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Conservation Status and Ecosystem Services Provided by Plant Species Associated with Cocoa-Based Agroforestry Systems in the Department of Biankouma (Central-Western Côte d'Ivoire)

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Abstract

Cocoa farming in Côte d'Ivoire remains largely extensive and often relies on deforestation. Indeed, this practice has had devastating consequences on the country's forest cover, leading to biodiversity loss and reduced ecosystem services. To remedy this problem, agroforestry remains a promising solution for environmental conservation. The overall objective of this study is to assess the contribution of cocoa-based agroforestry systems to biodiversity conservation and the well-being of populations in the department of Biankouma. To achieve this, floristic inventory methods combined with surveys were carried out in 35 plantations divided into seven age classes in order to determine the typology of agroforestry systems and to identify the conservation status of woody species present in agroforestry systems as well as ecosystem provisioning services. The analyses identified three types of cocoa-based agroforestry systems. These are a simple agroforestry system with mature cocoa trees practiced mainly by non-indigenous people, a complex agroforestry system with aging cocoa trees practiced mainly by indigenous people (83.3%), and a simple agroforestry system with young cocoa trees practiced mainly by non-indigenous people (52.6%). In addition, these agroforestry systems are home to many endangered species and endemic species. Beyond their role in species preservation, agroforestry systems provide supply services to populations in several areas, the most prominent of which are medicine and food. In short, cocoa-based agroforestry systems represent a promising alternative for combining agricultural sustainability and biodiversity conservation in Côte d'Ivoire.

Keywords

Agroforestry Systems, Biodiversity Conservation, Cocoa Farming, Ecosystem Services, Côte d'Ivoire

1. Introduction

Since gaining independence, Côte d'Ivoire has focused its economic development on agriculture, a sector that accounts for 20.6% of national GDP and generates 47% of exports [1]. This focus has enabled Côte d'Ivoire to become the world leader in cocoa bean production [2], making this product a strategic resource in both economic and social terms. Indeed, Ivorian cocoa accounts for 40% of global production, with an annual output of 2,200,000 tons [3], contributing 15% of GDP and playing an essential role in job creation. Approximately 600,000 farmers in this sector directly support the livelihoods of 6 million people [4].

However, the traditional method of cocoa cultivation, practiced since colonial times, remains largely extensive and often leads to deforestation. The forest area in Côte d'Ivoire is estimated at 2.97 million hectares in 2020, compared to 16 million hectares in 1880 [5], representing 9.2% of the total land area, including 2.88 million hectares of natural forest and just over 92,000 hectares of reforestation [5]. Cocoa farming is thus identified as one of the main causes of forest cover degradation in tropical regions, responsible for 30% of deforestation in Côte d'Ivoire [6]. Forests are ideal habitats for a variety of plant species, so the expansion of cocoa cultivation at the expense of forests is synonymous with the disappearance of local plant diversity and the reduction of essential ecosystem services.

In light of this worrying situation, agroforestry appears to be a promising solution for reconciling agricultural development and environmental conservation, while promoting the well-being of local populations [7] through the provision of ecosystem services. Agroforestry is an ancient practice that combines trees with agricultural crops and/or livestock farming and brings many benefits to rural communities.

Based on this observation, the following questions arise: What are the different types of agroforestry systems (AFS) in the Department of Biankouma? How do they contribute to biodiversity conservation?

To address these concerns, this study has set itself the following general objective: The general objective of this study is to assess the contribution of cocoa-based agroforestry systems to biodiversity conservation and the well-being of the populations of the Biankouma Department. By well-being of the populations, this study refers to the improvement of the socio-economic conditions of the populations through the supply services that AFS provide them. Specifically, the study will first 1) determine the typology of agroforestry systems; then 2) identify the conservation status of woody species present in AFS; and 3) determine the ecosystem services provided by these agroforestry systems.

2. Methodology

2.1. Presentation of the study area

This study was conducted in the Biankouma Department, located between 7˚21'00" and 8˚06'00" north latitude and 7˚03'00" and 8˚15'00" west longitude. This department in western Côte d'Ivoire is 233 km from Daloa and 46 km from the city of Man, which is also the capital of this region. It is located in a transition zone between the rainforest and mesophilic sectors. There are savanna and forest formations with mixed formations intermingling [8]. The population living in this department is mainly engaged in agriculture. In fact, these populations are mainly involved in the cultivation of coffee, rice, cassava, and oil palms [9]. Recently, they have become interested in cocoa farming [10].

This study was conducted in six (06) villages in the Biankouma Department, namely Bounta, Touoba, Moroulé, Somba, Chocopleu, and Klapleu (**Figure 1**).

