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# Plant species diversity in cocoa and rubber tree landscapes in Côte d'Ivoire

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## ABSTRACT

In Côte d'Ivoire, although slash and burn practice, particularly associated with cocoa and rubber farming, have greatly contributed to the degradation of forest cover and biodiversity loss. There is a dearth of studies documenting the latter. A study was conducted in the central-west and southern regions respectively with the objective to bridge this gap by assessing the diversity of trees species in cocoa and rubber landscapes. An inventory of tree species in eighteen cocoa and rubber plantations was conducted respectively in 45 plots of 400 m² each. Also, 15 plots of the same area were delimited in forests considered as reference systems. Cocoa plantations are 8 times richer than rubber plantations. Moreover, tree density varied from 36 to 56.8 stems.ha$^{-1}$ in cocoa plantations including 6 species with special-status for conservation and from 0 to 5 stems.ha$^{-1}$ in rubber plantations. This study confirmed that rubber farming is a driver of tree diversity loss thereby revealing the need to work out credible rubber agroforestry options. As for cocoa farming, the high diversity of companion trees is indicative of the high potential of transitioning to cocoa agroforestry. The contribution of this study to agroecological transition based on cocoa and rubber agroforestry in Côte d'Ivoire is discussed.


**Keywords:** Agroecological transition, Cocoa, Resilient tree-commodity landscapes, Rubber, Tree diversity, Sustainability.

## INTRODUCTION

The loss and degradation of natural habitats due to land conversion is recognized as the greatest contributor to the decline of biodiversity (Millennium Ecosystems Assessment, 2005). In fact, many ecosystem goods and services such as wood and non-wood production, soil protection, water and

 
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air quality disappear due to forests conversion. Despite the implementation of protective measures, the deforestation continues unabated both inside and outside the protected areas, especially in the tropical forests to the benefit of agriculture. The latter is also one of the main drivers of greenhouse gas (GHG) emissions in developing countries. In 2018, agriculture and related land use emissions accounted for 17% of global GHG emissions (FAO, 2020). However, the maintenance of the balance of ecosystem depends largely on biodiversity conservation. The tropical domain has the largest proportion of the world's forests (45%) which is subject to forest loss with the highest rate of deforestation observed in Africa during the period from 2010 to 2020, at 3.9 million hectares (FAO, 2002). Since 1960's, Côte d'Ivoire has lost nearly 90% of its forest cover and is known to display one of the highest deforestation rates in the world, estimated at more than 200,000 ha of forest per year (UTCATF, 2018). Extensive agriculture based on cash crops (cocoa, rubber, oil palm, cashew, etc.) is one of the main causes of this loss. Among these cash crops, cocoa farming covers more than 2 million hectares with 2.3 million tons of beans produced, thereby keeping the country in its position of top cocoa producer (World Bank, 2019). This achievement is attributable to the widespread of the full sun cocoa systems farming, a slash-and-burn cropping system set up at the expense of the potential fertility of forested lands. It was encouraged by agricultural extension services in the 1980s with the introduction of a hybrid variety adapted to full sun conditions and the distribution of a guide establishing a list of trees considered undesirable (Smith-Dumont et al., 2014).

The drop in the farmgate price of cocoa and the sudden increase in the first income from rubber producers, resulted in a mimicry effect in the 2000s. It then appeared that crop diversification is one of the solutions to improve farmers income. Over the last two decades, rubber cultivation has experienced spectacular growth because of market importance through the increase in natural rubber price per kilogram. The difficulty of replanting cocoa on depleted soils unlike rubber cultivation that requires less nutrients has also encouraged its adoption (Assiri et al., 2009). Despite the economic benefits, the rapid expansion of cocoa and rubber cultivation has contributed to forest cover decrease. The south of the country is one of the areas that host several forest relics to date, as well as protected areas (Abrou et al., 2019). As a result, forests are subject to anthropogenic pressures (urbanization, agriculture, etc.) that could have a strong impact on biodiversity and ecosystem services, thus contributing to the overall forest disappearance in the country.

Over the past few decades, the ability of cocoa and rubber cultivation to conserve floristic diversity has been the subject of several studies around the world (Tata, 2011; Lan et al., 2017; Sonwa et al., 2017; Zequeira et al., 2021). However, in Côte d'Ivoire, few studies have concerned the potential for the conservation of floristic diversity in cocoa and rubber plantations. Several studies conducted in cocoa farms support the assumption that agroforestry practices have the potential to conserve biodiversity (Kpangui et al., 2015; Cissé et al., 2016; Sonwa et al., 2017). Forest conversion to rubber plantation could reduce floristic species richness (Lan et al., 2017). Nevertheless, several authors argued that rubber tree farming could restore degraded areas by improving forest cover and soil quality (Jong, 2001; Adahé, 2014).

The high rate of conversion of forests into cocoa and rubber landscapes in humid and sub-humid areas of Côte d'Ivoire and the subsequent impacts on forest cover have triggered concerns about devastating consequences associated to climate change, threat on the cocoa supply chain, acute poverty of rural communities, food and nutritional insecurity. In the context of current agroecological transition and given the need to design deforestation free tree-based commodity farming, it's necessary to jointly assess the implications of rubber and cocoa farming on the floristic diversity of companion tree species. The main objective of this study was to assess the floristic diversity and composition of tree communities in cocoa and rubber tree plantations as well as forest portions considered reference systems.

## MATERIALS AND METHODS

### Study sites

The study was conducted in rubber and cocoa plantations located on two different sites according to the availability of the different stand of cultivations. The first site is in the village of Tiéviessou (05°20'39.5", 05°21'11.1" N; 04°53'12.0", 04°53'26.8" W) of the District of Grand-Lahou, southern Côte d'Ivoire (Figure 1).

This area belongs to the first rubber producing region and thereby hosts older rubber plantations. The climate belongs to the transitional equatorial type. The average annual temperature is 26.6°C with an average annual rainfall of 1,784 mm for the period of 2008 to 2018 including the study year which is 2018 (www.climate-data.org). The vegetation belongs to the ombrophilous sector of the Guinean forest domain. The landscape is dominated by the National Park of Azagny, rubber plantations, oil palms plantations, a few cocoa plantations and food crops spreading around Tiéviéssou village and two settlements Agnouanssou and Bétesso. The soils are ferralitic with sandy loam and clay texture. Local populations mainly live from agriculture and fishing.

The second study site is in Oumé, central-west of Côte d'Ivoire, between coordinates 6°30'0"N and 5°31'60" W (Figure 2).

This site belongs to a former cocoa production hotspot which continues to drive the livelihood of the communities. The climate is a subequatorial type characterized by two rainy seasons and two dry seasons. The average annual rainfall over the 10 years (2008–2018) is 1,384 mm with an average annual temperature of 26.2°C in the same period (www.climate-data.org). The natural vegetation is semi-deciduous forests including cocoa plantations, teak plantations and crop fields spread around three settlements, namely Petit Bouaké, Djekoffikro and Nkroadjo. The "Téné Classified Forest", a state-owned forest reserve, is one of the main protected forests in the area. The soils are ferralsols, with a sandy-loam texture.

