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Spatio-temporal analysis of vegetation dynamics in new protected areas: Exploring the partial nature reserve of Aghien (southern Côte d'Ivoire)

Ménéké Distel KOUGBO [1,*], Sounan Gatien TOURE [1, 2], Richard Kouassi KOUADIO [1], Aménan Sylvie KONAN [3], Brahima COULIBALY [1] and Djah François MALAN [3]

[1] *National Center for Agronomic Research, Forest and Environment Program, Côte d'Ivoire.*
[2] *Félix Houphouët Boigny University, Climate Change, Biodiversity and Sustainable Agriculture Laboratory, Côte d'Ivoire.*
[3] *Nangui Abrogoua University, Botany and Plant Diversity Development Laboratory, Côte d'Ivoire.*

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Abstract

The Aghien Partial Nature Reserve, located in the district of Abidjan, is a new protected area that requires special monitoring because it is subject to strong urbanization pressure. To analyse the spatio-temporal dynamics of land use at this site, field data was first collected, followed by processing of Landsat OLI/TIRS images of the reserve from 2020 and 2024. Parameters such as the average annual rate of spatial expansion (T), the conversion rate (Tc), the transition matrix and the conversion intensity were then calculated. Finally, a forecast was made for land-use dynamics up to 2032. A total of ten land-use units were identified within the administrative boundaries of the reserve. Among these units, old rubber plantations, fallow land and secondary forests are the most represented plant formations. Over the period from 2020 to 2024, vegetation dynamics are marked by the expansion of secondary forests (Tc = 9.48%; T = 2.26%), young palm plantation (Tc = 15.01%; T = 3.50%) and bare soil (Tc = 18.50%; T = 4.24%). However, the forecast to 2032 shows a significant expansion of fallow land (Tc = 11.66%; T = 0.92%) and secondary forest (Tc = 26.46%; T = 1.96%). This reflects the gradual restoration of floristic diversity in the reserve's landscape. However, given the persistence of certain human activities, the site needs to be monitored.

Keywords: Land use; Vegetation; Protected area; Aghien

1. Introduction

Faced with the ever-increasing fragmentation and degradation of natural habitats, the primary role of protected areas is to ensure the sustainability of biological diversity and ecological processes [1]. Through this biodiversity, protected areas help to increase resilience and reduce the vulnerability of human societies to climate change [2, 3]. In addition, this natural resource management system would provide ecologists and decision-makers with a pool of plant and animal material that would be highly useful in restoring degraded ecosystems and manufacturing pharmaceuticals [4, 5]. In view of these advantages, initiatives to set up networks of protected areas have seen the light of day and continue to multiply in almost every country in the world [1].

In Côte d'Ivoire, in order to limit the rapid erosion of biological diversity caused by the significant decline in its natural heritage, the national network of protected areas has been gradually expanded. According to the Ivorian Parks and Reserves Office (OIPR), from 2007 to the present day, the number of protected areas has risen from thirteen to eighteen, spread across the country's different phytogeographical zones. One of the most recent is the Réserve Naturelle Partielle d'Aghien (RNPA) created by decree n°2020-561 of July 8, 2020. Like all nature reserves, the Aghien site is an ecosystem

* Corresponding author: Ménéké Distel KOUGBO

with great potential for securing flora and fauna biodiversity and providing goods and services. However, due to its location in the Abidjan district (south of Côte d'Ivoire) and anthropic pressures within it, monitoring is essential to understand the dynamics of its vegetation and minimise the risks of degradation. In this respect, since its creation to date, the available data mainly concern land use in the watershed and the Abidjan district in which the site in question is located [6, 7]. Furthermore, these studies do not accurately provide the state of vegetation within the reserve's administrative boundaries. It is therefore likely that no precise data exist on the vegetation dynamics of the Aghien Partial Nature Reserve. However, such a study would enable effective ecosystem monitoring and sustainable management planning. The aim of our study is therefore to analyse the spatio-temporal dynamics of land use in the Aghien Partial Nature Reserve. Specifically, we will first determine the state of the reserve's land cover in 2020 and 2024, then assess changes over time, and finally make a forecast of the land cover in 2032.

2. Material and methods

2.1. Study site

The Aghien Partial Nature Reserve (RNPA) is located in the southern part of Côte d'Ivoire, between latitudes 5°20″00 and 5°30″00 North and longitudes 3°56″53 and 3°48″00 West (Figure 1). It borders the villages of Bébakoi, Debarcadère, Ahoué Andokoi, Akandjé, Akoyaté, Aghien, Aghien Télégraphe and the La Mé station of the National Centrer of Research Agronomic. Its hydro-graphic network is formed by the Aghien lagoon, itself fed by the Djibi river to the north and the Mé river to the south. The local climate is of the transitional equatorial type, characterised by a long rainy season and a long dry season alternating with a short rainy season and a short dry season [8]. Phytogeographically, the reserve belongs to the Guillaumet and Adjanohoun [9] Guinean domain, more precisely to the ombrophilous sector dominated by forested areas subject to agriculture. Current vegetation is characterised by industrial crops (palm, rubber), fallow land and secondary forests.

