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Reforestation based *Tectona grandis L.f.* and conservation of floristic diversity in the department of Boundiali, north of Côte d'Ivoire

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Abstract

The north of Côte d'Ivoire, which is mainly dominated by savanna, has been the subject of few floristic studies. The aim of this study is to characterize the flora associated with teak plantations in the department of Boundiali. Data collection based on floristic inventories combined surface survey methods with the so-called itinerant method. The analyses were carried out on 10,000 m^2 plots. They included teak plantations less than 15 years old on the one hand and teak plantations more than 15 years old on the other. The study thus made it possible to show greater floristic diversity in teak plantations less than 15 years old. The study also revealed that the number of species in teak plantations decreases as the age of the plantation increases. Furthermore, by harboring five vulnerable species and large-diameter species, teak plantations contribute to the conservation of wood resources in northern Côte d'Ivoire. The finding is that, apart from teak, various plant species are growing in the plantations. The difficulty observed is maintaining the different species in teak plantations over the years. To achieve this, awareness campaigns targeting teak plantation owners appear to be a first step toward reversing the trend.

Keywords: Floristic Diversity; Structural Diversity; Teak Plantation; Associated Flora; Boundiali

1. Introduction

Human activities are the main cause of forest ecosystem degradation in Côte d'Ivoire [1]. This anthropization poses a serious threat to the future of the populations that depend on these forests due to the deterioration of the services they provide. Côte d'Ivoire, which had a forest cover of more than 16 million hectares in the 1900s, now has only 2.97 million hectares [2]. Faced with this erosion of its forest cover, the country embarked on extensive reforestation programs at a very early stage. As part of this effort, teak (*Tectona grandis* Linn.f.) became the main species used for reforestation in Côte d'Ivoire, accounting for around 90% of the area planted in 1999 [3]. 's work [4] reveals that the first plots planted with teak date back to 1929 in the Bouaké region in central Côte d'Ivoire, in the sub-Sudanese savannahs. The primary reasons for introducing teak into the country were to supply energy to the steam trains on the Abidjan-Ouagadougou line and to build timber reserves for the construction of railcars and service wood for railroad ties [5].

Teak cultivation has thus flourished since its introduction in the northern part of Côte d'Ivoire, which includes the department of Boundiali. Teak plantations remain both on rural land and on permanent state-owned land [6]. However, unlike the vegetation of the country as a whole, which has been the subject of several studies, including the work of [7] , and [8], teak plantations remain poorly documented in terms of the floristic and structural diversity of plant species other than teak found there. The overall objective of this study is to characterize the flora of teak plantations in the

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department of Boundiali. Specifically, it aims to (1) analyze the diversity of the flora in teak plantations; (2) assess their conservation value; and (3) determine the structure of the floristic species associated with teak trees.

2. Methodology

2.1. Presentation of the study area

The department of Boundiali, which belongs to the Sudanese sector, is located in the northern part of Côte d'Ivoire, more precisely in the Bagoué region between longitudes 6°50'0" W and 6°0'0" W and latitudes 9°0'0" N and 10°0'0" N (Figure 1). The departments neighboring Boundiali are Kouto and M'Bengué to the north, Kani and Dianra to the south, Korhogo to the east, and Madinani and Seguélon to the west (Figure 1). The climate in this area is tropical subhumid, characterized by a dry season from November to May and a rainy season from June to October [9]. The relief of the Boundiali department is dotted with plains, inselbergs, and mountains of volcanic origin and features a vast series of plateaus from north to east, defined as a peneplain with an altitude ranging from 400 to 500 m [10]. The vegetation is characterized by dry open forests, savannas (wooded, arboreal, and shrubby), a few pockets of dense dry forest, and gallery forests [10]. The population consists of the Senufo people (approximately 75% of the population living in the north and southeast), the Malinke people, estimated at 20%, who live in the center and west of the department, and the Peul people [6]. Socio-economic activities are mainly focused on agriculture and livestock farming [11].