### Sampling design and data collection

Data collection was carried out in rubber and cocoa plantations with the respective reference forests as controls. For each landscape type, a range of plantations of 7, 15 and 30-year-old measuring 1 ha were selected. Each plot was designated three times to capture the heterogeneity of the landscape. Two sample designs, single plot and nested plots are used, as documented by N'Gbala et al. (2017) and summarized by Figure 3.

In this study, rubber and cocoa plantations were sampled using a single plot design. For this purpose, five sampling units of 900 $m^2$ (30 m x 30 m) size were delimited in each plantation. In each sampling unit, a large quadrant of 100 $m^2$ (10 m x 10 m) was used to census all live trees having a DBH ≥ 5 cm at four angles, and separated by 10 m. As baseline forests have high variability in tree size, distribution, and structure, a nested plot design was more appropriate. To that effect, four large quadrants of 100 $m^2$ were set up and all live trees having DBH ≥ 10 cm were recorded. A sub-quadrant of 5 m x 5 m were set up in each largest quadrant of 100 $m^2$ for the inventory of all live trees having a DBH ≥ 5 cm (Figure 3).

### Data analysis

#### *Alpha diversity*

Shannon's diversity index (H') quantified the species richness of plants communities based on the number of species and their relative abundance. It is determined following equation (1):

$$H' = -\sum_{i=1}^{S}(ni/N)/\ln(ni/N) \quad (1)$$

where, ni is number of individuals of the species in a sample, N is total number of individuals of all species present in the sample, S is total number of species in the community.

The diversity is low when H' is less than 3, medium if H' is between 3 and 4 and high when H' is greater than or equal to 4.

The Piélou's index of Evenness (E) was associated to H' index to reflect the distribution of individuals among species in a sample according to equation 2:

$$E = H'/\ln S \quad (2)$$

where, H' is the Shannon index, S is the total number of species in a habitat.

The similarity concept was used to verify the homogeneity of studied plots taken two by two regarding their floristic composition. This is determined from Sørensen coefficient of similarity calculated for two habitats according to equation (3):

$$CS = \left(\frac{2c}{a+b}\right) \times 100 \quad (3)$$

where, CS is the similarity index, c is number of species common to both samples, a is number of species specific to the first sample, b is number of species belonging to the second sample.

With a similarity coefficient greater than or equal to 50%, the two sites concerned are considered floristically identical.

***Structural diversity***

The structural diversity of the vegetation was evaluated through stems density, basal area and horizontal vegetation structure. They were determined according to equation (4) and equation (5):

$$D = n/s \quad (4)$$

$$S = \sum(\pi\, d^2/4) \quad (5)$$

where, D is the stem density per hectare, n is number of stems in the sample, s is total plot area in ha, S is basal area ($m^2.ha^{-1}$) and d is stem diameter.

**Statistical analysis**

To compare the average values of tree diversity (Shannon and Piélou index) and abundance (Stem density, basal area) measured for the 7-, 15-, and 30-year-old plantations and forests in each study site, a one-way ANOVA parametric test or its alternative (Kruskal-Wallis' test) were used. For cases with significant differences, post hoc multiple comparison tests, Tukey HSD for parametric test and Dunn's test for non-parametric test, were used. All tests were performed using R software version 3.6.2 with a significance level of 5%.