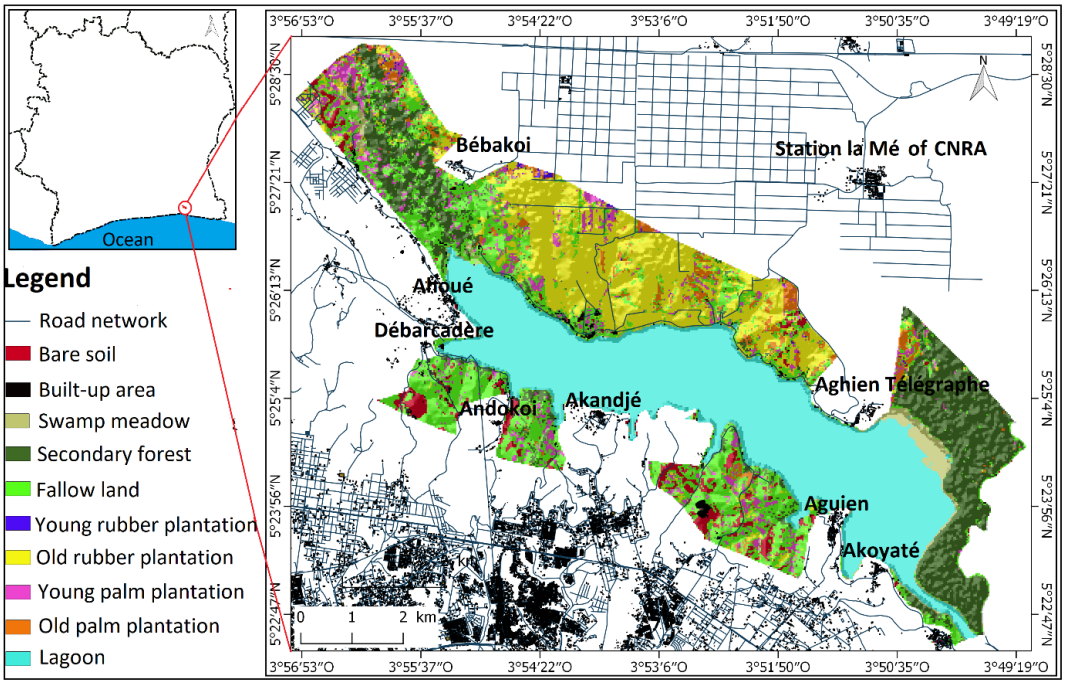

Figure 1 Map showing the geographical location of the Aghien Partial Nature Reserve

2.2. Methodology

2.2.1. Satellite image acquisition and pre-processing

In order to determine the changes that have taken place in the Reserve's land use from its creation to the present day, two satellite images with a spatial resolution of 30 meters were first acquired from the https://earthexplorer.usgs.gov/ site. These were the Landsat OLI/TIRS images of April 5, 2020 (scene P195/R056) and March 15, 2024 (scene P195/R056). The images were then enhanced and geometrically corrected using ENVI 5.1 software. Finally, the study area was extracted from these images, following the administrative boundaries of the Reserve.

2.2.2. Processing land use data from 2020 to 2024

In order to achieve a good discrimination of the Reserve's vegetation types, a ″false color composition″ 5/4/3 was applied to the study area from the 2020 and 2024 images. Then, on the basis of field data collected during a vegetation inventory mission carried out in 2022, a supervised classification of the reserve's land cover was carried out using the maximum likelihood algorithm. After validating the classification using the confusion matrix, overall accuracy and Kappa coefficient [10], the Reserve site was extracted from the study area and imported into QGIS software version 2.18.15 in raster format. This made it possible to determine the evolution parameters, shapes and intensity of conversion undergone by the different land-use classes in the reserve from 2020 to 2024.

Analysis of land use parameters

The analysis of evolution parameters focused on the average annual rate of spatial expansion (Equation 1) and the rate of conversion (Equation 2) of land use units. These parameters were calculated using the ″MOLUSCE″ extension of QGIS software version 2.18.15. The annual conversion rate corresponds to the degree of transformation of a given land-use class into other classes, while the spatial expansion rate reflects the degree of growth in the area of a given land-use class.

$$\boldsymbol{T} = \frac{\boldsymbol{lnS_2 - lnS_1}}{(\boldsymbol{t_2 - t_1}) \times \boldsymbol{ln2{,}71828}} \times \mathbf{100} \qquad (1)$$

$$\boldsymbol{Tc} = \frac{\boldsymbol{S_{it1} - S_{is}}}{\boldsymbol{S_{it1}}} \times \mathbf{100} \qquad (2)$$

In these equations, **T** : annual spatial expansion rate (%) ; **S1** and **S2** : area of a landscape unit at date t1 and t2 ; **Tc** : conversion rate (%) ; **Sit1** : area of land-use unit i at initial date t1 ; **Sis** : area of the same unit remaining stable at date t1.

Detection of land-use class shapes and conversion intensities

The forms of conversion of the Reserve's land-use units were determined through analysis of the transition matrix generated by the ″MOLUSCE″. Extension. For a given land-use unit, this matrix provides information on the nature of changes, area losses and gains, and stable areas from 2020 to 2024. The diagonal of this matrix represents stable areas. The gross gain for each category is obtained by subtracting the persistence from the column total, while the gross loss is obtained by subtracting the persistence from the row total. The observed intensities of change were obtained by running the analysis programs ″Pontius Matrix 41″ and ″Intensity Analysis 03. xlms″ from Aldwaik and Pontius [11] on the transition matrix.

