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Development of the Cocoa Economy and Landscape Configuration in Western Côte d'Ivoire

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Abstract

This study hypothesizes that population movements in search of agricultural land in western Côte d'Ivoire have intensified land pressure, leading to significant landscape modification in this region. The objective of this study is to determine the spatial transformations occurring in the landscape of western Côte d'Ivoire following the development of cocoa cultivation, using the Biankouma Department as a case study. To achieve this, remote sensing techniques and principles of landscape ecology were applied to identify the spatial transformation processes observed in western Côte d'Ivoire. During the study period, the land cover units in the Biankouma Department experienced varying degrees of change. Indeed, the landscape of the study area, once dominated by forest and savanna patches, is now mainly characterized by cocoa plantations and savanna patches. The regression of forest and savanna areas during the study period is illustrated by the disappearance of their patches from the landscape. Conversely, the spatial transformation processes observed for the classes of cocoa plantations, degraded forest, cropland and fallow, and bare soil and settlement, are characterized by creation. In an effort to assist authorities in decision-making regarding land-use planning and natural resource conservation in this area, the study aims to model this landscape.

Keywords: Matrix; Spatial transformation processes; Land cover map; Cocoa plantation; West Africa

1. Introduction

The socio-economic needs of human populations are currently being met through the transformation of most of the Earth's landscapes by human activities [1]. Among the landscapes affected by human influence, forest landscapes are by far the most impacted, as they provide numerous environmental services and host a biodiversity that represents two-thirds of all terrestrial species [2]. Of all the pressures exerted by humans on forests, deforestation in tropical regions has reached alarming levels [3]. In Africa, particularly in tropical areas, annual deforestation was estimated at 2.8 million hectares for the period 2010–2015 [4].

As the world's leading cocoa producer since 1977, Côte d'Ivoire has faced a drastic reduction in its forest cover [5]. Indeed, cocoa cultivation in the country is responsible for about 30% of total deforestation [6]. This dependence on forests has led to the successive shifts of cocoa production centers from the eastern region of Côte d'Ivoire to the forest zones of the Central-West and then the South-West, passing through the pre-forest areas of the Central-East [7-8].

In the early 2000s, as cocoa orchards aged and production stagnated or declined in the South-West—known as the country's last cocoa belt [9]—farmers and agricultural laborers began migrating toward the western forested areas [5].

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This study hypothesizes that the movement of populations in search of agricultural land in western Côte d'Ivoire has increased land pressure, resulting in significant modifications of the region's landscape. The objective of this study is to determine the spatial transformations occurring in the landscape of western Côte d'Ivoire, using the Biankouma Department as a case study.

2. Methodology

2.1. Study Area

The present study was conducted in the western part of Côte d'Ivoire, within the Tonkpi Region, specifically in the Biankouma Department (Figure 1). The study area comprises ten protected areas, the most important of which is the Mont Sangbé National Park.