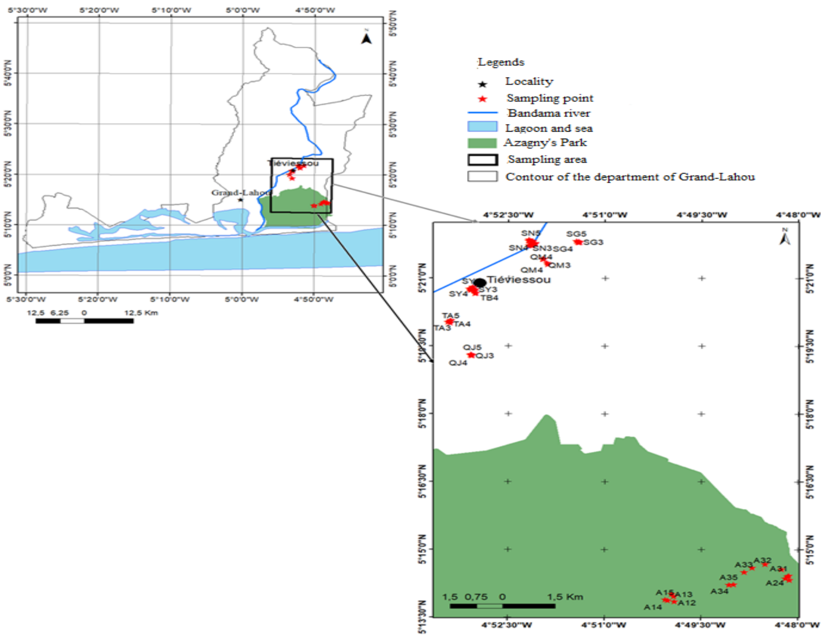



**Figure 1:** Study site along with the allocation of sampling points in Tiéviessou, southern of Côte d'Ivoire.

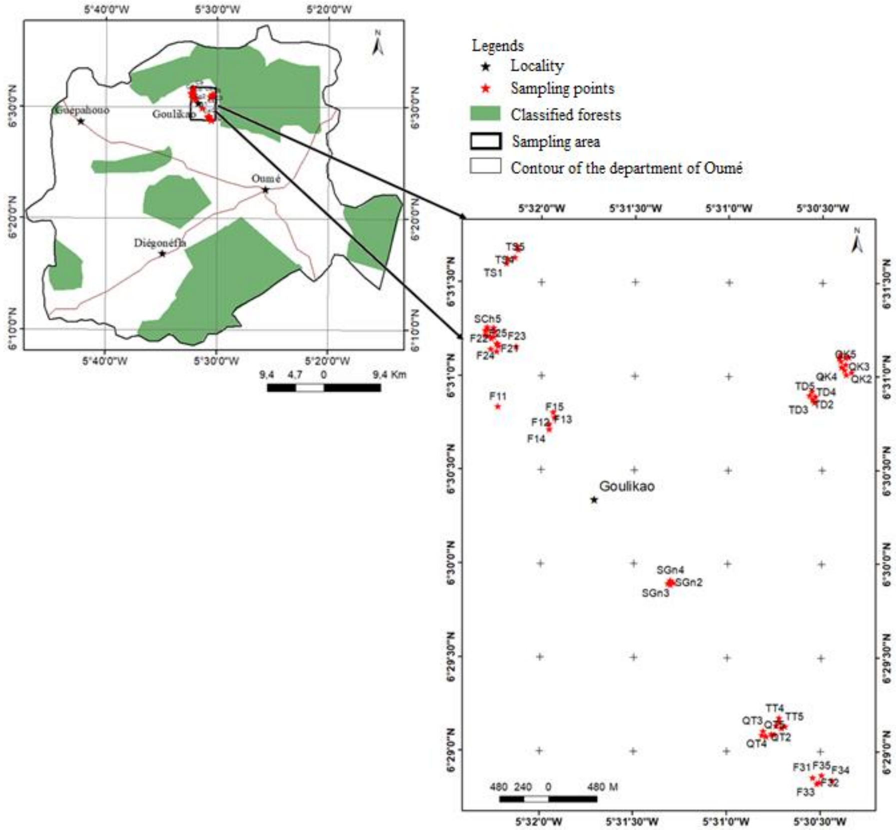



**Figure 2:** Study site along with the allocation sampling points in Goulikao, Central-Western Côte d’Ivoire.

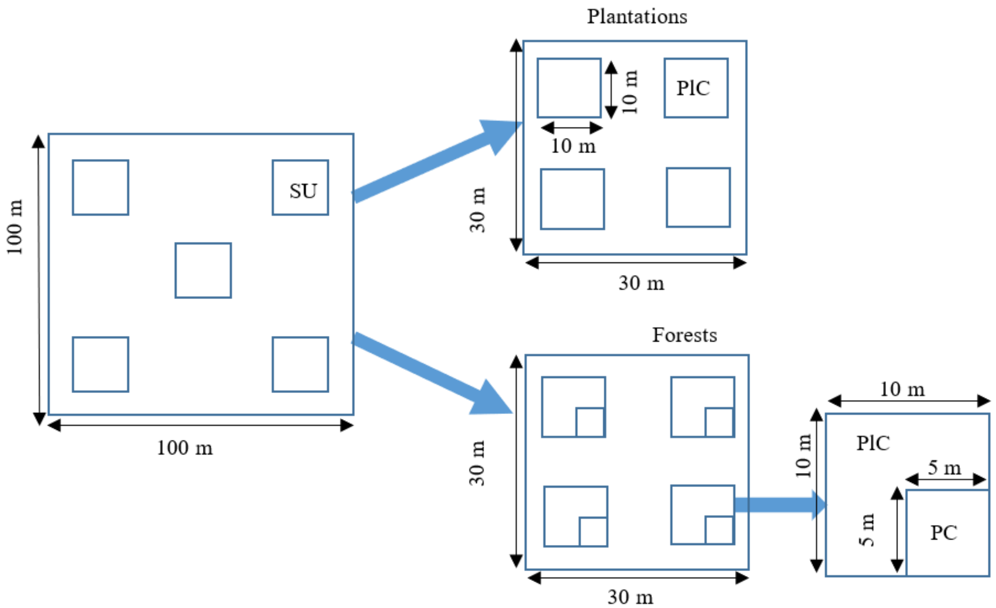



**Figure 3:** Sampling design in a plot. SU: sampling unit; PlC: small plot; PC: large quadrat.

## RESULTS

### Associated tree species diversity

In the rubber landscape, 50 species belonging to 40 genera and 25 families were recorded in 15 plots of forests and 5 tree species belonging to 5 genera and 4 families were registered in rubber plantations in a set of 45 plots. As for the cocoa landscape, 51 tree species (45 genera, 25 families) were recorded in forests and 39 species belonging to 33 genera and 13 families were inventoried in cocoa plantations. The number of tree species was higher in forests whatever the site (Table 1).

Considering the habitat according to their age, the 15-year-old rubber and cocoa plantations recorded the highest number of associated tree species with 3 and 20 species, respectively as shown in Table 1. The average number of associated tree species varied between forests and plantations regardless of the site ($P < 0.001$). Shannon diversity index is low in general and showed significant variation between habitats in both sites. In the rubber landscape ($F = 498.5$; $P < 0.001$), forests have the highest diversity index equal to 1.9 ± 0.08 (Table 1.A) while the diversity is nearly nil in all rubber plantations. As for the cocoa production landscape, forests are the most diverse tree community (2.59 ± 0.08). They are followed by cocoa plantations with a mean value of 0.17 ± 0.05 ($\chi^2 = 34.59$; $p < 0.001$). Intermediate values are reported in Table 1.

There was a significant difference between habitats as referred to Piélou equitability index. In the rubber zone, forests have the highest equitability value of 0.773 ± 0.02 while the equitability indices of rubber plantations were statistically equal as shown in Table 1.A ($F = 1081$; $p < 0.001$). Similarly, in the cocoa landscape ($\chi^2 = 34.59$; $p < 0.001$), forests recorded the highest equitability index value (0.887 ± 0.02) according to Table 1.B.

### Beta diversity

In the rubber landscape, the forest is floristically different from the rubber plantations. The highest degree of similarity was observed between young rubber plantations (7-year-old) and old rubber plantations (30-year-old) with a value of 50% (Table 2).

In cocoa landscape, no similarities were observed between habitats for their floristic composition. However, the tree community of young cocoa plantations was relatively close to that of old cocoa plantations with similarity rate of 40% (Table 3).

### Tree species composition of cocoa and rubber plantations

The dominant family in Azagny and Goulikao forests was Malvaceae with 9 and 10 species, respectively (Figures 4 and 5). In rubber plantations, the Fabaceae family dominated with two species.

As for cocoa plantations, there were five dominant families with at least 3 species that included Malvaceae, Fabaceae Anacardiaceae, Moraceae and Rutaceae (Figure 5). The largest family was Malvaceae, which had 6 tree species accounting for 17% of the total species.

Three tree species were common to cocoa farms, namely *Irvingia gabonensis* (Irvingiaceae), *Persea americana* (Lauraceae) and *Ricinodendron heudelotii* (Euphorbiaceae). Concerning the biological types, microphanerophytes were more abundant in the forests of both sites. The only tree species present in the 7-year-old rubber plantations was *Piptadeniastrum africanum*, a megaphanerophyte, whereas the 30-year-old rubber plantations harbored a mesophanerophyte, *Pycnanthus angolensis*. In the 15-year-old rubber plantations, one megaphanerophyte, *Ceiba pentandra*, one mesophanerophyte, *Albizia zygia* and one microphanerophyte, *Rauvolfia vomitoria* were represented. For cocoa plantations, mega and mesophanerophytes were dominant in 15-year-old cocoa plantations with 7 and 9 species, respectively, while microphanerophytes were more abundant in 7-year-old cocoa plantations with 9 species (Table 4).