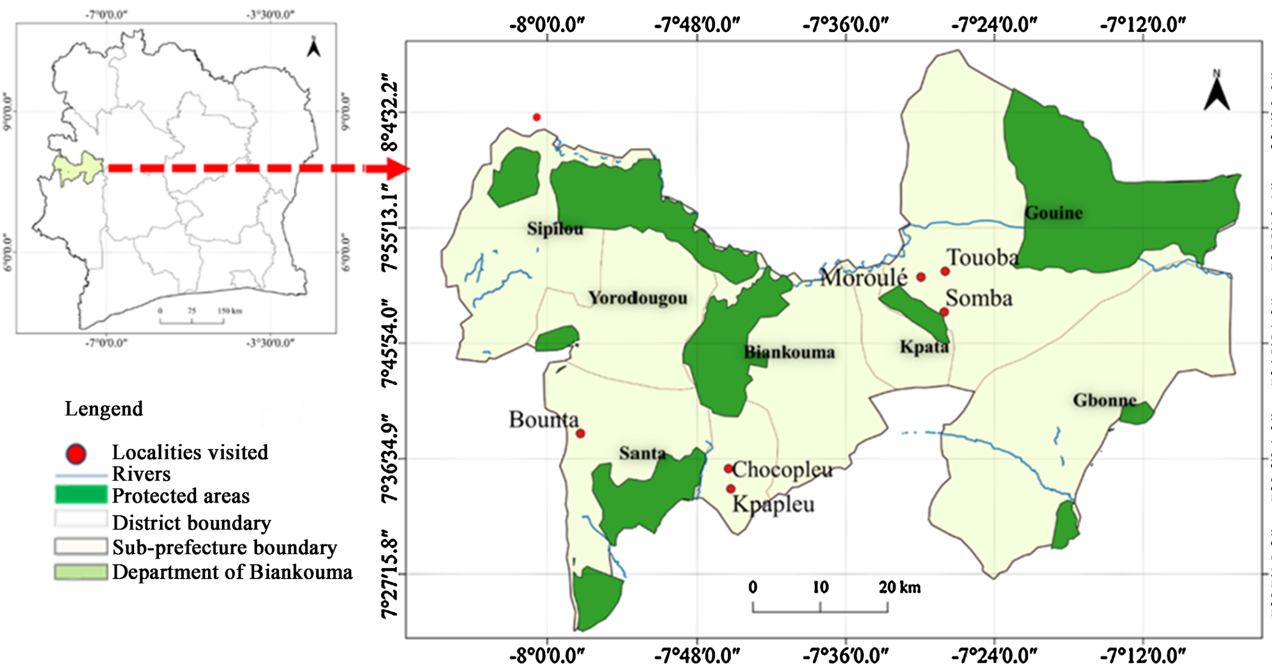


Figure 1. Geographic location of the Biankouma Department in Côte d'Ivoire.

2.2. Selection of Cocoa Plantations

The choice of locations and plantations visited was based on various criteria, including the number of cocoa farmers, annual cocoa bean production, accessibility of the location, presence of trees in the plantations, and age of the plantation. In addition, these different cocoa plantations were divided into seven (07) age classes. These are the age classes [0 - 4] years, [5 - 10] years, [11 - 15] years, [16 - 20] years, [21 - 25] years, [26 - 30] years, and ≥30 years. The different age classes were determined using data from surveys conducted as part of the Cocoa4future project. The choice of age classes was based on the work of Assiri *et al.* [11].

2.3. Data Collection

Experimental design

For data collection, inventory methods associated with ethnobotanical surveys were carried out in selected cocoa plantations. For the floristic inventories, plots covering an area of 0.5 ha (100 m × 50 m) were set up to record all non-woody species (banana trees and palms) and woody species (trees and shrubs) with a diameter greater than or equal to 8 cm [12] [13]. Woody species are defined as trees and shrubs other than crops. For each identified individual, the circumference was measured at a height of 1.30 m above the ground for woody species and palms. Within each plot, subplots measuring 20 m × 20 m, or 400 m^2 (**Figure 2**), were established using GPS and a decameter [14] in order to count and record the number of cocoa trees and all associated crops. In addition, dendrometric measurements were taken in the 400 m^2 subplots. The diameter of the cocoa trees was measured 30 cm above the ground using a caliper. The height of the cocoa trees was also measured using a graduated rod. For coffee trees, the diameter was measured 15 cm above the ground, while that of cashew trees was measured 1.30 m above the ground [15]. In total, data was collected from 40 plots of 5000 m^2 each and 40 subplots of 400 m^2 each, distributed across each of the seven (07) age classes. Subsequently, itinerant surveys were carried out in the one-hectare plantation to identify all woody and non-woody species that had not been recorded in the plots.

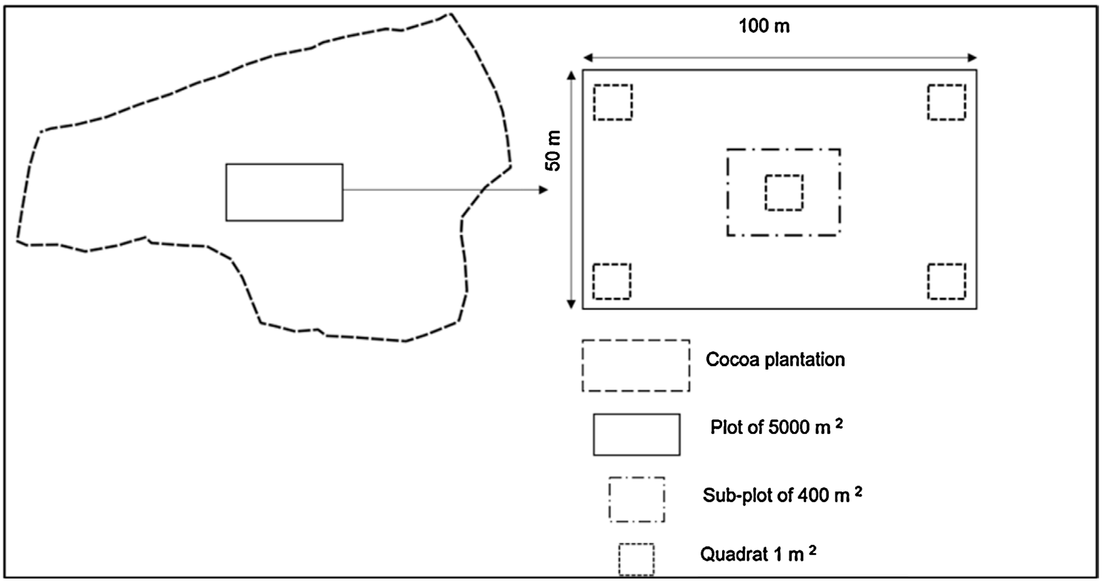


Figure 2. Floristic data collection system.

Surveys of cocoa producers

Surveys were also conducted among landowners using a questionnaire to determine the ecosystem services provided by agroforestry species. The questionnaire focused mainly on the species present in the plantation and their areas of use. A total of 35 producers were surveyed.

Data analysis

The floristic data collected were used to determine the specific diversity and structural diversity of the cocoa plantations. Specific diversity was assessed by calculating the floristic richness and Shannon diversity index [16]. The distribution of associated species in age classes was assessed on the basis of the Pielou equitability index [17].

By definition, plant diversity is the number of plant species present at a given site [18]. It was determined by counting the number of species recorded. In addition, the number of genera and families were also recorded. The classification of plant species used was that of the Angiosperm Phylogeny Group III [19].