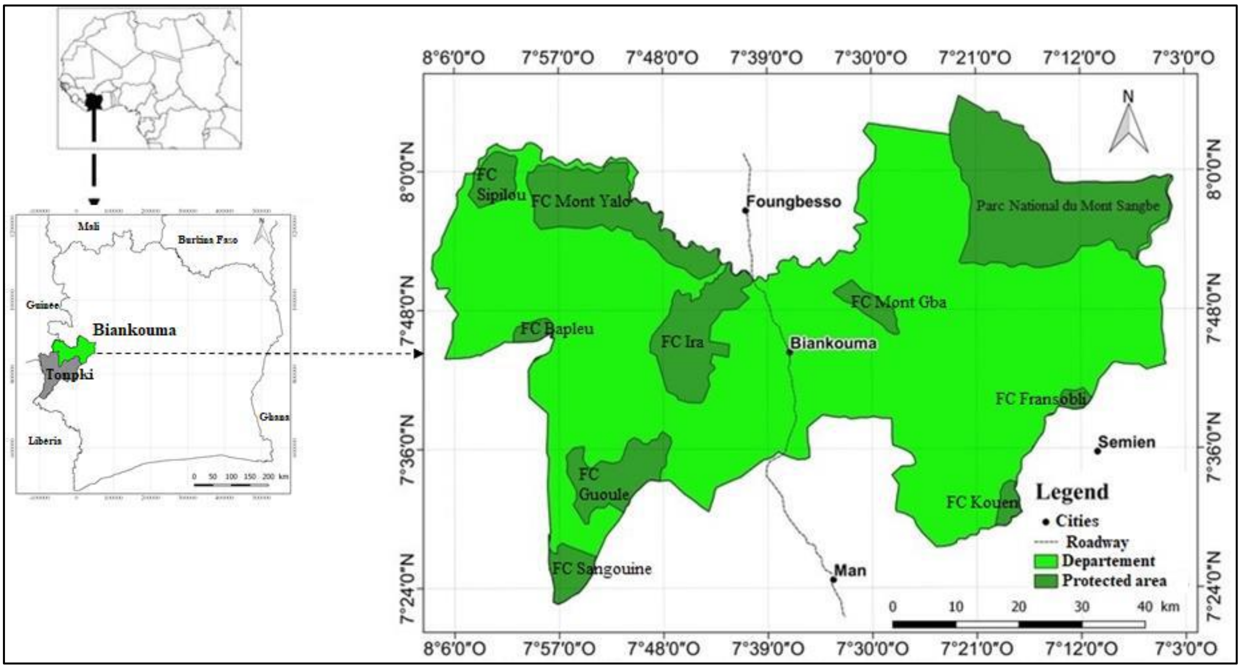

Figure 1 Location of the Biankouma department in the west of Côte d'Ivoire

2.2. Development of Land Use Maps of the Biankouma Department Landscape

Two Landsat satellite images with a spatial resolution of 30 meters, acquired in 2002 and 2018 and covering the Biankouma area, were used in combination with georeferenced vector data. Using a vector file delineating the boundaries of the Biankouma landscape, the study area was extracted from the full satellite scene. The reduced size of the working window helped minimize the processing time required for various digital operations [10]. False-color composites were then generated from the reduced and/or raw spectral bands to identify the combinations that best discriminated between different land use classes. Several field campaigns were conducted between March and October 2018 to describe and validate the various land use classes identified during the preliminary image processing stage. Vegetation formations were characterized based on physiognomic criteria such as stratification, structure, and dominant plant species [11-12]. A supervised classification approach was applied, involving the use of training areas defined from accurately georeferenced field-verified sites [13]. The classification results were validated using accuracy indices derived from a confusion matrix [14-15]. After classifying the 1985, 2002, 2013, and 2018 images of the Biankouma landscape, the area of each land use class was determined through a post-classification analysis performed in the ENVI software. These areas were subsequently used to calculate the proportional representation of each land use category.

2.3. Identification of Spatial Transformation Processes in the Biankouma Department Landscape

Spatial structure indices constitute a complementary approach for analyzing the structural dynamics of the landscape [16]. These indices often serve as indicators of the impact of human activity on landscape morphology [17]. The interpretation of these spatial structure indices leads to an understanding of the spatial transformation processes occurring within the landscape. Indeed, the identification of spatial transformation processes is based on the evolution of area (a), perimeter (p), and number of patches (n) between times T_0 and T_1 by comparing the values of a_0, p_0, and n_0 at T_0 with a_1, p_1, and n_1 at T_1 [18-19]. The combination of the number of patches (n) and the total patch area (a) makes it possible to describe ten spatial transformation processes, as outlined in the decision tree developed by [19] (Figure 2). These ten spatial transformation processes are aggregation (patch fusion), suppression (disappearance of one or more patches), creation (formation of new patches), deformation (change in patch shape without area change), enlargement (expansion of patch size), perforation (formation of holes within patches), displacement (patch translocation), shrinkage (reduction of patch size), fragmentation (breakdown of continuity into several disjoint patches), and dissection (subdivision of patches by linear features). To distinguish between fragmentation and dissection, a threshold value (t = 0.5) is used. This threshold (t) is compared to an observed value (t_obs = a_1 / a_0). If t_obs < t, the dominant process in the landscape is fragmentation ; otherwise, it is dissection [20].