Considering the endemism and the special-status of species, forests in rubber landscape harbored more species with special-status of which 5 tree species endemic to West African forest block (*Tieghemella heckelii*, *Maesobotrya barteri*, *Placodiscus attenuatus*, *Rinorea oblongifolia*, *Tarrietia utilis*), 2 endangered species (*Placodiscus attenuatus*, *Tieghemella africana*), 6 species considered as vulnerable (*Tarrietia utilis*, *Sterculia oblonga*, *Guarea cedrata*, *Drypetes pellegrinii*, *Tieghemella heckelii*, *Anopyxis klaineana*) and one near threatened species (*Milicia excelsa*). However, the rubber plantations did not harbor any tree species with a specific conservation status. In the cocoa landscape, forests contain 4 vulnerable species (*Cola reticulata*, *Nesogordonia papaverifera*, *Terminalia ivorensis*, *Trichilia ornithothera*) including 2 trees species endemic to the West African forest block (*Cola reticulata*, *Trichilia ornithothera*), and 1 near threatened species (Milicia excelsa). The mature cocoa plantations hosted 3 species (*Milicia excelsa*, *Irvingia gabonensis*, *Pterygota macrocarpa*) while young (7-year-old) and old (30-year-old) cocoa plantations hosted each one 1 species (*Irvingia gabonensis*) with special-status of conservation (Table 4).

## Structural diversity of associated trees

### Tree density and basal area

Tree density and basal area varied significantly from one habitat to another in both rubber and cocoa zones. In the rubber production zone, the forests recorded the highest tree density with a value of 1,551.7 trees.ha$^{-1}$, covering a basal area of 39.4 m².ha$^{-1}$. These were followed by the 15-year-old rubber plantations with 5 trees.ha$^{-1}$, covering a basal area of 0.5 m².ha$^{-1}$, reported in Table 5.A. Concerning the cocoa landscape, the tree density was higher in the forest with a value of 1,228.3 trees.ha$^{-1}$ corresponding to a basal area of 22.7 m².ha$^{-1}$. Considering cocoa plantations, the density of companion trees increased relatively with the age of the plantations and the highest value recorded in 30-year-old cocoa farms was 81.7 trees ha$^{-1}$ as shown in Table 5.B. However, the highest values of basal area were recorded in 15-year-old cocoa farms (11.7 m².ha$^{-1}$).

### Distribution of companion trees by diameter class

The distribution of associated trees by diameter class, according to each land use type in rubber landscapes revealed less variability (Figure 6). Individuals belonging to the 5–10, 10–20 and 20–30 cm classes were more abundant in forests. The three associated trees present in 15-year-old rubber plantations were distributed in the 20–30, 30–40 and 60–70 cm diameter classes (Figure 6).

As for the cocoa landscape, the distribution of companion trees by diameter class, revealed variable shapes (Figure 7). In the forest, stems belonging to 40–50 cm class were the most abundant with a density of 593.3 stems ha$^{-1}$ while in the cocoa plantations, young stems (5–10 cm) were the most abundant. They were followed by 40–50 cm class in the young and old (7- and 30-year-old) cocoa plantations. In the 15-year-old cocoa farms, several diameter classes were represented and young trees belonging to 5–10, 10–15 and 15–20 cm classes were the most abundant (Figure 7).

**Table 1:** Floristic richness and diversity of different plantations and forests in rubber (a) and cocoa (b) zones.

| | **Habitats** | **Specific richness** | **Average number of species (species.m$^{-2}$)** | **Shannon index** | **Evenness index** |
|---|---|---|---|---|---|
| A. | NP of Azagny | 42 | 12 ± 0.9[a] | 1.90 ± 0.08[a] | 0.78 ± 0.02[a] |
| | Rubber, 7 years | 1 | 0.07 ± 0.07[b] | 0.01 ± 0.01[b] | 0.01 ± 0.01[b] |
| | Rubber, 15 years | 3 | 0.2 ± 0.1[b] | 0.02 ± 0.01[b] | 0.03 ± 0.02[b] |
| | Rubber, 30 years | 1 | 0.07 ± 0.07[b] | 0.01 ± 0.02[b] | 0.01 ± 0.01[b] |
| | | - | $F = 141.3$<br>$P < 0.001$ | $F = 498.5$<br>$P < 0.001$ | $F = 1081$<br>$P < 0.001$ |
| B. | Goulikao forests | 51 | 18.67 ± 0.83[a] | 2.59 ± 0.08[a] | 0.89 ± 0.02[a] |
| | Cocoa, 7 years | 13 | 1.20 ± 0.33[b] | 0.14 ± 0.06[b] | 0.12 ± 0.04[b] |
| | Cocoa, 15 years | 20 | 1.80 ± 0.40[b] | 0.17 ± 0.04[b] | 0.09 ± 0.03[b] |
| | Cocoa, 30 years | 13 | 1.87 ± 0.43[b] | 0.20 ± 0.05[b] | 0.08 ± 0.03[b] |
| | | - | $F = 223.8$<br>$P < 0.001$ | $\chi^2 = 34.59$<br>$P < 0.001$ | $\chi^2 = 34.59$<br>$P < 0.001$ |

NP: National Park. For each line, values followed by the same letter are not significantly different at the 5% threshold.

**Table 2:** Sørensen's similarity coefficients according to the different habitats of rubber landscape.

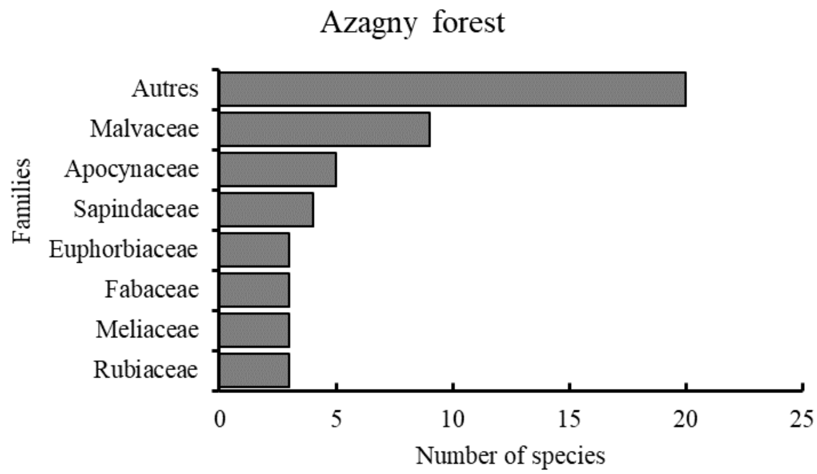
| Habitats | FA | H7 | H15 | H30 |
|---|---|---|---|---|
| FA | 1 | 3.85 | 3.70 | 3.85 |
| H7 | | 1 | 33.33 | 50.00 |
| H15 | | | 1 | 33.33 |
| H30 | | | | 1 |

FA: Azagny forests, H7: 7-year-old rubber plantations; H15: 15-year-old rubber plantations; H30: 30-year-old rubber plantations.

