations, show with precision the traces of human activities located on the edge of the Nimba chain. These results are consistent with observations made by (IUCN, 2020) It says that population pressure and the need for food produce repeated fires to promote activities such as hunting, grazing, opening fields and. The repetition of these fires slowly changes mountain ecosystems and opens the heritage site to uncontrolled activities. These remarks show the pressure that the animals could suffer. Environmental protection activities are not yet able to effectively mitigate human practices. This method of environmental monitoring through drone technology is evolving by the Institute of Environmental research of Bossou. Drone technology helps monitor land at the local level and contributes to improved management and decision-making strategies (Ngabinzeke et al., 2016)

Diachronic images on the territory of Gbere in DRC identified land use changes related to slash-and-burn farming practices between April and July 2015 (Semeki Ngabinzeke et al., 2018).

On the southern side of the range, the location of the city of N'Zoo in front of the mountain is a serious threat to the biodiversity of the Nimba Mountains. Access to the central area can be done in this case without difficulty with especially the lack of control. No other method of sustainable agricultural production is yet being considered by farmers with the aim of reducing their impacts on wetlands.

Conclusion

The increase in population and associated anthropogenic consequences, as well as the presence of mining and road companies in the Nimba Mountains Biosphere Reserve, has particularly The UNESCO heritage site is under threat. These factors are the real cause of the various changes observed in plant formation and in sensitive habitats such as hydrological regime (watercourses). Human activities such as shifting agriculture have significantly reduced the area of primary forest that existed in the buffer zone. This has reduced the duration of fallow. The central area is now the target of illegal activities (poachers, fishermen, village extension, etc.), which continuously isolate conservation areas by breaking ecological corridors. These different activities associated with the increased use of pesticides in cultivated lowlands, have a huge impact on the habitats of several endemic species including the Micropotamogale. The majority of the water courses in the buffer zone are affected by the use of plant protection products, thus also affecting pollinating insects. The results of this study offer an idea of environmental education for farmers and students in order to preserve the values of the Nimba Mountains Biosphere Reserve in Guinea.

Recommendation

At the end of this study, we recommend the introduction in the training plan of schools located in the Biosphere Reserve of the Nimba Mountains, environmental education courses for students. This will help them understand the importance and function of ecosystems in human life. They will also be able to educate their parents about certain unsustainable practices.

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