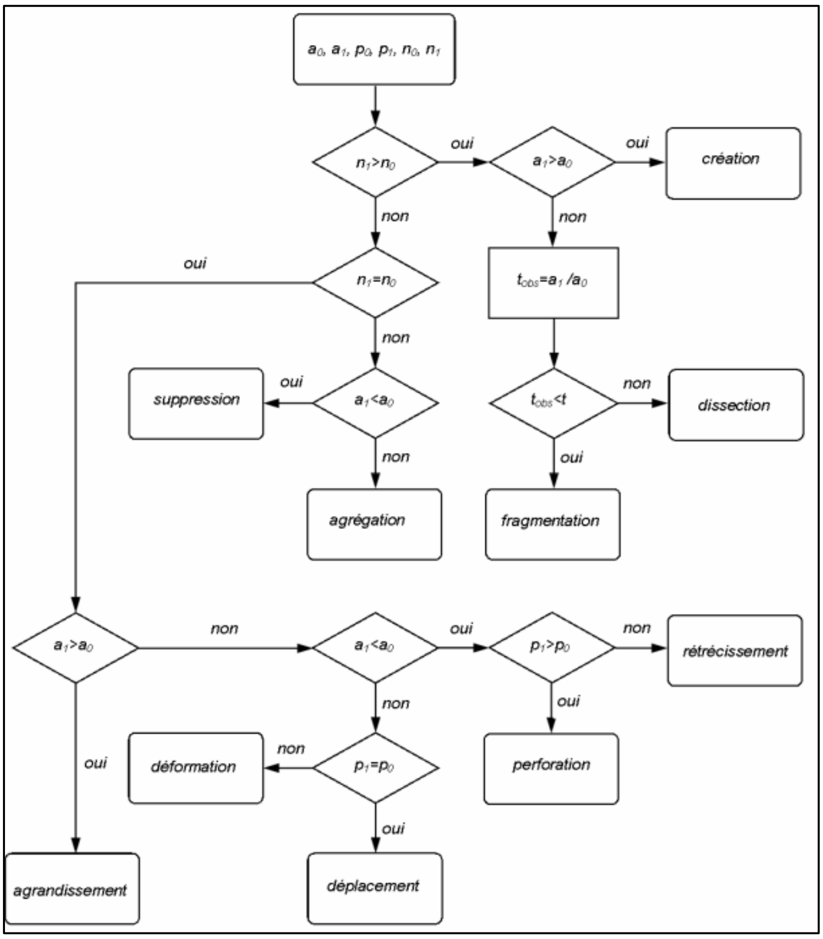

Figure 2 Decision tree for identifying spatial transformation processes [19].

The parameters a0, p0, and n0 refer respectively to the area, perimeter, and number of patches before the transformation, whereas a1, p1, and n1 are the corresponding values after the change in configuration

3. Results

3.1. Land Use Dynamics in the Biankouma Department Between 1985 and 2018

Digital processing of multispectral images made it possible to produce land use maps for the years 1985, 2002, 2013, and 2018 (Figure 3). The Kappa coefficients derived from the confusion matrices of the 2002 and 2018 classifications are 0.87, indicating good classification accuracy. Visually, it can be observed that the forest and savanna areas, which dominated the Biankouma Department in 2002, gradually disappeared by 2018 in favor of cocoa plantations and degraded forests. Both rural areas and protected zones within the department have been affected by human activities.

Between 1985 and 2018, Biankouma's land use underwent significant changes. In 1985, the landscape of the Biankouma Department was dominated by dense forest, degraded forest, and savanna. These land cover classes accounted for 34.7% (167,930 ha), 16.7% (80,930 ha), and 40.6% (196,420 ha) of the total landscape, respectively (Table 1). Cocoa plantations, crop–fallow mosaics, and bare soil and settlement areas were less represented, with respective proportions of 3.7% (17,770 ha), 0.5% (2,450 ha), and 3.9% (18,660 ha).