2.2.3. Prospective land use modeling to 2032

To predict the land use of the nature reserve by 2032, environmental data (access road, density of built- up areas, topography and slopes) were first acquired for the site. Then, using these data and the 2020 and 2024 land-use maps, transition probabilities were calculated using the Artificial Neural Network (ANN) method after 100 iterations in Randon mode. After validation of the ANN method (Kappa> 0.5), simulation of the 2032 land-use map was performed on the spatial allocation of transition probabilities using the Cellular Automata (CA) method of the MOLUSCE″″ extension. This made it possible to determine the shapes and intensity of land-use class conversions that will take place from 2020 to 2032.

3. Results

3.1. Reserve land use in 2020 and 2024

Analysis of the landscape condition of the nature reserve in 2020 and 2024 reveals ten land-use classes with a Kappa coefficient close to 1 and an overall accuracy of over 90% (Figure 2). These are secondary forest, swamp grassland (periodically flooded grassland formation), fallow land, young rubber plantations (0 to 7 years), old rubber plantations (25 years and over), young palm groves (0 to 5 years), old palm groves (25 years and over), bare soil, built-up areas and the Aghien lagoon. However, in terms of area, the classes most represented in the reserve's land use in 2020 and 2024 are lagoon (34.02% -33.95%), fallow land (20.30% - 19.65%), old rubber plantations (17.05% - 16.98%) and secondary forest (14.76% - 16.16%).

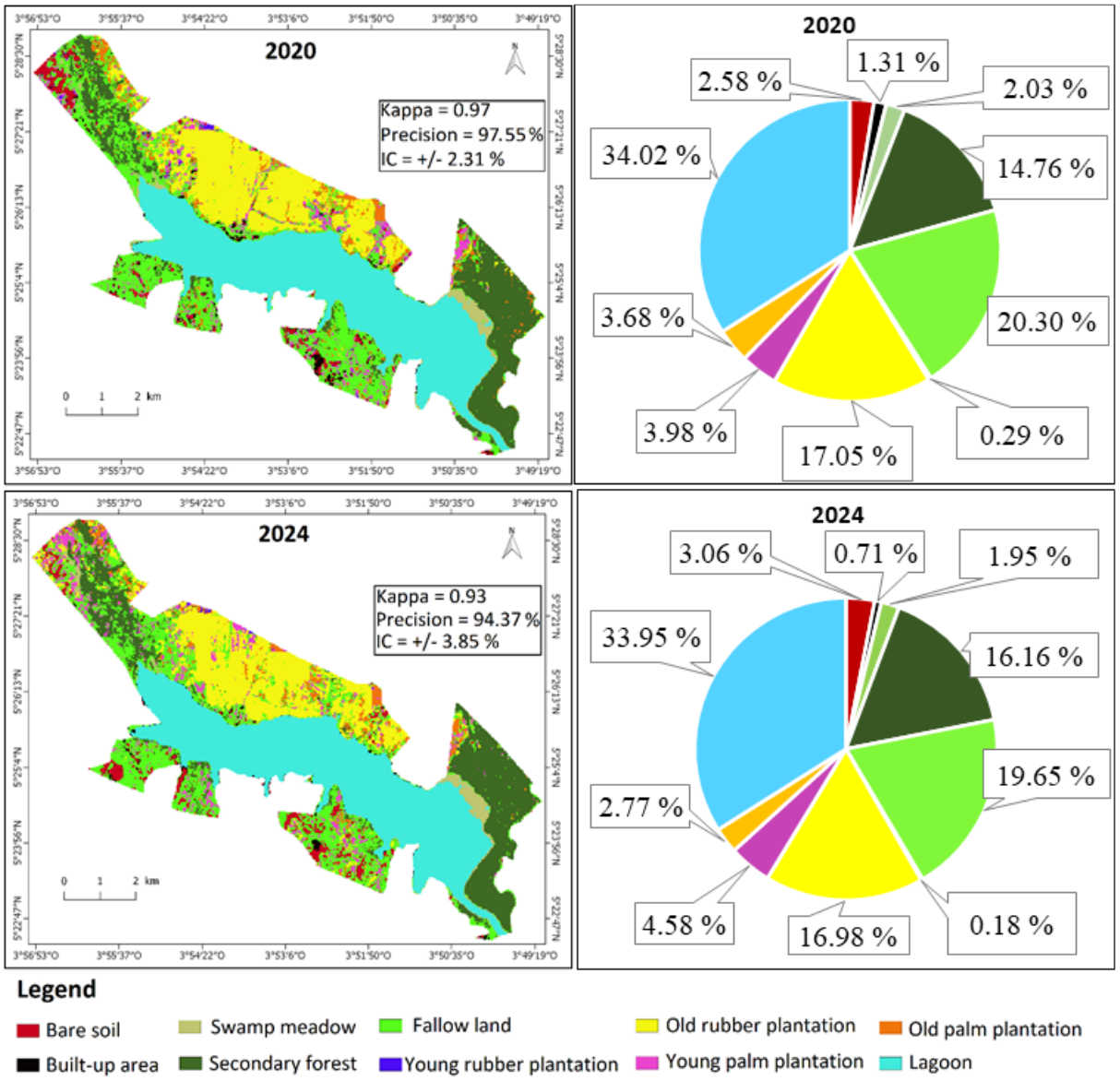

Figure 2 Land-use structure of the Aghien Partial Nature Reserve in 2020 and 2024

3.2. Spatio-temporal expansion of land-use classes from 2020 to 2024

3.2.1. Annual rate of expansion and conversion of land use classes between 2020 and 2024

From 2020 to 2024, the landscape of the nature reserve was marked by both expansions and regressions in area at the level of land-use classes (Table 1). Secondary forests, bare soil and young palm groves are gaining in area, with annual expansion rates of 2.26%, 4.24% and 3.50% respectively. In contrast to the dynamics of these land-use units, a regression in the area of the other seven classes is observed. Of these, the classes most affected are built-up areas (Tc= -45.48%), young rubber plantations (Tc= -38.80%) and old palm plantation (Tc= -24.75%).