**Table 3:** Sørensen's similarity coefficients according to the different habitats of cocoa landscape.

| **Habitats** | **FG** | **C7** | **C15** | **C30** |
|---|---|---|---|---|
| FG | 1 | 27.69 | 33.33 | 6.15 |
| C7 | | 1 | 34.29 | 21.43 |
| C15 | | | 1 | 40 |
| C30 | | | | 1 |

FG: Goulikao forests; C7: 7-year-old cocoa plantations; C15: 15-year-old cocoa plantations; C30: 30-year-old cocoa plantations.



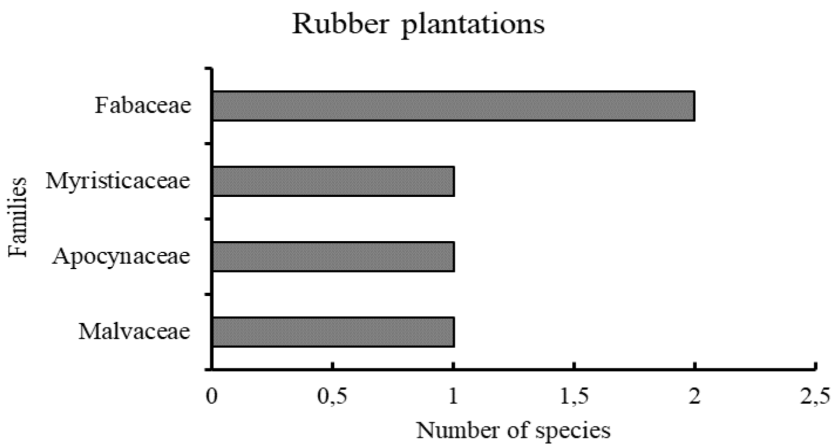
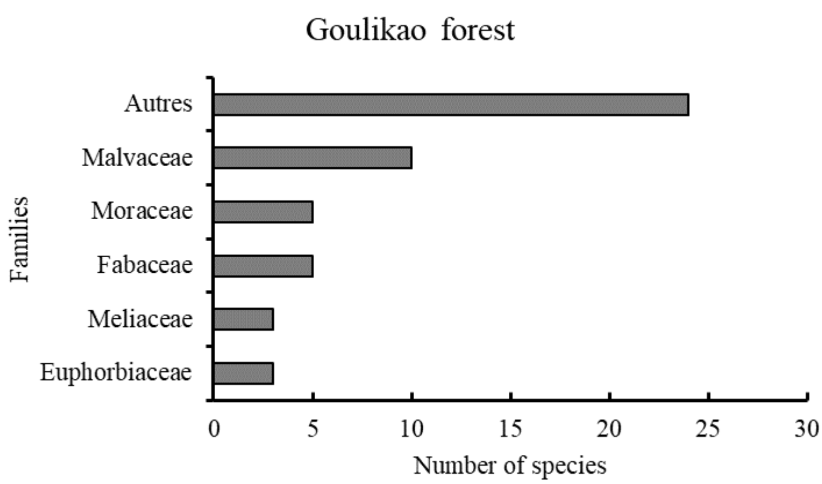




**Figure 4:** Distribution of species according to the different families in forests and rubber plantations.



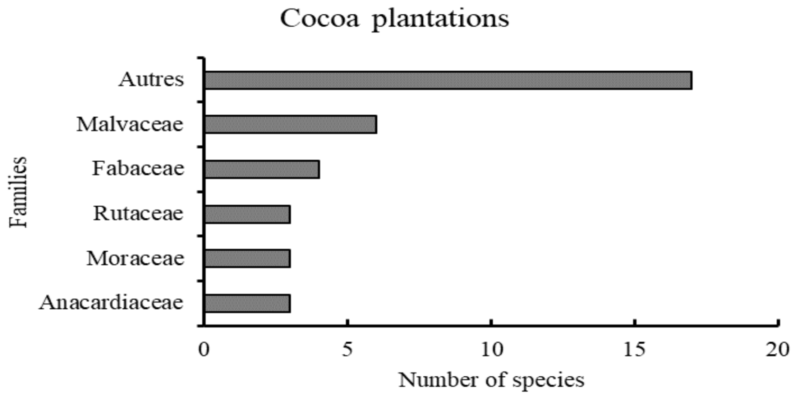



**Figure 5:** Distribution of species according to the different families in forests and cocoa plantations.

**Table 4:** Species richness according to phytogeographical distribution and specific ecological status in the rubber (A) and cocoa (B) landscapes.

| **Habitats** | **MP** | **mP** | **mp** | **GCW** | **i** | **EN** | **NT** | **VU** |
|---|---|---|---|---|---|---|---|---|
| Azagny forests | 10 | 13 | 29 | 5 | 0 | 2 | 1 | 6 |
| Rubber 7 years | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Rubber 15 years | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| Rubber 30 years | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| Goulikao forests | 12 | 12 | 27 | 2 | 2 | 0 | 1 | 4 |
| Cocoa 7 years | 1 | 3 | 9 | 0 | 3 | 0 | 0 | 1 |
| Cocoa 15 years | 7 | 9 | 4 | 0 | 5 | 0 | 1 | 2 |
| Cocoa 30 years | 1 | 6 | 6 | 0 | 5 | 0 | 0 | 1 |

MP: Megaphanerophytes; mP: Mesophanerophytes; mp: microphanerophytes; GWC: Endemic taxon to the forest block in western Togo; i: Introduced or cultivated taxon; EN: Endangered; VU: Vulnerable taxon; NT: Near Threatened.

**Table 5:** Tree density and basal area of forest and companion tree species in different plantations.

| | **Landscapes** | **Land use type** | **Companion tree density (Trees.ha$^{-1}$)** | **Companion tree basal area (m$^2$.ha$^{-1}$)** |
|---|---|---|---|---|
| A | Rubber | Forest | 1551.7 | 39.38 |
| | | Rubber 7 years | 1.7 | 0.05 |
| | | Rubber 15 years | 5.0 | 0.48 |
| | | Rubber 30 years | 1.7 | 0.10 |
| B | Cocoa | Forest | 1228.3 | 22.7 |
| | | Cocoa 7 years | 51.7 | 1.7 |
| | | Cocoa 15 years | 56.7 | 11.7 |
| | | Cocoa 30 years | 81.7 | 6.3 |