By 2018, the landscape was mainly composed of savanna and cocoa plantation classes, which covered 35% (169,260 ha) and 30.3% (146,640 ha) of the department, respectively. The dense forest class accounted for only 33,190 ha, or 6.9% of the study area. The cropland–fallow and bare soil–settlement classes covered 4.8% (23,070 ha) and 4.5% (21,870 ha), respectively.

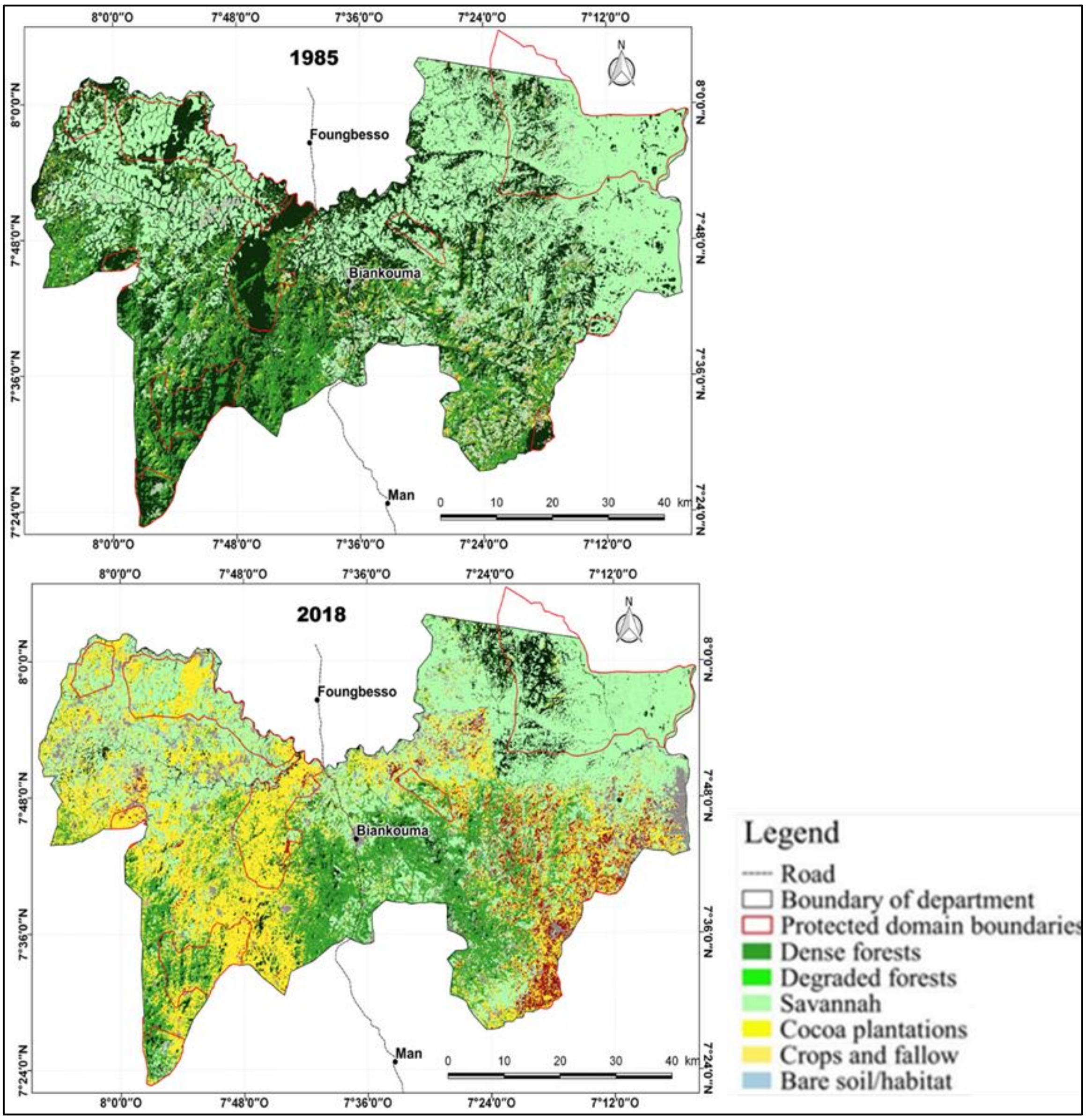

Figure 3 Land cover maps of the Biankouma Department for 2002 and 2018

Table 1 Changes in the proportions of land use/land cover classes between 1985 and 2018

	1985		2018	
Land cover	Sup (ha)	(%)	Sup (ha)	(%)
Forest	167 930	34,7	33 190	6,9

Degraded forest	809 30	16,7	90 150	18,6
Cocoa plantation	17 770	3,7	146 640	30,3
Crops and fallow	2 450	0,5	23 070	4,8
Savannah	196 420	40,6	169 260	35
Bare soil/habitat	18 660	3,9	21 870	4,5
Total	484 170	100	484 170	100

3.2. Annual Evolution of Land Use Types in the Biankouma Department