Table 1 Annual rate of spatial expansion (T) and conversion (Tc) of land-use units in the Aghien Partial Nature Reserve between 2020 and 2024.

Land use classes	**Area (ha)**		**Tc (%)**	**T (%)**
	2020	2024		
Secondary forest	830.61	909.36	9.48	2.26
Swamp meadow	114.03	109.8	-3.71	-0.95
Fallow land	1142.64	1106.1	-3.20	-0.81
Young rubber plantation	16.47	10.08	-38.80	-12.27
Old rubber plantation	959.4	955.8	-0.38	-0.09
Young palm plantation	224.19	257.85	15.01	3.50
Old palm plantation	207.27	155.97	-24.75	-7.11
Bare ground	145.44	172.35	18.50	4.24
Built-up area	73.62	40.14	-45.48	-15.16
Lagoon	1914.48	1910.7	-0.20	-0.05
Total area	5628.15	5628.15		

3.2.2. Qualitative and quantitative transition of land use classes between 2020 and 2024

Over the period from 2020 to 2024, with the exception of secondary forests, swamp grasslands, fallow land and old rubber plantations, the other six classes lost more than half their initial area (Table 2). Young palm plantation, old palm plantation, built-up areas and bare ground lost 43.47%, 29.08%, 51.91% and 43.02% of their initial area to fallow land respectively. Over the same period, 10.79% and 16.03% of the initial area of fallow land and old palm plantation were converted to secondary forest. These losses were offset by gains in all land-use classes (Figure 3A). However, the intensity of Gains and Losses in the area of secondary forests and old rubber plantations is below the threshold (25%), while the intensity of changes in the other eight classes is above (Figure 3B).

Table 2 Transition matrix for land-use units in the Aghien Partial Nature Reserve between 2020 and 2024. Sfo: Secondary forest, Sme: Swamp meadow Fla: Fallow land, Yru: Young rubber plantation, Oru: Old rubber plantation, Ypa: Young palm plantation, Opa: Old palm plantation, Bso: Bare soil, Bar: Built-up area, Lag: Lagoon

	Sfo	**Sme**	**Fla**	**Yru**	**Oru**	**Ypa**	**Opa**	**Bso**	**Bar**	**Lag**	**Area in 2020 (%)**
Sfo	12.99	0.05	1.38	0.00	0.06	0.11	0.10	0.05	0.01	0.00	14.76
Sme	0.02	1.36	0.34	0.00	0.03	0.01	0.00	0.01	0.07	0.20	2.03
Fla	2.19	0.33	10.88	0.03	1.91	2.30	0.78	1.57	0.21	0.09	20.30
Yru	0.00	0.00	0.09	0.04	0.04	0.05	0.03	0.03	0.00	0.00	0.29
Oru	0.27	0.00	2.34	0.02	13.08	0.68	0.63	0.02	0.00	0.00	17.05
Ypa	0.06	0.01	1.73	0.03	0.82	0.73	0.23	0.34	0.02	0.00	3.98
Opa	0.59	0.00	1.07	0.04	0.75	0.22	0.96	0.05	0.00	0.00	3.68
Bso	0.02	0.00	1.11	0.01	0.26	0.38	0.02	0.70	0.07	0.00	2.58
Bar	0.01	0.00	0.68	0.00	0.04	0.10	0.00	0.21	0.25	0.01	1.31
Lag	0.00	0.19	0.02	0.00	0.00	0.00	0.00	0.08	0.09	33.65	34.02
Area in 2024 (%)	16.16	1.95	19.65	0.18	16.98	4.58	2.77	3.06	0.71	33.95	100.00