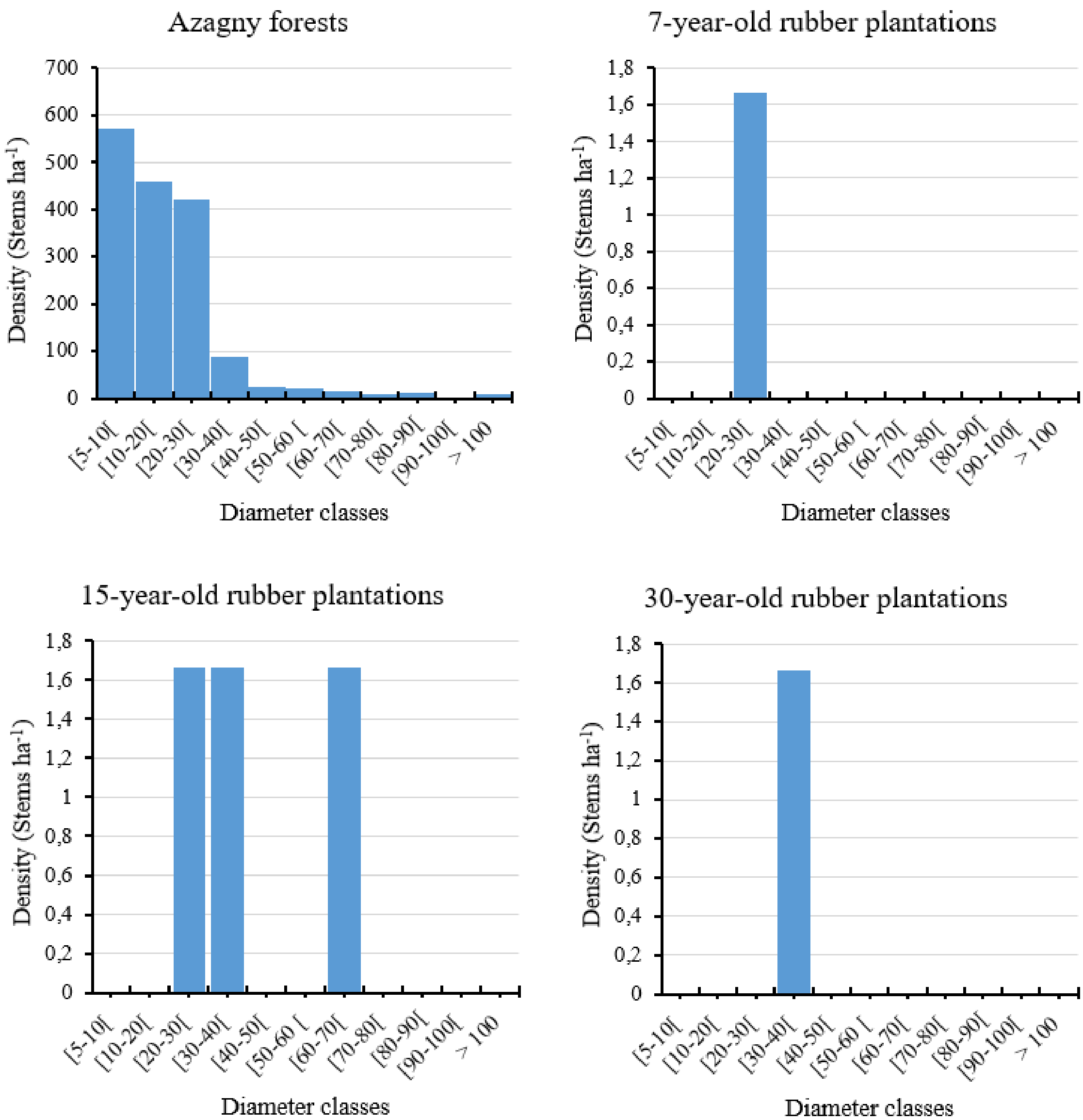



**Figure 6:** Distribution of stems density according to diameter classes in land use types across the rubber landscape.

## DISCUSSION

### Impact of cocoa and rubber cultivation on tree species diversity

The floristic diversity of forest varies significantly following the conversion of forests to cocoa or rubber plantations. The average number of species as well as the Shannon index indicate a drop in floristic diversity in plantations. Indeed, changes in forest cover through the establishment of agroecosystems are one of the primary drivers of the loss of floristic diversity. Even though natural environment is deeply modified due to the land clearing, regular weeding operations to prevent weed and other tree communities from developing and becoming potential competitors, some tree species persist in the cocoa and rubber plantations.