During the different study periods, natural vegetation types—namely forests and savannas—experienced a regression in their surface areas, in contrast to anthropogenic areas, which showed an expansion. Between 1985 and 2018, the Biankouma Department recorded an annual decrease of 2.4% in forest area (Figure 4). Similar trends were observed for the savanna, which showed an annual reduction rate of 0.4% over the same period.

In contrast, degraded forests experienced an increase in area between 1985 and 2018, with an estimated annual growth rate of 0.3%. Cocoa plantations also expanded significantly during the study period, showing an annual growth rate of 22% between 1985 and 2018.

As for the cropland–fallow class, it recorded an annual increase in surface area during the same period, with an annual growth rate of 25.5%. Finally, the bare soil and settlement class also expanded slightly, with an annual increase of 0.5% between 1985 and 2018 (Figure 4).

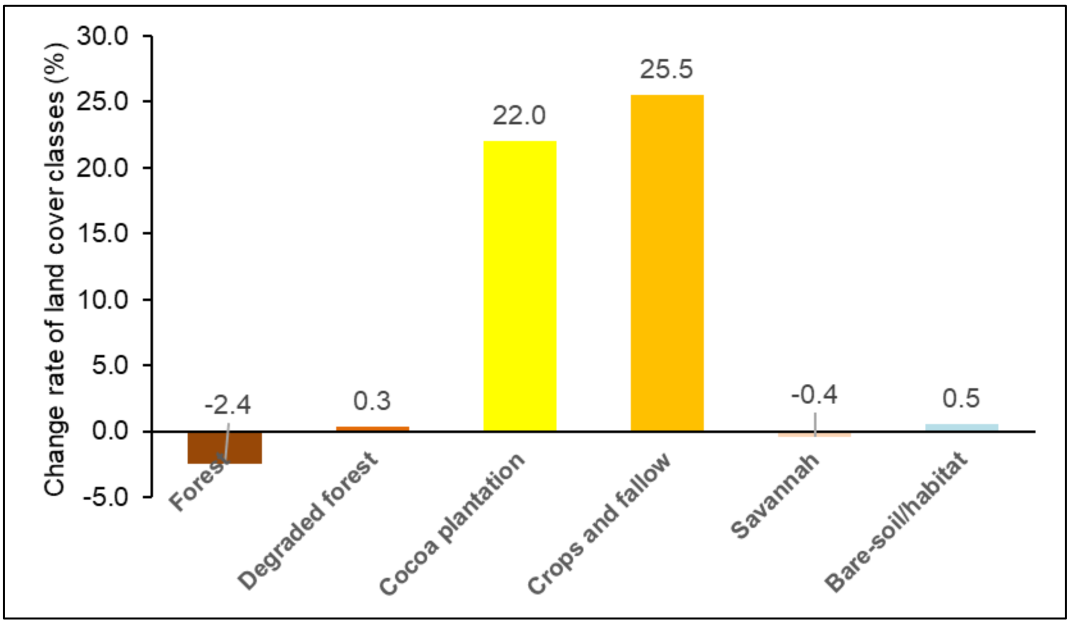

Figure 4 Annual rate of change of land use class areas in Biankouma from 1985 to 2018