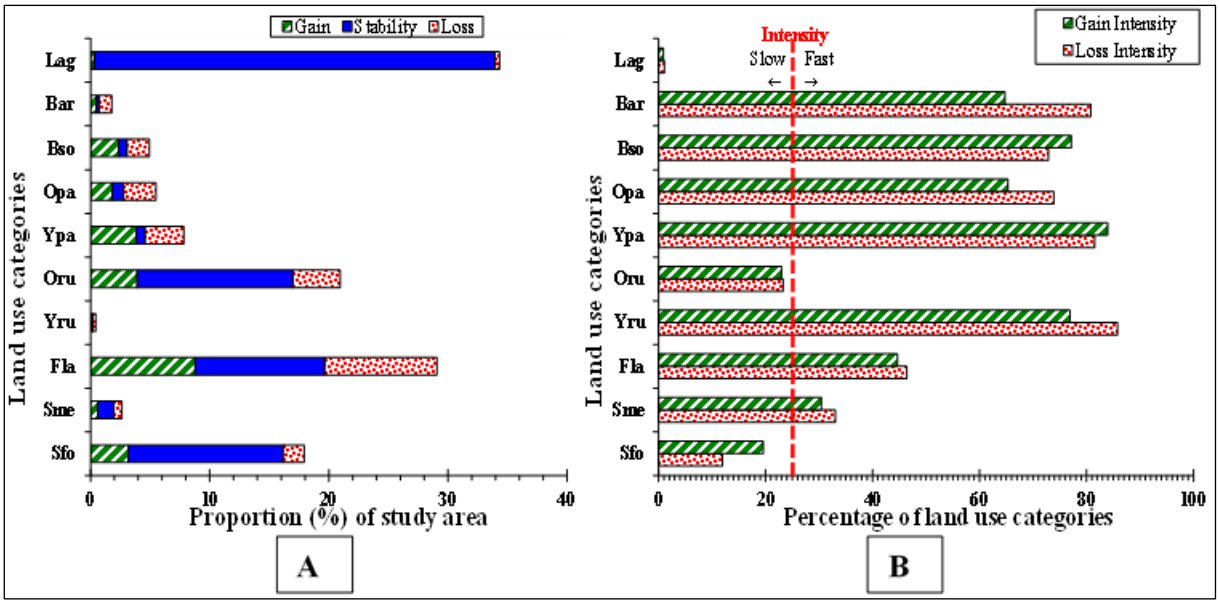

Figure 3 Rate of change of land-use units in the Aghien Partial Nature Reserve between 2020 and 2032. Sfo: Secondary forest, Sme: Swamp meadow Fla: Fallow land, Yru: Young rubber plantation, Oru: Old rubber plantation, Ypa: Young palm plantation, Opa: Old palm plantation, Bso: Bare soil, Bar: Built-up area, Lag: Lagoon

3.3. Prediction of land use dynamics in 2032 under the influence of urbanization

3.3.1. Spatio-temporal expansion of land-use classes between 2020 and 2032

Land cover forecasts for 2032 still reveal the presence of ten classes (secondary forest, swamp grassland, fallow land, young and old rubber plantations, young and old palm plantations, bare soil, built-up areas and Aghien lagoon) with a Kappa coefficient close to 1 and an overall accuracy of over 90% (Figure 4). However, in this year, fallow land (22.67%), old rubber plantations (20.24%) and secondary forests (18.66%) will be the most represented in the vegetation of the nature reserve.

A review of the conversion rate of land use units (Table 3) shows that, compared with the 2020 areas, the vegetation of the nature reserve will be marked by an expansion of secondary forests (Tc= 26.46%), fallow land (Tc= 11.66%) and old rubber plantations (Tc= 18.72%). On the other hand, there was a significant decline in young palm plantations (Tc= -83.98%), old palm plantations (Tc= -82.33%), built- up areas (Tc= -75.67%), young rubber plantations (Tc= -68.31%) and bare soil (Tc= -65.10%).

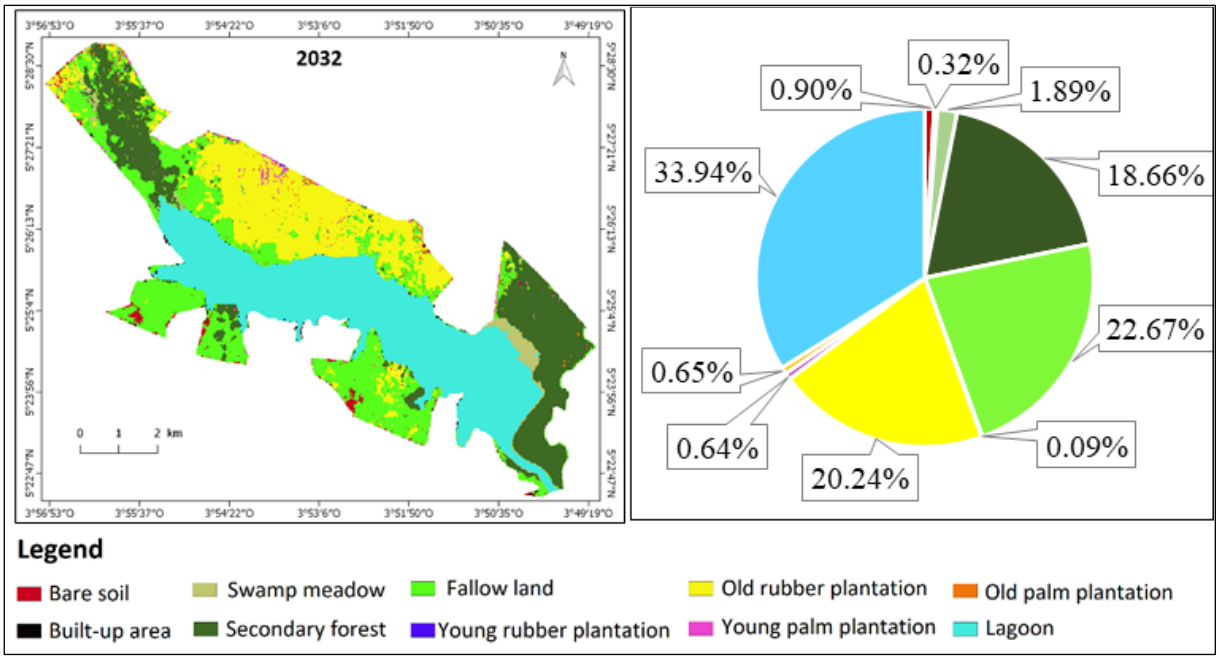

Figure 4 Probable structure of land use in 2032

Table 3 Probable annual rate of spatial expansion (T) and conversion (Tc) of land-use units in the Aghien Partial Nature Reserve between 2020 and 2032.