Shannon diversity index (H) reflects the diversity of species that make up the populations of an environment. It establishes a link between the number of species and the number of individuals in the same ecosystem or community. It was determined using the following mathematical formula:

$$H = \sum \left(\frac{ni}{N}\right) * \ln\left(\frac{ni}{N}\right) \quad (1)$$

where H is the Shannon index; ni is the number of individuals for each species; N is the total number of individuals.

Pielou's evenness index measures the homogeneous distribution of species in the population in relation to a theoretical equal distribution for all species. It varies from 0 to 1. Its mathematical formula is as follows:

$$E = \frac{H}{\ln S} \quad (2)$$

E represents Pielou's evenness index, H' represents the Shannon index, and S represents the total number of species in the environment.

Structural diversity was determined based on density and height calculations. Density was calculated using the following mathematical formula:

$$d = \frac{N}{s} \quad (3)$$

where d represents density; N, the total number of species; s, the area in hectare.

The average heights of woody species, non-woody species (banana and palm trees), cocoa trees, and associated crops were determined.

Identification of agroforestry systems

To determine agroforestry systems, a multiple factor analysis (MFA) coupled with an ascending hierarchical classification (AHC) was performed based on qualitative and quantitative variables. The qualitative variables consisted of age classes, farmer origin, and previous crop. The quantitative variables consisted of the age of the plantation, structural parameters, and the diversity of woody and non-woody species, cocoa trees, and associated crops (density, height, species richness, and diversity).

For each variable, a one-way analysis of variance (ANOVA) was performed on the calculated floristic parameters (diversity and floristic richness indices) and structural parameters (density, height). When a significant difference was observed between the average for a given parameter, Tukey's test was performed to identify homogeneous classes.

The Chi-square test was performed on qualitative variables (origin, previous crop). These various tests made it possible to discriminate between the characteristic variables of each agroforestry system. R software was used for all statistical tests.

Determination of species conservation status

Conservation status takes into account endemic species and those listed on the International Union for Conservation of Nature's Red List.

To determine endemic species, the list of species obtained was cross-referenced with that of Aké-Assi [20], and the list of rare or now rare and endangered species was cross-referenced with the list of the International Union for Conservation of Nature [21] to determine endangered species. Cross-referencing the two lists made it possible to determine the numbers of vulnerable (VU), least concern (Lc), near threatened (Nt), and endemic (GCW; GCi) species recorded during the inventories.

Determination of provisioning services

To determine ecosystem provisioning services, survey data were entered using Excel spreadsheets and processed using R software. The frequency of citations for each category of use was then analyzed.

$$Fc = \frac{nc}{Nr} \quad (4)$$

where Fc is the frequency of citations for a category of use expressed as a percentage, nc is the number of citations for a category of use, and Nr is the number of respondents.

3. Results

3.1. Characterization of Cocoa Plantations in the Department of Biankouma

The floristic inventory carried out in the various sampled plots identified 161 species divided into 48 families and 124 genera. The most represented family in terms of number of species is Fabaceae, with 23 species, or 14%. This family is followed by Moraceae (10%), Euphorbiaceae (6%), Meliaceae (6%), Rubiaceae (5%) and Sterculiaceae (5%), which comprise 15, 10, 10, 5, and 5 species, respectively (**Figure 3**).

3.1.1. Densities of Cocoa Trees and Associated Species

One-way analysis of variance (ANOVA) showed that the average densities of cocoa trees and woody species are statistically different according to age class

(Tukey's test, $p < 0.05$) (**Table 1**). In terms of average cocoa tree densities, low densities were observed in plantations aged 0 to 4 years, with a value of 1,770 individuals/ha, and high densities in plantations aged 16 to 20 years. However, across all plantations, there was a decrease in cocoa tree density with the age of the plantations. With regard to the densities of woody species other than crops, the highest value, 150 individuals/ha, was obtained in plantations aged 0 to 4 years. On the other hand, no significant difference ($p > 0.05$) was observed in the densities of associated crops, banana trees, and palm trees according to the age of the plantations. However, the average densities of crops associated with cocoa trees, banana trees, and palm trees remain higher in plantations over 30 years old, with values of 250 individuals/ha, 191.6 individuals/ha, and 180.4 individuals/ha (**Table 1**).

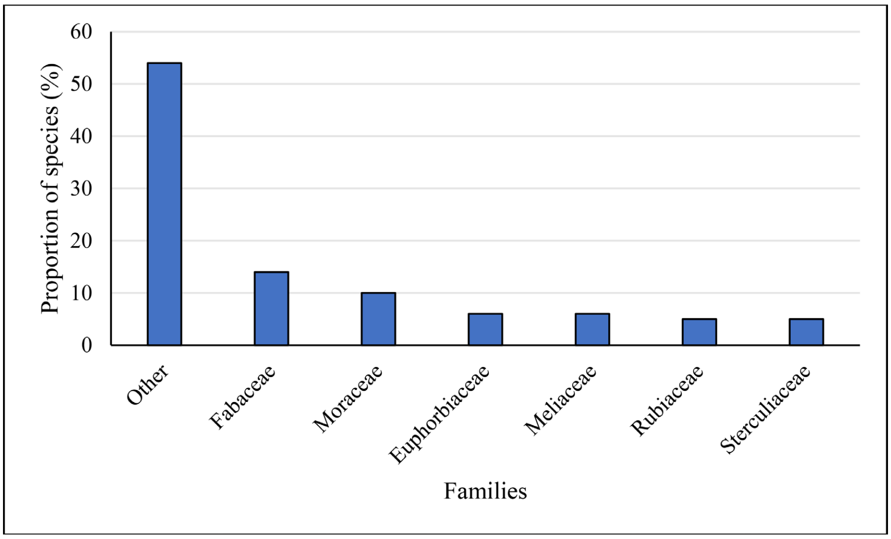


Figure 3. Distribution of the most represented families in cocoa plantations.

Table 1. Average densities of species present in cocoa plantations according to age classes.