3.3. Dynamics of Spatial Structure and Spatial Transformation Processes in the Biankouma Landscape

The analysis of the spatial structure dynamics of the study area reveals that, over the 1985–2018 period, each land use class underwent different transformation processes. Between 1985 and 2018, the dense forest and savanna classes experienced a process of patch suppression, while the degraded forest, cocoa plantation, cropland–fallow, and bare soil–settlement classes experienced a process of patch creation. Specifically, the forest class showed a decrease in the number of patches—from 14,297 to 14,006—and a reduction in total patch area, which declined from 1,679 km^2 to 332 km^2 (Table 2), indicating a process of forest patch suppression (Table 3). Similarly, the savanna class exhibited a decrease in the number of patches—from 42,631 to 37,874—and a reduction in total patch area, which decreased from 1,964 km^2 to 1,693 km^2 (Table 2), reflecting a process of savanna patch suppression (Table 3). Conversely, during the study period, the cocoa plantation class showed an increase in the number of patches—from 13,155 to 16,737—and an increase in total patch area, from 178 km^2 to 1,466 km^2 (Table 2), corresponding to a process of cocoa patch creation

(Table 3). The degraded forest class also showed an increase in the number of patches—from 12,104 to 13,895—and an increase in total patch area, from 809 km² to 901 km² (Table 2), reflecting a process of degraded forest patch creation. Regarding the cropland–fallow class, it exhibited an increase in the number of patches—from 3,417 to 8,571—and an increase in total patch area, from 25 km² to 231 km² (Table 2), indicating a process of cropland–fallow patch creation. Finally, during the study period, the bare soil and settlement class showed an increase in the number of patches—from 7,580 to 7,636—and an increase in total patch area, from 187 km² to 219 km² (Table 2), resulting in a process of bare soil and settlement patch creation.

Table 2 Spatial structure indices calculated in 1985 and 2018 for each land use/land cover class in the Biankouma Department

	Forest	Degraded forest	Savannah	Cocoa plantation	Crops and fallow	Bare soil/habitat
1985						
n_{1985}	14297	12104	42631	13155	3417	7580
a_{1985}	1679	809	1964	178	25	187
p_{1985}	27886	17528	44385	7444	1276	5172
2018						
n_{2018}	14006	13895	37874	16737	8571	7636
a_{2018}	332	901	1693	1466	231	219
p_{2018}	9630	18034	34128	26308	6578	5253

np = number of patches of the class, a = total area of the class (km²), p = total perimeter of the class (km)

Table 3 Spatial transformation processes of land use/land cover classes in the Biankouma Department during the period 1985–2018

		1985-2018
Forest	np	$np_{1985} > np_{2018}$
	a	$a_{1985} > a_{2018}$
	p	$p_{1985} > p_{2018}$
	PTS	**Loss**
Degraded forest	np	$np_{1985} < np_{2018}$
	a	$a_{1985} < a_{2018}$
	p	$p_{1985} < p_{2018}$
	PTS	**Creation**
Savanannah	np	$np_{1985} > np_{2018}$
	a	$a_{1985} > a_{2018}$
	p	$p_{1985} > p_{2002}$
	PTS	**Loss**
Cocoa plantation	np	$np_{1985} < np_{2018}$
	a	$a_{1985} < a_{2018}$
	p	$p_{1985} < p_{2002}$
	PTS	**Creation**
Crops and fallow	np	$np_{1985} < np_{2018}$

	a	$a_{1985}<a_{2018}$
	p	$p_{1985}<p_{2018}$
	PTS	**Creation**
Bare soil/habitat	np	np1985<np_{2018}
	a	a1985<a_{2018}
	p	p1985<p_{2018}
	PTS	**Creation**