Land use classes	Area (ha)		Tc (%)	T (%)
	2020	2032		
Secondary forest	830.61	1050.39	26.46	1.96
Swamp meadow	114.03	106.47	-6.63	-0.57
Fallow land	1142.64	1275.84	11.66	0.92
Young rubber plantation	16.47	5.22	-68.31	-9.58
Old rubber plantation	959.4	1139.04	18.72	1.43
Young palm plantation	224.19	35.91	-83.98	-15.26
Old palm plantation	207.27	36.63	-82.33	-14.44
Bare ground	145.44	50.76	-65.10	-8.77
Built-up area	73.62	17.91	-75.67	-11.78
Lagoon	1914.48	1909.98	-0.24	-0.02
Total area	5628.15	5628.15		

3.3.2. Qualitative and quantitative transition of land use classes between 2020 and 2032

Between 2020 and 2032, with the exception of secondary forests, swamp grasslands, fallow land and old rubber plantations, the other six classes will have lost more than half their initial area (Table 5). Young rubber plantations, young palm plantation, old palm plantation, built-up areas and bare soil lost 55.29%, 56.03%, 41.03%, 75.57% and 60.85% of their initial area to fallow land respectively. These losses for all land use classes will be offset by gains (Figure 3A). However, in terms of intensity, losses in the area of secondary forests and old rubber plantations are below the threshold (25%), while their gains are above (Figure 3B). This is in contrast to the other eight classes, where both Losses and Gains are above the intensity threshold.

Table 5 Probable transition matrix for land-use units in the Aghien Partial Nature Reserve between2020 and 2032. Sfo: Secondary forest, Sme: Swamp meadow Fla: Fallow land, Yru: Young rubber plantation, Oru: Old rubber plantation, Ypa: Young palm plantation, Opa: Old palm plantation, Bso: Bare soil, Bar: Built-up area, Lag: Lagoon

	Sfo	**Sme**	**Fla**	**Yru**	**Oru**	**Ypa**	**Opa**	**Bso**	**Bar**	**Lag**	**Area in 2020 (%)**
Sfo	13.38	0.05	1.19	0.00	0.06	0.01	0.05	0.01	0.00	0.00	14.76
Sme	0.10	1.33	0.30	0.00	0.04	0.00	0.00	0.01	0.06	0.20	2.03
Fla	3.69	0.31	12.46	0.02	2.87	0.20	0.18	0.38	0.10	0.09	20.30
Yru	0.00	0.00	0.16	0.02	0.08	0.01	0.01	0.01	0.00	0.00	0.29
Oru	0.43	0.00	2.04	0.01	14.20	0.26	0.10	0.01	0.00	0.00	17.05
Ypa	0.19	0.01	2.23	0.02	1.30	0.08	0.05	0.09	0.01	0.00	3.98
Opa	0.79	0.00	1.51	0.01	1.08	0.04	0.24	0.01	0.00	0.00	3.68
Bso	0.06	0.00	1.67	0.01	0.52	0.04	0.01	0.23	0.04	0.00	2.58
Bar	0.03	0.00	0.99	0.00	0.09	0.01	0.00	0.12	0.06	0.01	1.31
Lag	0.00	0.18	0.10	0.00	0.00	0.00	0.00	0.04	0.05	33.64	34.02
Area in 2032 (%)	18.87	1.91	22.47	0.09	20.33	0.64	0.66	0.80	0.27	33.94	100.00