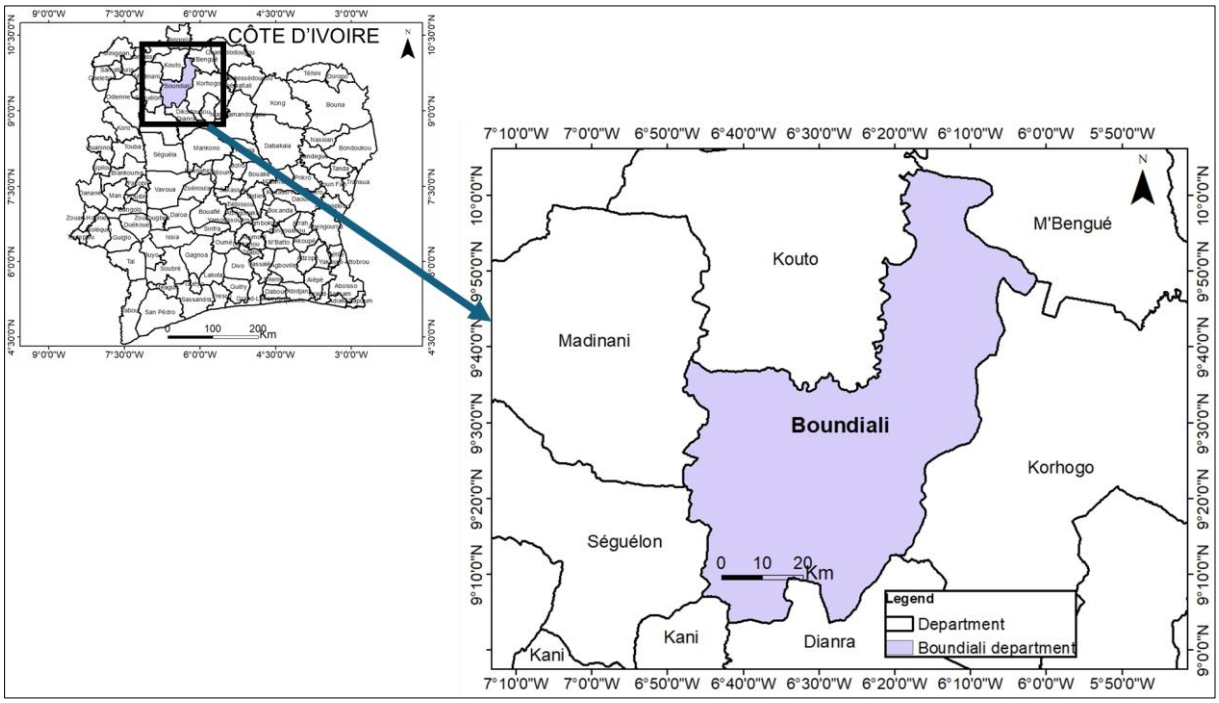

Figure 1 Presentation of the study area

2.2. Data collection

The forest inventory is the main method used to carry out this study. To do this, sampling sites were selected using the stratified sampling method. This method involved determining the age of teak plantations in the department of Boundiali based on a survey, as the age of teak plantations is a factor that can affect the conservation of biological diversity. The teak plantations were therefore subdivided into two classes: those less than 15 years old and those over 15 years old, in order to determine the impact of the age of the plantations on biodiversity conservation. Next, floristic inventories were carried out in these environments using two complementary floristic survey methods: surface surveys and itinerant surveys. A total of six (06) plots were inventoried, including three (03) plots of 1 ha each (100 m x 100 m) per environment. Sub-plots were then set up in each of the plots according to the age of the plantations [12]. For plantations less than 15 years old, the size of the sub-plots was 600 m^2 (20 m x 30 m). For plantations older than 15 years, the sub-plots were 900 m^2 (30 m x 30 m) [12]. The information collected during the inventory includes the name of the species, the diameter at breast height (DBH), and the height of individual woody plant species. In order to obtain a more comprehensive view of the flora in the area, mobile inventories were used to supplement the surface surveys. This method consisted of noting the presence of all species not found in the plots.