Variables	Modalities	Age classes							
		[0 - 4]	[5 - 10]	[11 - 15]	[16 - 20]	[21 - 25]	[26 - 30]	Over 30 years	Tukey's test
Densities	Cocoa trees	1770^{ab}	2365^{ab}	2445^{ab}	2475^{b}	1245.83^{ab}	1477.78^{ab}	1000^{a}	3.70
	Related crops	220^{a}	105^{a}	220^{a}	25^{a}	54.17^{a}	13.89^{a}	250^{a}	1.18
	Banana trees	100.8^{a}	108.4^{a}	54.8^{a}	131.6^{a}	124.67^{a}	160.67^{a}	191.6^{a}	0.8
	Woody	150^{b}	104^{ab}	50.4^{ab}	56.8^{ab}	31^{ab}	17.11^{a}	86^{ab}	2.91*
	Palm trees	57.2^{a}	35.2^{a}	57.2^{a}	44^{a}	106.33^{a}	56.22^{a}	180.4^{a}	1.47

Values with the same letters in the same row are statistically identical at the 5% level.

3.1.2. Heights of Cocoa Trees and Woody Species on Cocoa Plantations Visited

The one-way analysis of variance (ANOVA) revealed significant differences in the average heights of cocoa trees and woody species according to the age classes of the plantations (Tukey's test, $p < 0.05$). In terms of cocoa trees, the average height increases gradually with age, reaching a maximum of 4.47 m in the 26 - 30 age class. However, in plantations over 30 years old, the average height decreases to 2.87 m, reaching a level comparable to that of young plantations (0 to 4 years and 5 to 10 years), Figure 4(a).

A similar trend is observed for associated woody species. The greatest heights are reached between 16 and 30 years of age, with a maximum of 14.41 m for the 26 - 30 age group. Conversely, the youngest plantations (0 - 15 years) and those over 30 years old have lower heights, with average values of 5.5 m (Figure 4(b)).

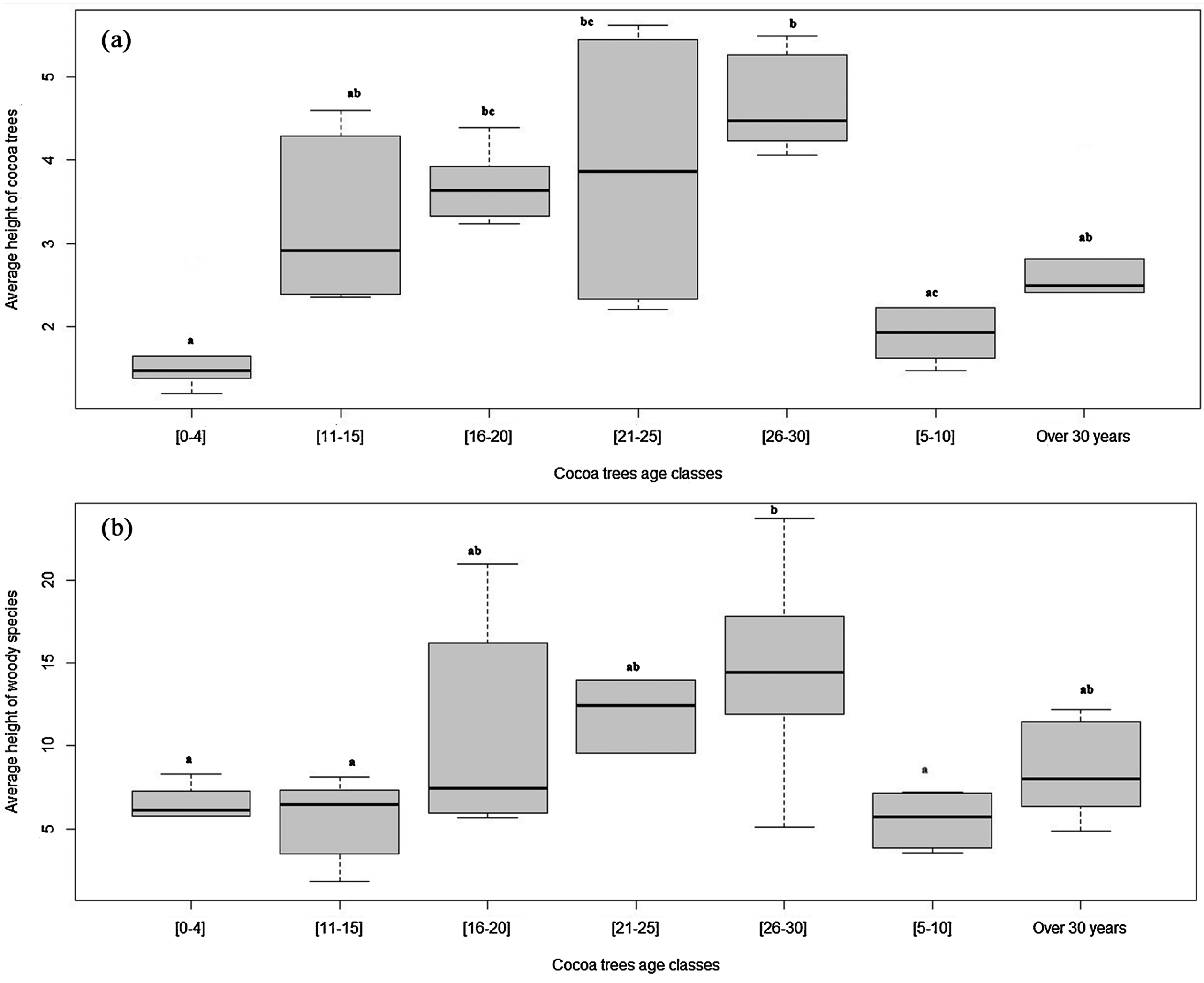


Figure 4. (a) Average height of cocoa trees (Values followed by the same letter are statistically identical at the 5% threshold); (b) Average height of and woody species (Values followed by the same letter are statistically identical at the 5% threshold).

3.2. Typology of Agroforestry Systems in the Department of Biankouma

3.2.1. Factors Determining the Typology of Agroforestry Systems

Multiple factor analysis (MFA) was used to establish a typology of agroforestry systems. The main factors used in this analysis included: the density of associated woody species, the density of associated crops, the density of non-woody species, the density of cocoa trees, the age of cocoa trees, the previous crop, and the origin of the farmer.