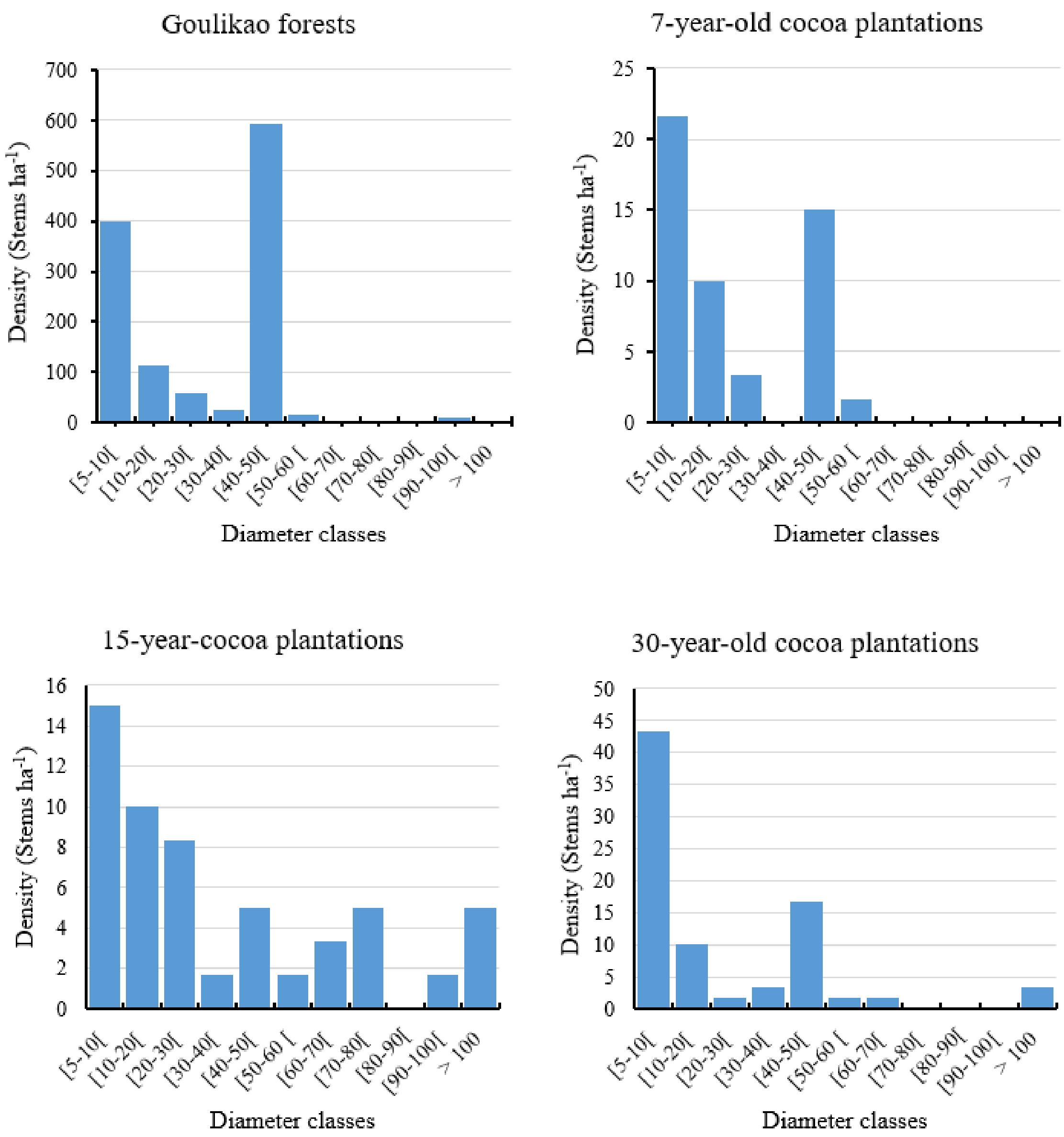



**Figure 7:** Distribution of tree density according to diameter classes in land use type of the cocoa landscape.

However, companion tree diversity did not vary significantly with age. This demonstrates that the presence of companion tree species is subject to the willingness of farmers' choice based on the need for shade, and the ecological value, nutritional and economic value of the associated tree species. This result corroborates the observations provided by Kpangui et al. (2015) and Adou Yao et al. (2016) in cocoa orchards of the forest-savanna transition zones in central Côte d'Ivoire. According to Adou Yao et al. (2016), the knowledge of useful services by local communities leads to the maintenance and preservation as well as the introduction of diverse species in cocoa plantations. The works of Zequeira et al. (2021) and Schroth and Harvey (2007), also underlined this fact. The species richness (39 species) recorded in the three categories of cocoa plantations for a total of 1,200 m² is roughly similar to that recorded in Mexico in the cocoa plantations of the locality of Soconusco with a value of 35 species for 13 plots of 1,000 m² each (Suárez-Venero et al., 2019). In cocoa plantations in south-west Côte d'Ivoire, an average of 32 tree species were also recorded. Companion tree species to rubber were spared to provide shelter to farmers and their families or to mark the boundary between two neighboring plantations. Following their work in the Listed Forest of Téné and its surroundings in the department of Oumé (Côte d'Ivoire), Sangne and Kouassi (2015) pointed out that cocoa plantations are more diversified than teak monocultures, confirming once again the fact that monocultures are less diverse, in terms of companion tree species than agroforestry systems (Niether et al., 2020).

On the other hand, Sørensen's coefficient indicates that there is a significant dissimilarity in the floristic composition of cocoa and rubber plantations according to age and between forest islands and plantations. These results confirm that tree species are spared or associated with crops according to farmers' needs. In cocoa plantations, farmers prefer exotic fruit species (*Persea americana*, *Citrus* spp.) and a few indigenous species with high economic value such as *Irvingia gabonensis* (Irvingiaceae) revealing that tree are integrated on purpose in cocoa plantations (Adou Yao et al., 2016; Kouadio et al., 2021). Also, the floristic composition of the forest before the establishment of the cocoa plantation could justify the variation in its floristic composition. Nevertheless, the mature (15-year-old) and old (30-year-old) cocoa plantations were relatively close in terms of their floristic composition. The observed similarity between the 7-year-old and 30-year-old rubber plantations in terms of the floristic composition, could be linked to fact that both agroecosystems displayed 1 tree species each that is *Piptadeniastrum africanum* (Fabaceae) for the 7-year-old and *Pycnancthus angolensis* (Myristicaceae) for the 30-year-old rubber plantations. This similarity could be explained by the fact that the rubber plantations are subject to the same management practice. Thus, the strict monoculture practiced in rubber cultivation since its introduction in Côte d'Ivoire resulted in less diversified rubber tree landscapes throughout the country (Penot and Ollivier, 2009). This monoculture is characterized by regular weeding and the removal of any trees that can potentially become a competitor with rubber trees for soil nutrients and water. Nevertheless, recent agroforestry practices adopted in Côte d'Ivoire are restricted to the immature period of the rubber trees, either to reduce the effort and cost of weeding or to generate additional income before the latex production period (Obouayeba et al., 2006). In that case, the associated plant species are generally annual plants, whose growth is limited by the shade created by the rubber canopy from 5$^{th}$ or 6$^{th}$ year of cultivation. The findings of Tata (2011) reflected these results by highlighting that rubber monocultures had the lowest floristic diversity and had no companion tree species.

The presence of endemic and special-status species in cocoa plantations appears to the outcome of the sensitization work carried out by the “Société de Prestation de Service pour l’Agriculture Biologique Durable” (SIPRES) to transition to cocoa-based agroforestry to increase the resilience of the plantations to the effects of climate change by maintaining shade and improving soil quality. It does so by encouraging the production of nurseries of local forest species such as *Irvingia gabonensis*, *Ricinodendron heudelotii*, *Terminalia ivoiriensis* in view of their introduction in monoculture cocoa plantations. Indeed, cocoa-based agroforestry systems have long been the subject of studies to determine which species are compatible with the cocoa tree (Gala Bi et al., 2017; Sanial, 2018). Similar cases have been reported in Southern Cameroon multistrata cocoa farms where most species had a special status (Nomo et al., 2008). In addition, fruits tree species are introduced into cocoa farms by farmers to supplement their income and for their consumption. Also, some species, such as *Milicia excelsa*, have been spared by the farmers to provide income from the timber industry. Endemic species and species with a particular status present in cocoa plantations indicates that cocoa-based agroforestry systems play an important role in biodiversity conservation. These tree species that have become rare or vulnerable find an appropriate setting for their conservation and this approach may contribute to reducing anthropogenic pressures on residual forests (Sanial, 2018). Cocoa plantations are the most diverse environments compared to rubber plantations.

**Cocoa and rubber plantations, habitats with varied stand structure**

Both cocoa and rubber tree plantations are less structured than reference forests, which are known to be multi-stratified environments as a result of land forest conversion into perennial tree crops. Cocoa plantations are more structured than rubber plantations with a higher number of associated trees. The low stem density of companion tree species in rubber plantations could be due to the type of farming system adopted and the biological structure of the species cultivated. Indeed, rubber is a fast-growing and light-demanding plant. Conversely, cocoa is an understorey plant that tolerates shade and therefore is a good candidate for agroforestry system wanted by several producers, anxious to perpetuate the management knowledge acquired over the centuries (Kouadio et al., 2018; Sanial, 2018). The association of rubber trees with others tree species could elicit greater competition for light as well as for nutrients and be a possible source of disease. Also, the presence of shade under the rubber trees could inhibit the growth of some forest species. However, the presence of forest species found in rubber plantations reveals the persistence of some of them which are fast growing species. Furthermore, the presence of the species *Rauvolfia vomitoria* in rubber plantations could be the result of an opening in the canopy due to a windfall. On the other hand, the density of companion trees found in 7-year-old cocoa plantations was higher than in 8-year-old cocoa plantations located in the locality of M'Brimbo in east-central Côte d'Ivoire as shown by Gala Bi et al. (2017). They inventoried an average of 26 tree.ha$^{-1}$ while 7-year-old cocoa plantations of Goulikao harbored 36 tree.ha$^{-1}$ of companion species. This difference could be explained by the fact that all types of cocoa agroforestry systems (unshaded, low, medium and dense shade systems) were taken into consideration in Gala Bi et al. (2017) works.