2.3. Data processing and analysis

The identification of the plant species inventoried followed the APG IV nomenclature. The analyses focused on the diversity of plant species associated with teak plantations in the department of Boundiali and the conservation value of these species. The study of plant diversity consisted of determining the floristic and structural diversity of species associated with teak plantations. The assessment of floristic diversity was based on alpha diversity, which corresponds to the diversity within a site estimated by floristic richness [13], species diversity (Shannon-Weaver diversity index) and evenness [14], which quantifies the heterogeneity of a site's biodiversity.

The Shannon index (H') is expressed by the following equation:

$$H' = -\sum_{i=1}^{s} \left(\frac{n_i}{N}\right) \ln \left(\frac{n_i}{N}\right)$$

Where $n_i$is the number of individuals of species i and N is the total number of individuals of all species. The values of this index vary between 0 and LnS, which is the maximum diversity (S being the total number of species in the environment). When the population is composed of a single species, H' is equal to 0, while for a flora with a high number of species, it tends towards LnS.

Piélou's evenness index (E) represents the ratio of H' to the theoretical maximum diversity (LnS) in the population. This index varies from 0 to 1. The closer the value of E is to 1, the more evenly the individuals in the environment are distributed among the species that compose it. However, low values correspond to the presence of a number of rare species or a small number of dominant species [15]. It is calculated using the following equation:

$$E = \frac{H'}{LnS}$$

The conservation value of teak forests has been assessed based on the chorology and conservation status of plant species. This conservation status has been determined through the presence of species with special status ([16, 17]. Based on criteria of rarity of certain taxa at the national, regional, or international level, authors such as [8, 13, 18, 19] have proposed lists of species that are threatened with extinction due to anthropogenic activities. Thus, the threatened species of the Boundiali teak forest flora were listed by comparing the floristic lists with those of [8, 13, 18, 19].

Chorology is defined as the study of the geographical distribution of living species [20] Thus, the species recorded in the teak forests were classified according to their geographical distribution (Table 1).

Table 1 Chorological affinities of species

Abbreviation	Full name	Authors
GC	Species of the Guinea-Congo region	[21]
GCW	Species endemic to West African forest blocks	
HG	Species endemic to the forests of the Upper Guinea phytogeographic region	
SZ	Sudano-Zambesian species	
GC-SZ	Transitional species between Guineo-Congolese and Sudano-Zambesian regions	
i	Exotic or introduced species	
SZ	Species from the Sudano-Zambesian region	
GCi	Endemic species of Côte d'Ivoire	
NEO	Neotropical	[22]
PAN	Pantropical	

The conservation value of teak forests was determined based on the presence of species with special status [17]. Based on criteria relating to the rarity of certain taxa at the national, regional, or international level, authors Aké-Assi [8, 13, 18, 19] proposed lists of species that are threatened with extinction due to human activities. Thus, the threatened species of the Boundiali teak forest flora were listed by comparing the floristic lists with those of Aké-Assi [8, 13, 18, 19].

The structure of the vegetation was analyzed based on the density and distribution of individuals in diameter and height classes [23].

Density (D) represents the number of individuals per unit area. It is obtained by dividing the total number of individuals in the sample (N) by the sampled area (S). It is expressed as the number of individuals per hectare. It is calculated using the following formula:

$$D = \frac{N}{S}$$

Diameter structure, also known as horizontal structure, is a parameter used to characterize a forest stand that studies the arrangement and distribution of individuals along the horizontal plane. The distribution of stems by environment was analyzed by measuring the circumferences of all trees and shrubs greater than or equal to 10 cm using a tape measure. Following the work of [24] , we grouped the individuals into seven diameter classes: [5; 15[; [15; 20[; [20; 35[; [35; 50[; [50; 65[; [65; 80[and [80; 95[.

The distribution of individuals by height class is based on the distribution of the number of stems per height class or the height structure. It provides information on the vertical stratification of the stand. Individuals of each species were classified according to their height, following the proposal in [14], into six (6) classes: I (0 to 2 m), II (2 to 4 m), III (4 to 8 m), IV (8 to 16 m), V (16 to 32 m) and VI (> 32 m).