The first two axes of the Multiple Factor Analysis account for 34.18% of the variance in the relationships between the floristic characteristics of cocoa plantations and environmental and human factors (**Table 2**) and were therefore used to determine the different groups of AFS.

Table 2. Eigenvalues and contribution of descriptive variable groups for Biankouma agroforestry systems.

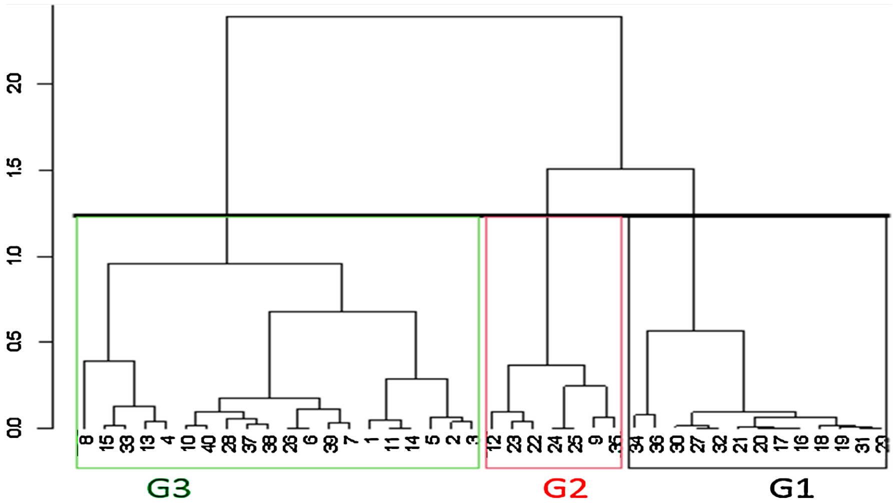
	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalue	3.64	2.39	1.67	1.46	1.39
Percentage of inertia	20.61	13.57	9.48	8.29	7.85
Cumulative inertia percentages	20.61	34.18	43.66	51.96	59.81
Contribution of variable groups used					
Density	14.15	21.34	10.03	11.27	15.61
Height	18.84	0.90	2.45	1.45	0.51
Age of cocoa trees	10.13	18.86	0.02	0.06	1.95
Floristic diversity	13.62	7.10	0.58	3.07	0.49
Previous crop	11.14	3.04	36.81	42.51	21.66
Age class cocoa	20.94	29.31	47.80	39.83	43.61
Origin of the farmer	11.17	19.44	2.31	1.79	16.17

3.2.2. Description of the Factors Determining the Typology of Agroforestry Systems

The ascending hierarchical classification (AHC) performed on the first five factor axes of the AFM, which account for 59.81% of the total inertia, highlights three groups of agroforestry systems (AFS) derived from cocoa plantations (**Figure 5**). There are 12 factors involved in the formation of AFS. They consist of qualitative and quantitative variables, with 2 and 10 respectively (**Table 3** and **Table 4**). In terms of quantitative variables, the five most significant are, in order of importance: the age of the cocoa trees, the height of the associated trees, the height of the cocoa trees, the density of oil palms, and species diversity (Shannon). The qualitative variables are represented by age class, previous crop, and the origin of the cocoa farmers.

3.2.3. Description of Agroforestry Systems

The first agroforestry system, type 1 (AFS1), comprises mature plantations with an average age of 25 years (60%). These plantations were previously forests (100%) and are mainly operated by non-indigenous people (73.3%) (**Table 3**). AFS1 is characterized by a high density of banana trees, reaching 173.47 individuals per hectare. The average density of cocoa trees is 1623.33 individuals per hectare. The



G = Group.

Figure 5. Ascending hierarchical classification of agroforestry systems.

density of associated crops is 38.33 individuals per hectare, while that of woody species and palm trees is 17.73 and 51.33 individuals per hectare, respectively. In terms of flora, AFS1 has an average species richness of 9 species, but relatively low diversity indices, with a Shannon index value of 0.76 and a Piélou equitability index of 0.36. On the other hand, the average heights of cocoa trees (4.49 m) and woody species (14.92 m) are relatively high compared to other AFS (Table 4).

Agroforestry system type 2 (AFS2) mainly includes plantations belonging to the over-30-year-old age class, established on previous forestry crops (83.3%) and mostly operated by indigenous people (83.3%) (Table 3). AFS2 is characterized by a high density of palm trees (216.33 individuals per hectare), banana trees (159.67 individuals/ha), and woody species (89 individuals/ha). Unlike AFS1, the average density of cocoa trees is low, at 1,079.17 individuals per hectare. This system has a low density of associated crops, amounting to 208.33 individuals per hectare. AFS2 is characterized by a high average species richness, with 21 species per plantation, and moderate values for the Shannon diversity index (1.90) and Pielou's equitability index (0.63) (Table 4).

Agroforestry system type 3 (AFS3) is characterized by young cocoa plantations belonging to the age classes [0 - 4 years], [5 - 10 years], and [11 - 15 years]. These plantations are mainly established on previous forest (57.9%) and fallow land (26.3%) (Table 3). AFS3 is mainly practiced by non-native populations (52.56%). The average age of the cocoa trees is around 10 years. This system is characterized by a high density of cocoa trees (2117.11 individuals per hectare) and a relatively high density of woody species (64.4 individuals/ha). However, the densities of associated crops (143.42 individuals per hectare) and banana trees (82.63 individuals per hectare) are low. AFS3 has a high species richness, with an average of 18 species per plantation, as well as moderate Shannon diversity (1.85) and Piélou equitability (0.65) indices. The average height of cocoa trees is approximately 2.59 m, while that of woody species reaches 5.52 m (Table 4).

Table 3. Qualitative variables characterizing agroforestry systems.