STP = Spatial transformation processes

4. Discussion

Vegetation cover in western Côte d'Ivoire, as illustrated by the case of the Biankouma Department, underwent profound changes under the influence of cocoa cultivation between 1985 and 2018. Forests and savannas, which previously formed the landscape matrix, were progressively replaced by perennial crops, primarily cocoa plantations. This transformation affected forests more severely than savannas during the study period. Indeed, between 1985 and 2018, forest areas decreased annually by 2.4%, whereas savanna areas declined at an annual rate of 0.4%. This regression of forest and savanna cover during the period is reflected in the suppression of their patches within the landscape. Between 1985 and 2018, both the number of patches and the total patch area decreased for the forest and savanna classes, leading to biodiversity loss due to the direct destruction of natural habitats. The expansion of cocoa cultivation occurred through successive stages following the dynamics of agricultural pioneer fronts [21]. This process begins with the aggregation of cocoa patches and the creation of degraded forests and crop–fallow mosaics, while forests and savannas undergo dissection. These spatial transformations in land use classes mark the beginning of a cocoa production cycle in the department. In practice, the rehabilitation of old cocoa plots and/or the conversion of aging coffee plantations lead to the aggregation of cocoa patches and the formation of crop–fallow mosaics. Forests and savannas are gradually infiltrated, and access roads are opened and maintained by local populations, explaining the dissection observed in these classes. Benefiting from the shade provided by tall trees, local populations clear the understory and directly introduce cocoa seeds, resulting in the creation of degraded forest patches. This method of establishing cocoa farms is common in Ivorian classified forests [22-23-24]. During this period, forested areas were primarily converted into cocoa plantations. The use of forest lands as a precursor to cocoa cultivation can be explained by the fact that forest ecosystems provide ideal conditions for the development of cocoa and coffee crops in Côte d'Ivoire [25]. Moreover, deforestation is often used as a strategy for land acquisition, as clearing and cultivating land grants de facto ownership rights to those who cleared it [26]. This conversion of forest areas (dense and degraded forests) into farmland has also been reported by Freud et al. (2000), who found that 89% of agricultural lands in Côte d'Ivoire are established on cleared primary or secondary forests. The decline in forest cover is a clear sign of ecosystem disturbance and impedes ecological restoration [17]. The intense human pressure on natural vegetation observed between 1985 and 2018 in the Biankouma Department could also be linked to the socio-political and military crisis that affected Côte d'Ivoire from 2002 to 2011 [28-29]. Indeed, armed conflicts led to the abandonment of forest management throughout the country, particularly in the western regions. These forests, beyond serving as areas of illegal logging and farming, sometimes became battlefields and refugee camps [30]. By 2018, after the savanna, the landscape of Biankouma was dominated by cocoa cultivation. Thus, the cocoa plantation class appears to be the main driver of vegetation cover change in this part of Côte d'Ivoire, as observed throughout sub-Saharan Africa [31-32-33]. In fact, cocoa plantations, which occupied only 3.7% of the landscape in 1985, covered 30.3% in 2018. The creation of new cocoa patches reflects the growing importance of this land use class in the 2018 landscape. Similarly, as with cocoa plantations, the spatial transformation processes observed for cropland–fallow, degraded forest, and bare soil–settlement classes were characterized by patch creation.

5. Conclusion

This study, based on remote sensing techniques and landscape ecology principles, made it possible to identify the spatial transformation processes that occurred in the landscape of western Côte d'Ivoire following the establishment of cocoa plantations between 1985 and 2018. In 1985, this region was dominated by forest and savanna formations; today, it is largely covered by cocoa plantations. Forest and savanna areas experienced annual regression rates of 2.4% and 0.4%, respectively, between 1985 and 2018. The regression of these natural formations is reflected by the suppression of their patches within the landscape. Conversely, the spatial transformation processes observed for degraded forest, cropland–fallow, and bare soil–settlement classes were characterized by patch creation.

Compliance with ethical standards

Acknowledgements

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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