3. Results

3.1. Floristic diversity of species associated with teak plantations

Floristic inventories carried out in the teak plantations of the Boundiali department have made it possible to determine the species richness associated with the environment. In fact, there are 193 individuals spread across 21 species, 20 genera, and 12 families that are generally associated with teak trees (Table 2). In teak plantations less than 15 years old, we note the presence of 123 floristic individuals divided among 20 species, 17 genera, and 12 families. In plantations more than 15 years old, we note the presence of 70 floristic individuals divided among 12 species, 11 genera, and 7 families (Table 2).

Of the 193 tree species individuals that were recorded, three species in particular were predominant. In order of abundance, these are *Lophira lanceolata* Van Tiegh. ex Keay with 25 individuals, *Afzelia africana* Sm. ex Pers. with 23 individuals, and *Sarcocephalus latifolius (*Sm.) E. A. Bruce with 21 individuals, representing 25%, 23%, and 11% of all species inventoried, respectively. In plantations less than 15 years old, the most abundant species are *Lophira lanceolata (*20%), *Afzelia africana (*14%) *and Mitragyna stipulosa* (DC.) Kuntze (10%). In contrast, in plantations over 15 years old, the dominant species are *Afzelia africana (*27%), *Sarcocephalus latifolius* (14%) and *Daniellia oliveri* (13%).

The values of the Shannon diversity index and Pielou's evenness index are shown in Table 2. In teak plantations less than 15 years old, the Shannon and Evenness indices are 1.63 bits and 0.12, respectively. In teak plantations over 15 years old, the Shannon index is 1.37 and the Piélou index is 0.07. The latter reflects an unequal distribution of individuals among species.

Table 2 Number of individuals, species, genera, and families, and diversity indices in teak plantations

Environment	Teak plantations < 15 years old	Teak plantations ≥ 15 years old	Total
Number of individuals	123	70	193
Number of species	20	11	21
Number of genera	17	11	20
Number of families	12	07	12
Shannon index	1.63	1.37	
Pielou's equity index	0.12	0.07	

3.2. Structural diversity of species associated with teak plantations

Per hectare, teak plantations in the department of Boundiali are home to an average of 49 individuals of species other than teak. In addition, there is a large difference between the density of individuals of species found in teak plantations less than 15 years old and those in teak plantations more than 15 years old (Figure 2). In fact, in teak plantations less than 15 years old, the average density of tree species individuals counted is 63 per hectare. In contrast, we counted only 35 tree species individuals per hectare in teak plantations over 15 years old.

The diameters of the tree species inventoried in the teak plantations range from 5 to 108 cm, with an average of 38 cm. In addition, individuals with diameters between 35 and 50 cm and between 20 and 35 cm are the most abundant in teak plantations over 15 years old, with respective frequencies of 41% and 25%. Large-diameter trees (d > 65 cm) account for only 12% of all individuals. However, in young plantations, individuals with diameters between 5 and 15 cm and then between 20 and 35 cm are the most abundant. Large-diameter trees (d > 65 cm) account for only 4% of all individuals of the species (Figure 3).

The heights of the inventoried plant species vary between 0 and 17 m. In teak plantations less than 15 years old, trees between 2 and 4 m tall are the most numerous, accounting for 49% of the total. They are followed by trees between 4 and 8 m tall (36%). In teak plantations over 15 years old, the predominant heights are between 4 and 8 m and between 8 and 16 m. These classes represent 55% and 35% of the trees inventoried in this type of plantation. The least abundant individuals are those between 0 and 2 m (Figure 4).