The high number of large-diameter species (40–50, 70–80 and ≥ 100 cm) in 15-year-old cocoa farms could be due to the presence of spared tree species in plantations. The absence of large trees in 7-year-old cocoa farms indicates that the largest trees were removed during the establishment of plantation. The spared medium diameter trees (10–40 cm) and introduced trees grow to large diameters during the following 15 years. The reduction in the number of large-diameter trees in 30-year-old cocoa plantations is a result of selective removal of trees in this diameter class by farmers when older cocoa farms present a need for shade reduction (Kpangui et al., 2015; Sonwa et al., 2017; Kouadio et al., 2018). Shade may be considered as a potential source of diseases that could negatively influence the growth of cocoa trees especially when its management is poorly controlled (Kouadio et al., 2018; Sanial, 2018). In Goulikao, large trees were, for the most part, located towards the extremities of the plantations and met the need for shade for cocoa trees. Our results corroborated those of Konan et al. (2011) who revealed that individuals of medium circumference (10–40 cm) were most represented in young cocoa plantations (1–5 years) in the Goulikao locality (Kpangui et al., 2015; Sonwa et al., 2017).

As for rubber tree plantations, associated trees were within the range of 20–30 cm class diameter. This result reveals that some trees associated with rubber trees can be the result of natural regeneration. The management of this regenerated tree can participate in the diversification of rubber production systems.

**Conservation potential of cocoa and rubber plantations**

The decline in plant diversity is more marked in rubber plantations than in cocoa plantations. Indeed, compared to rubber plantations, cocoa plantations recorded a high number of associated trees owing, certainly, to the cropping practices and the ecology of keystone species that is different in both cases. Although subjected to slash and burn during their establishment, cocoa trees known as understorey species can cope with the presence of others, which is not the case for rubber. The presence of companion trees underlines the difference between the cocoa and rubber cultivation systems. Since its introduction in Côte d'Ivoire, as in many West African countries, cocoa farming has been practiced under the agroforestry system (Asase et al., 2009; Sonwa et al., 2017). These systems range from the simple to the complex and produce multiple ecosystem services. The introduced tree species have edible, medicinal, artisanal and ecological values (Zequeira et al., 2021). In contrast, in rubber cultivation, the associated crops are usually herbaceous. The latter are maintained until the 3rd and 4th years of cultivation, which corresponds to the stage of deployment of the crown of the rubber trees, and disappear under the effect of shading, unfavorable to their growth. However, the presence of the five tree species in the rubber plantations revealed that it is possible to consider an association of rubber with forest species as well as perennial crops. The rubber tree-based agroforestry systems found in Asia and Latin America, under the initiative of small producers for several decades, are the proof (Penot and Ollivier ,2009). In Southeast Asia, rubber was directly introduced into secondary forests in the form of a complex agroforestry system called "jungle rubber". In recent decades, so-called "improved" agroforestry systems have been initiated after the loss of forest due to the attempted monoculture under the initiative of the state (Jongrungrot et al., 2014). On this basis, rubber trees have been associated with both forest and fruit species. Also, in Côte d'Ivoire for the past twenty years, experiments have been conducted in the main rubber production areas located in the south-west and south-east regions by Kéli et al. (2005) and Snoeck et al. (2013). These highlighted the possibility of introducing food crops or perennial species in intercropping with rubber trees during the first 3 or 4 years of planting, without endangering the rubber trees (Penot and Ollivier, 2009; Warren-Thomas et al., 2020). Penot and Ollivier (2009) emphasized that farmers consulted in Thailand and Indonesia did not observe significant decrease in rubber production in agroforestry systems compared to rubber monocultures. In addition, rubber association with cocoa or coffee in Côte d’Ivoire did not show any negative impact on the level of rubber tree production in a wide-spaced system (10 and 16 m) as shown by Kéli et al. (2005) and Snoeck et al. (2013). Testing these practices in farmer fields for promotion along with widespread campaigns for effective adoption could be a better strategy to combat the loss of floristic diversity in rubber cultivation. The current pledge of the “Coffee and cocoa board” of Côte d’Ivoire to integrated 60 million of companion trees in cocoa plantations by 2030 is a good commitment which can pave the way for a bright future for the cocoa sector.

However, it is noteworthy that cocoa-based agroforestry systems are threatened by "full sun" cultivation, which is increasingly developed by farmers (Assiri et al., 2009; Konan et al., 2011; Cissé et al., 2016; Sanial, 2018). During the installation of cocoa plantations, some large trees are removed for banana trees and some local medicinal species. New attempts to introduce trees are encouraged in view of the evolution of climate change in order to move, for most plantations, from simple agroforestry systems to mixed or complex agroforestry systems. The cropping system is therefore very decisive in the modeling and conservation of floristic diversity.

**Conclusion**

This study revealed that the diversity of tree species associated with cocoa in plantations, although lower than that of forests, is much higher than the diversity of tree species associated with rubber in plantations. Cocoa plantations harbored 39 tree species against 5 tree species in rubber plantations. The 15- and 7-year-old cocoa plantations are home to 4 and 2 special-status species, respectively. The density of stems of associated trees increases relatively with the age of plantations to reach 81.67 trees.ha$^{-1}$ in 30 year-old cocoa plantations. However, the basal area was higher in 15-year-old cocoa plantations. Trees recorded in rubber plantations were large trees with DBHs varying between 20 and 70 cm, while in cocoa plantations, trees of small and medium diameters are the most abundant. Moreover, the floristic diversity did not change significantly according to the age of the plantations in both landscapes. This revealed almost no similarity between them according to Sorensen's coefficient of similarity. The producers' management practices were responsible for the great difference observed between the floristic diversity of cocoa plantations and rubber plantations. As such, management practices could be an important factor for improving the management of these agroforestry systems, with a view to the sustainable conservation of plant diversity in cropping systems.

**COMPETING INTERESTS**

The authors declare that they have no competing interests.

**AUTHORS' CONTRIBUTIONS**

ANLA guided the methodological approach proposed by EJT, ANLA and CYAY. NOY provided assistance to tree species identification. ANLA analysed the data and wrote the original draft of the proposed manuscript. V-PGK, NEJA, ASFK, NOY, EJJT and CYAY review and editing the manuscript. All authors read and approved this manuscript.

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