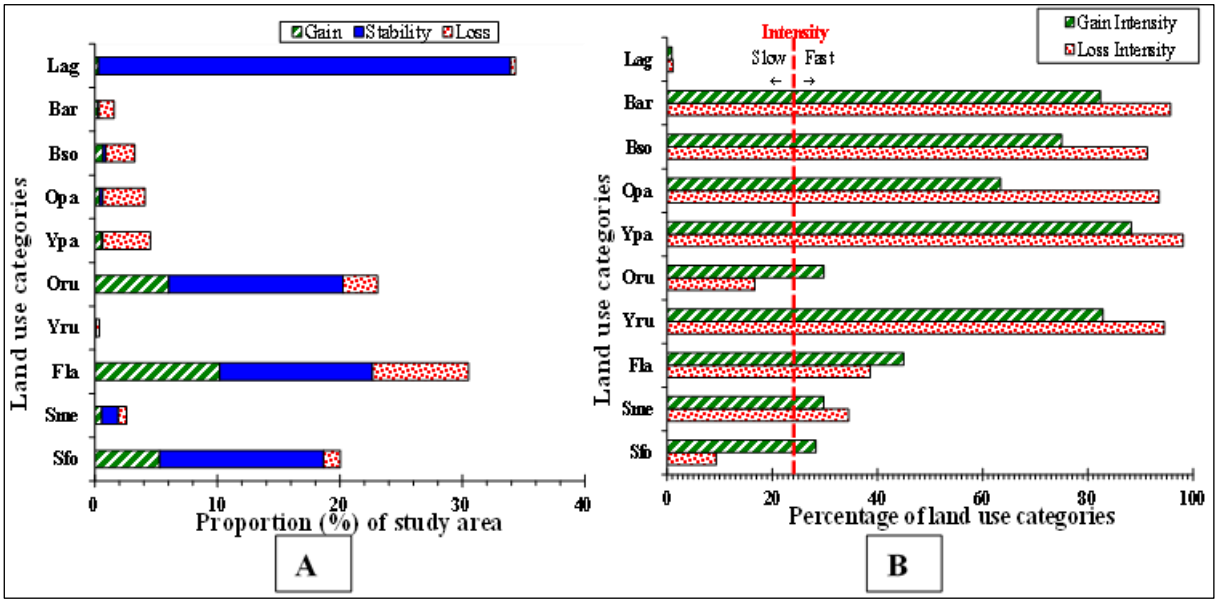

Figure 5 Rate of change of land-use units in the Aghien Partial Nature Reserve between 2020 and 2032. Sfo: Secondary forest, Sme: Swamp meadow Fla: Fallow land, Yru: Young rubber plantation, Oru: Old rubber plantation, Ypa: Young palm plantation, Opa: Old palm plantation, Bso: Bare soil, Bar: Built-up area, Lag: Lagoon

3.3.3. Intensity of forest vegetation recovery

Over the period from 2020 to 2032, the reconstitution of the nature reserve's forest flora will be intense on five land-use units (Figure 6). Fallow gains will be most intense on built-up areas, bare soil, old palm plantation, young palm plantation and young rubber plantations (Figure 6A). Over the same period, secondary forest expansion will be more intense on fallow land and old palm plantation (Figures 6B).

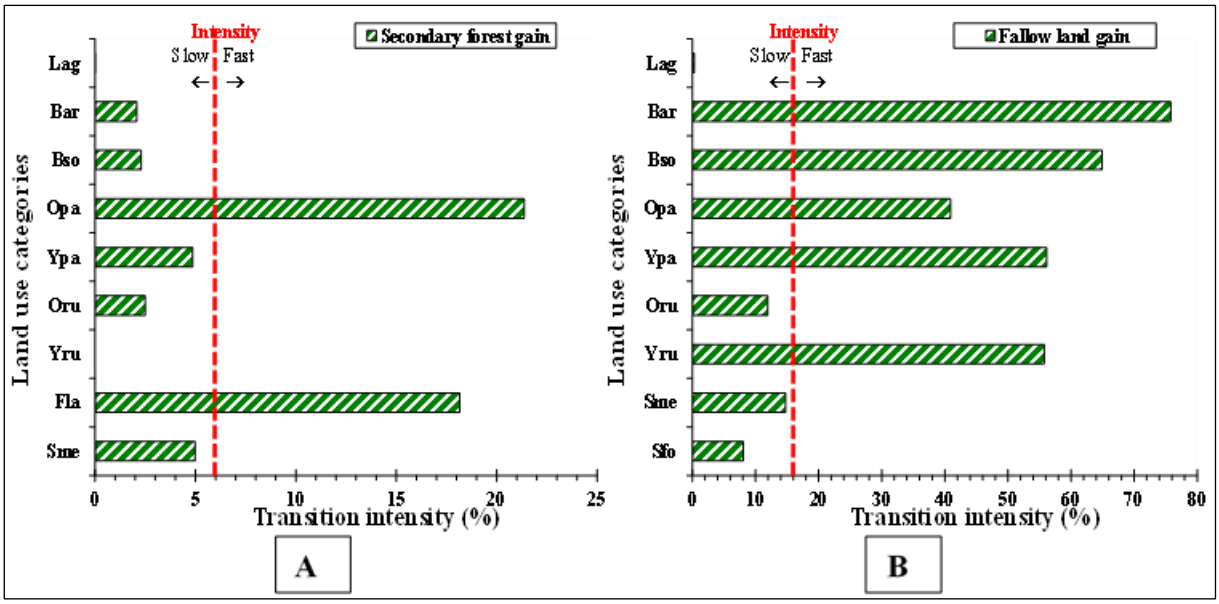

Figure 6 Probable intensity of conversion of land-use units to (A) fallow and (B) secondary forest within the boundaries of the Aghien Partial Nature Reserve from 2020 to 2032. Sfo: Secondary forest, Sme: Swamp meadow Fla: Fallow land, Yru: Young rubber plantation, Oru: Old rubber plantation, Ypa: Young palm plantation, Opa: Old palm plantation, Bso: Bare soil, Bar: Built-up area, Lag: Lagoon

4. Discussion

Establishing an ecosystem as a protected area makes it possible to secure the genetic heritage for the development of present and future generations. However, the state of conservation of the area's biological diversity needs to be closely monitored when it is located in an environment that is constantly deteriorating. Such is the case of the Partial Nature Reserve of Aghien, a new protected area whose administrative boundaries rub shoulders with built-up and cultivated areas.