	Modalities	AFS1	AFS2	AFS3	Chi-square test
Age class of agroforestry systems (years)	[0 - 4]	0	0	26.3	63.41
	[5 - 10]	0	0	26.3	
	[11 - 15]	0	0	26.3	
	[16 - 20]	13.3	0	15.8	
	[21 - 25]	26.7	16.7	5.3	
	[26 - 30]	60	0	0	
	>30 years	0	83.3	0	
Previous crops	Crops	0	0	5.3	9.147
	Forest	100	83.3	57.9	
	Fallow land	0	16.7	26.3	
	Savannah	0	0	10.5	
Origin	Non-native	73.3	0	10.5	23.03***
	Allogenic	13.3	16.7	52.6	
	Aboriginal people	13.3	83.3	36.8	

AFS: Agroforestry system; Significance threshold for chi-square tests: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

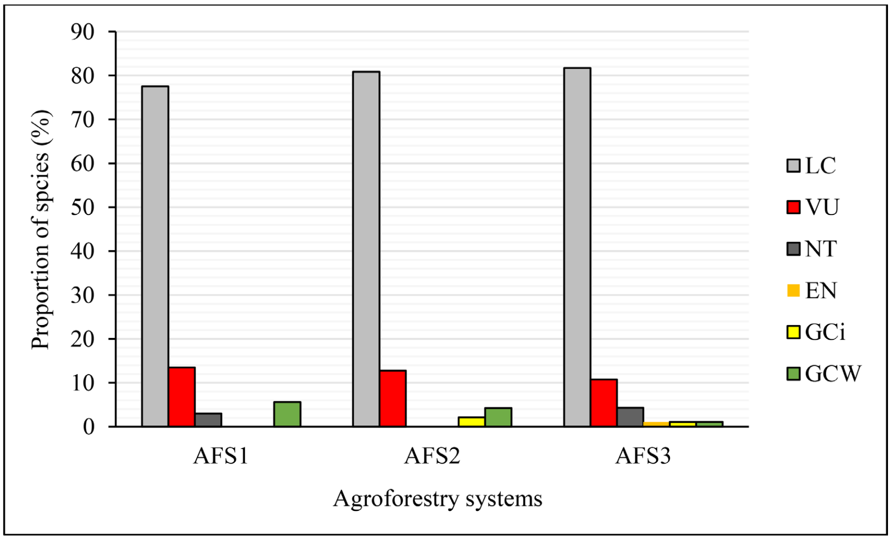
Table 4. Floristic characteristics of different agroforestry systems.

Variables	Modalities	AFS1	AFS2	AFS3	Test statistics
Age	Cocoa trees	25^{a}	43.50^{b}	10.11^{c}	49.96
Density	Banana tree	173.47^{a}	159.67^{ab}	82.63^{b}	3.39
	Cocoa trees	1623.33^{ab}	1079.17^{a}	2117.11^{b}	4.19
	Related crops	38.33^{a}	208.33^{a}	143.42^{a}	1.55
	Woody	17.73^{a}	89^{b}	64.4^{ab}	6.03
	Palm tree	51.33^{a}	216.33^{b}	49.79^{a}	10.77***
Floristic diversity	Floristic richness	8.86^{a}	21.33^{b}	18.42^{b}	7.54**
	Pielou's evenness	0.36^{a}	0.63^{ab}	0.65^{b}	6.69
	Shannon-Weaver index	0.76^{a}	1.90^{b}	1.85^{b}	9.86***
Height	Cocoa trees	4.49	2.76	2.59	17.61***
	Woody	14.92^{a}	9.39^{b}	5.52^{b}	26.43***

On the same line, values accompanied by the same letters are statistically identical at the 5% threshold. AFS: Agroforestry system.

3.3. Conservation Status of Woody Species in Different Agroforestry Systems

The analyses identified 122 species with special status, including 15 endangered species, five (05) endemic to the West African forest block (GCW) and one endemic to Côte d'Ivoire (GCi) across all AFS. The species endemic to the West African forest block (GCW) are represented by *Afzelia bella* Harms, *Diospyros heudelotii* Hiern, *Milicia regia* (A. Chev.) C.C. Berg, *Millettia lane-poolei* Dunn, and *Millettia rhodontha* Baill. Millettia takou Lorougnon is the only species endemic to Côte d'Ivoire. Among the threatened species, 14 species, or 10%, are vulnerable and one (01) is endangered (0.72%). Vulnerable species include *Afzelia africana* Sm. ex Pers, *Cordia platythyra* Bak, *Cussonia bancoensis* Aubrév. & amp; Pellegr., *Entandrophragma angolense* (Welw.) C. DC., *Garcinia kola* Heckel, *Khaya senegalensis* (Desr.) A. Juss. *Nesogordonia papaverifera* (A. Chev.) R. Capuron, etc. *Only Pterocarpus erinanceus* Poir. has been identified as an endangered species. At the level of the different AFS, more than 80% of the species surveyed are of minor concern according to the IUCN. However, in AFS2, vulnerable species account for a significant proportion, at 13%, followed by AFS1 and 3, at 10.75% each. Only AFS3 has one endangered (EN) species, at 1.08% (**Figure 6**).



AFS: Agroforestry systems; LC: Least Concern; VU: Vulnerable; NT: Near Threatened; EN: Endangered; GCW: Endemic to the West African forest block; GCi: Endemic to Côte d'Ivoire.

Figure 6. Species of special status in different agroforestry systems.

3.4. Ecosystem Services Provided by Agroforestry Systems in the Department of Biankouma

3.4.1. Species Providing Ecosystem Provisioning Services

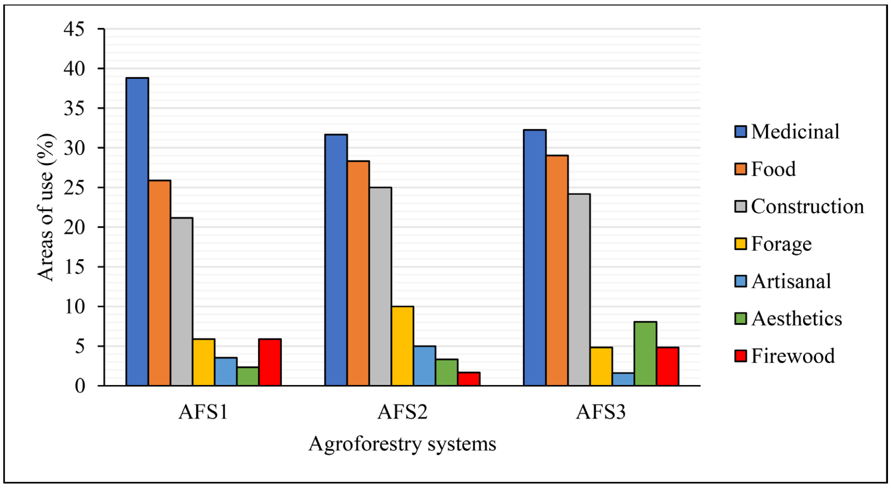
Among the 161 species identified in the 35 plantations, 11 are considered to be the main species providing provisioning services (**Table 5**), the most numerous of which are *Theobroma cacao* L., *Musa paradisiaca* L., *Elaeïs guineensis* Jacq., *Carica papaya* L., *Mangifera indica* L., *Persea americana* Mill., *Millettia zechiana* Harms, *Ficus exasperata* Vahl, *Citrus sinensis* (L.) Osbeck, *Morinda lucida* Benth, and *Psidium guajava* L.

Table 5. Frequency of citation of the main species providing provisioning services.

No.	Species	Number of individuals	Frequency (%)
1	*Theobroma cacao* L.	2876	70.57
2	*Musa paradisiaca* L.	2406	59.04
3	*Elaeis guineensis* Jacq.	111	2.72
4	*Carica papaya* L.	89	2.18
5	*Mangifera indica* L.	41	1
6	*Persea americana* Mill.	40	0.98
7	*Millettia zechiana* Harms	36	0.88
8	*Ficus exasperata* Vahl	23	0.56
9	*Citrus sinensis* (L.) Osbeck	18	0.44
10	*Morinda lucida* Benth.	15	0.36
11	*Psidium guajava* L.	14	0.34

3.4.2. Areas of Use of Species Providing Provisioning Services

Seven (07) areas of species use have been recorded in agroforestry systems (AFS) in the Biankouma Department (Figure 7). These are medicinal, construction, food, cosmetic, firewood, and fodder. However, two are most prevalent in the various AFS: medicinal and food. Species used for medicinal purposes are numerous in AFS1, with a rate of 38.82%, followed by AFS3 and AFS2, with respective proportions of 32.26% and 31.67%. Species used for food are more important in AFS3, with a rate of 29.03%, followed by AFS2 and AFS1 with respective rates of 28.33% and 25.88%. Finally, species used in construction represent more than 25% of AFS2, 24.19% of AFS3, and 21.17% of AFS1.



AFS: Agroforestry system.

Figure 7. Species areas of use according to agroforestry systems.

4. Discussion

4.1. Floristic and Structural Diversity of the Cocoa Plantations in Biankouma

The floristic inventory of the various plantations revealed 161 species divided into 124 genera belonging to 48 families. These species mainly belong to the families Fabaceae (14%), Moraceae (10%), Euphorbiaceae (6%), Meliaceae (6%), Rubiaceae (5%), and Sterculiaceae (5%). The predominance of Fabaceae can be explained by several factors. First, these plants are often selected for their multiple uses, including firewood, medicine, and shade. In addition, Fabaceae are naturally abundant in many ecosystems, partly because they comprise three subfamilies [19]. Finally, their ability to fix atmospheric nitrogen plays a key role in soil fertility, thereby enhancing their ecological contribution [22].

Analysis of structural diversity showed a decrease in cocoa tree density with the age of the plantations. These results are consistent with the work of [7] in Cameroon. This trend could be explained by pruning and trimming practices, which become more intensive in older plantations in order to maintain good production [23]. Furthermore, the decline in woody species density with plantation age is a common process in tropical agroforestry systems aimed at increasing the production of young cocoa trees [23]. This reduction in woody species density often reflects more intensive management aimed at favoring cocoa trees at the expense of spontaneous plant diversity. As for non-woody species, especially banana trees, a high density is observed in plantations over 30 years old. This high density of banana trees in old plantations could be due to good management of suckers since the plot was established, which allows the original density to be maintained over a long period. It could also be explained by the aging of the cacao trees. When cocoa trees are aging, farmers tend to preserve more banana trees to provide shade for future young cocoa trees in case of replanting. Our results are similar to those of [24]. In their work in Ghana on the regeneration of old cocoa plantations, these authors showed that the regeneration of old cocoa plantations requires the densification of fruit species, particularly banana trees. In addition, the average height of cocoa trees shows a gradual increase with the age of the plantations. There is a reduction in the average height of cocoa trees in plantations over 30 years old, which is similar to that of plantations aged 0 to 4 years and 26 to 30 years. This reduction in the height of cocoa trees in plantations over 30 years old could be due to replanting. Our results corroborate those of [25]. Indeed, these authors have shown in their work that farmers replant by replacing dead or diseased cocoa trees.

4.2. Agroforestry Systems: A Balance between Biodiversity Conservation and the Provision of Ecosystem Services

Multivariate analysis identified three (03) agroforestry systems based on plantation age, floristic and structural diversity, type of associated species, previous crop, and producer origin. These variables have also been used in the determination of cocoa-based AFS by certain authors, notably [25]-[27].

The first agroforestry system (AFS1) consists of cocoa plantations aged 26 to 30 years, mainly resulting from forest conversion. These plantations are mainly managed by non-indigenous populations. They are characterized by a high density of banana trees and relatively low plant diversity. The average height of the cacao trees is 4.49 m and that of the woody plants is 14.92 m. This type of AFS is considered a simple mature agroforestry system. The high presence of banana trees in AFS1 could be justified by the fact that producers introduce banana trees for self-consumption and for commercialization, on the one hand, and by the replanting of old cocoa trees, on the other. Indeed, farmers introduce banana trees to provide shade for young cocoa trees while maintaining the old trees [28].