Remote sensing investigations reveal that from 2020 to 2024, the landscape composition of the nature reserve remains the same, with ten land-use classes. These are secondary forest, swamp grassland, fallow land, young and old rubber plantations, young and old palm plantation, bare soil, built-up areas and the Aghien lagoon. In contrast to the work of Diallo et al. [6], this classification accurately provides the different land-use units of the Aghien Partial Nature Reserve. Indeed, for a given land-use class, these authors generally associate two to three types of plant formations, which makes it difficult to monitor and interpret vegetation dynamics. However, according to their classification, the reserve's 2015 landscape would be dominated by palm plantation, rubber plantations, degraded forests, food crops and fallows. Five years later, in 2020, analyses showed that the landscape is marked by the remarkable presence of cash crops (rubber and palm), fallow land and secondary forests. A recent detailed study by Njeugeut et al. [7] also highlighted the remarkable presence of these crops in the 2020 landscape of the Abidjan district. This is due to the fact that palm plantation and rubber plantations have been the main source of income for farmers in the area since the 1970s [9]. This followed the establishment of industrial plantations by the Research Institute for Oils and Oleaginous Plants (IRHO) in 1963 and the creation of industrial rubber plantations by the Elaeis and Yacé companies. However, the land use observed shows a high level of degradation of the forest flora at the time the site was set aside.

On the other hand, over the period from 2020 to 2024, the dynamics in time and space were regressive for some land-use units and progressive for others. A striking example is the expansion of fallow land over large areas of anthropised zones such as young palm plantation, old palm plantation, built-up areas and bare soil. This would be the result of actions to protect the site and activate the natural regeneration process of the flora. Indeed, in the absence of anthropic action on degraded sites, it is accepted that the process of reconstitution of the flora is partly the result of the floristic potential that is expressed [12]. These include offshoots and seedlings (i.e., vegetative potential), soil seed bank (i.e., edaphic seminal potential) and, finally, contributions made after the opening of the forest canopy (i.e., advective or exogenous seminal potential). It was the amplification of this process that led to the conversion of around 10.79% of the initial fallow area into secondary forest. In contrast to this vegetation dynamic, which reflects the gradual healing of the reserve's degraded areas, fallow land is deteriorating in certain parts of the reserve. In fact, in the same period from

2020 to 2024, more than half of the increase in bare soil and young palm plantation occurred on fallow land. This situation can be explained by the fact that some local residents, unaware of the site's boundaries or dissatisfied with the cessation of their activities following the site's closure, continue to clear new plots. Land pressure due to the population explosion in the Aghien lagoon watershed could also explain this situation [6]. However, an extension of these activities could have negative impacts on the future of the nature reserve's vegetation.

Based on the data analysed, the future of the reserve, in terms of land use in 2032, reveals a reconstitution of the forest landscape characterised by the significant expansion of fallow land and secondary forests. Fallow land will extend over anthropised areas (built-up areas, bare soil and crops) and secondary forests over fallow land. This is a process of natural regeneration, during which ruderal species establish themselves first, followed by hemicryptophyte species and finally, the phanerophyte species that dominate forests [13]. However, apart from the action of floristic potential, this dynamic would be the result of a combination of several factors such as the presence of seed trees, seed dissemination vectors and environmental conditions favorable to the development of plant species. Indeed, according to the work of Odoukpé et al. [14], the enclosure of the site facilitates intense activity by certain wildlife species such as the Gendarme weaver *Ploceus cucullatus* (Müller, 1776) and the Palm swift *Cypsiurus parvus* (Lichtenstein, 1823). As they perform their vital functions, these species will actively contribute to the dissemination of forest plant seeds throughout the site. Thus, following MacArthur's [15] theory of the broken stick, the disseminated seeds will develop according to the availability of the resource, structuring the landscape over time. In addition, this reconstitution of the plant cover in this area with its rugged topography will help preserve the water quality of the Aghien lagoon, a potential drinking water reservoir for the city of Abidjan. Indeed, the recovery of vegetation cover on hillsides reduces the risk of soil erosion, which once produced would lead to flows of sludge, nutrients, pesticides and other harmful chemicals towards surface watercourses [16, 17]. Alongside this reconstitution of forest flora, forecasts to 2032 reveal a loss of 6.63% of the original area of marshy grassland to the lagoon. Nevertheless, over the period 2020 to 2032, small areas of fallow land and the lagoon will be colonised by this type of plant formation. In addition, the decline in the area of marsh meadows can be explained by the environment's vulnerability to flooding in the study area. Indeed, studies carried out by Eba et al. [18] in the commune of Bingerville and by Youn et al. [19] in the district of Abidjan have shown that the forward movement of the lagoon during rainy episodes significantly affects the areas located along its banks.

5. Conclusion

Knowledge of the land-use dynamics of the Aghien Partial Nature Reserve was at the heart of this work. Processing of satellite images coupled with field data revealed that the reserve's land is occupied by secondary forests, swampy grasslands, fallow land, young and old rubber plantations, young and old palm plantation, bare soil, built-up areas and the Aghien lagoon. In addition, since the site was protected, the vegetation has been gradually recovering. Fallow land is developing on bare soil and agricultural areas, while an intense recruitment process is underway in the secondary forests. Furthermore, forecasts to 2032 reveal a significant expansion of fallow land and secondary forests within the administrative boundaries of the RNPA reserve. However, given the presence of certain clearing marks observed over the period 2020 - 2024, strategies to secure the site need to be reinforced and the health of the vegetation needs to be assessed. This study can serve as a basis for monitoring the ecological processes of natural regeneration within the various land-use units of the reserve.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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