The second agroforestry system (AFS2) consists of cocoa plantations that are over 30 years old, established by indigenous populations on former forest land. This system is characterized by a high density of oil palms, a wide variety of plant species, and a high average height of woody species (9.39 m). The average height of the cocoa trees is approximately 2.76 m. This type of system could be considered a complex, aging agroforestry system. The high level of plant diversity observed within AFS2 could be explained by the indigenous people's in-depth knowledge of local species. When setting up their plots, they preserve a large number of species in their plantations for medicinal, nutritional, or cultural purposes. Indigenous people conserve more species in their plantations to maintain local biodiversity. In addition to maintaining local biodiversity, these species are better adapted to the climate. This also allows farmers to preserve or strengthen their cultural identity while promoting their local know-how. Our results corroborate those of [29]. These authors have shown in their work that traditional knowledge enables producers to ensure sustainable management of natural resources while maximizing species diversity and also promoting their local knowledge. This type of agroforestry system has also been described in other cocoa-growing regions of Africa, particularly in Cameroon [30]. Furthermore, the average height of cocoa trees being less than three (03) meters in this system could be explained by the fact that it is a replanting [25]. Indeed, as the plantation ages, farmers tend to replace dead or senescent trees with young cocoa seedlings [25].

Finally, the third type of agroforestry system (AFS3) consists of young cocoa plantations aged 0 to 15 years. These plantations have been cultivated previously as forests and fallow land and are mainly maintained by non-indigenous populations. They are characterized by a high density of cocoa trees (2117.11 individuals/ha) and a relatively high density of woody species (64.4 individuals/ha) with average heights of 2.59 m and 5.52 m, respectively. This type of system can be described as a simple, young agroforestry system. The significant floristic richness observed could be explained by the fact that young plantations are often in a transition phase, where agricultural practices are not yet fully intensified. Indeed, when creating plantations, farmers preserve a portion of the forest to create additional sources of income. Furthermore, human interventions such as intensive pruning or the use of pesticides are not yet systematically implemented. These results are consistent with studies conducted in West Africa, particularly in Ghana [31] and Côte d'Ivoire [32].

In addition, at least one species with special status was observed in all three AFS. This demonstrates that cocoa-based AFS contribute to the conservation of local biodiversity. Indeed, several species with special status have been noted in these various plantations, including *Afzelia africana* Sm. ex Pers, *Cordia platythyra* Bak, *Cussonia bancoensis* Aubrév. & Pellegr., *Entandrophragma angolense* (Welw.) C. DC., *Garcinia kola* Heckel, *Khaya senegalensis* (Desv.) A. Juss. *Nesogordonia papaverifera* (A. Chev.) R. Capuron, etc. These results demonstrate the importance of agroforestry systems in the conservation of biodiversity in general, and in particular of threatened and endemic species that still find favorable habitats there. These facts have been highlighted by [25] [33] and [34]. In their research carried out in central-western Côte d'Ivoire, these authors showed that most of our natural forests are now heavily anthropized due to the establishment of vast cocoa plantations, leading to the destruction or even disappearance of many species of interest. In order to safeguard these species of interest, farmers are domesticating them or introducing them into their plantations [35]. These species with special status also improve soil quality and create habitats for animals. They help to create a microclimate. These species with special status provide beneficial shade for young cacao trees and help to limit attacks from insects such as midges. They also help to create humidity around the cacao trees.

In addition, the agroforestry species preserved in AFS provide products in seve, the most common being medicinal and food products. The medicinal field is the most important, with more than 30% of species in the various AFS. This dominance of the medicinal field of use could be explained by the importance that producers attach to plants in the treatment of various diseases, but also by the remoteness or even absence of health centers, farmers turn to traditional medicine to meet their health needs because of the high cost of modern medicine [36]. In other words, these species contribute to the health of the population. These results corroborate those of [37] in Ghana and [25] in Côte d'Ivoire, who also highlighted the crucial role of medicinal plants in traditional agroforestry systems. In addition to their medicinal uses, products from cocoa trees and agroforestry species are used in the food sector. This shows that products from cocoa trees and agroforestry trees help to ensure food security for local populations. Indeed, products from associated species such as beans, almonds, fruits, seeds, and buds serve as subsistence and additional sources of income for producers [24]. This income from the sale of cocoa and agroforestry products enables producers, on the one hand, to provide for their families and improve their livelihoods and, on the other hand, to maintain their plantations through the purchase of agricultural equipment and inputs for pest control, the payment of agricultural labor, and the purchase or rental of new equipment. on the other hand, to maintain the plantation by purchasing agricultural equipment and inputs for pest control, paying agricultural labor, and purchasing or renting new plantations in preparation for the following year's cocoa season [38].

5. Conclusions

The main objective of this study, which is to assess the contribution of cocoa-based agroforestry systems to biodiversity conservation and the well-being of populations in the department of Biankouma, has identified three cocoa-based agroforestry systems in the department of Biankouma. These are the simple agroforestry system with mature cocoa trees practiced mainly by non-indigenous people (AFS1), the complex agroforestry system with aging cocoa trees practiced mainly by indigenous people (83.3%) (AFS2), and the simple agroforestry system with young cocoa trees practiced mainly by non-indigenous people (52.6%) (AFS3). Furthermore, analysis of conservation status has shown that 15 species are threatened, of which 14 species (11.47%) are vulnerable and one (01) species (0.82%) is endangered. This significant number of threatened species, such as *Khaya senegalensis*, *Entandrophragma angolense*, *Pterocarpus erinaceus*, *Terminalia ivorensis*, *Ricinodendron heudelotii*, etc., in the various AFS demonstrates their contribution to biodiversity conservation. In addition to their contribution to biodiversity conservation, these AFS provide ecosystem services in seven (07) areas of use, the most frequent of which are medicinal and food.

Based on these results, it would be important to promote and strengthen these agroforestry systems in order to preserve biodiversity, but also to support the livelihoods of local populations. In addition, further studies will focus on ecological and socioeconomic values, while taking into account market access for agroforestry tree products and carbon, as well as local governance arrangements that could influence SAF management.

Authors' Contributions

All co-authors whose names appear on the submission have made a substantial contribution to this study. They all participated in field data collection, various analyses, and manuscript writing. All authors have read and approved the final manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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