Figure 2 Density of tree species individuals by age class in teak plantations

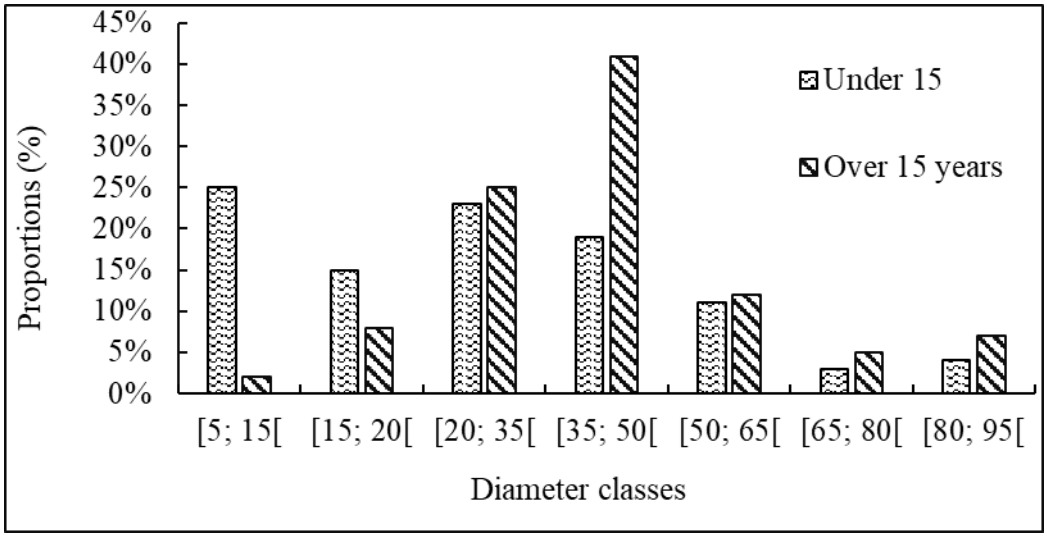

Figure 3 Distribution of diameter classes by age group in teak plantations

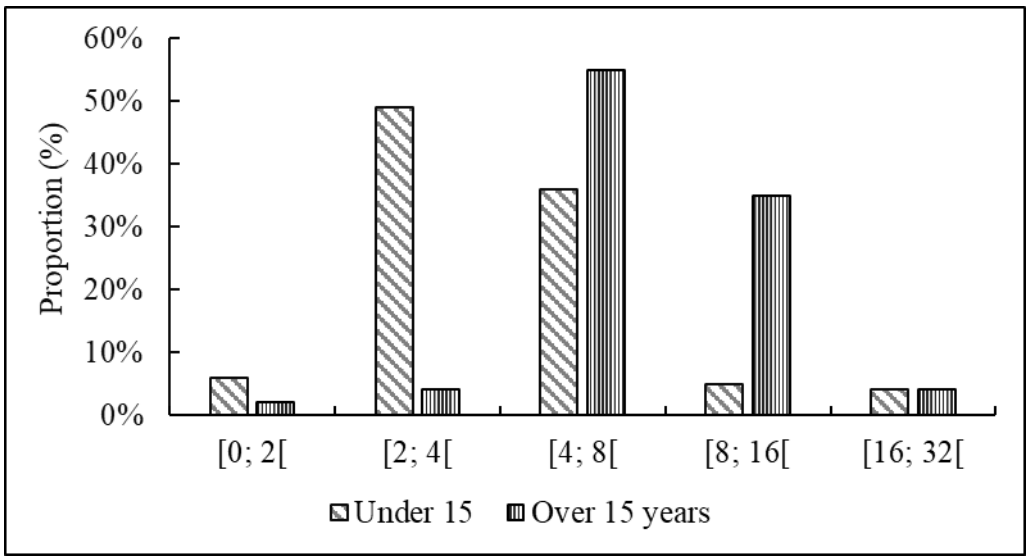

Figure 4 Distribution of the number of individuals recorded by height class

3.3. Conservation value of teak plantations

The species inventoried in the teak plantations of the Boundiali department consist of species from the dense humid forest of the Guineo-Congolese (GC) domain, the Sudano-Zambesian (SZ) region, the Guineo-Congolese and Sudano-Zambesian (GC-SZ) transition regions, as well as introduced or cultivated species (i). The most abundant species are those from the Sudano-Zambesian region (50% of species) and those from the Guineo-Congolese and Sudano-Zambesian regions (24% of species). The least abundant species are introduced species, representing 3% of the total. Both teak plantations less than 15 years old and those over 15 years old contain species belonging to the four geographical areas mentioned above (Figure 5). Furthermore, in both environments, the most abundant species are those from the Sudano-Zambesian region, with frequencies of 53% and 55% for young and old plantations, respectively. They are followed by species from the Guineo-Congolese and Sudano-Zambesian regions. Introduced species are the least abundant in both environments.

Of the 21 species inventoried in the plots, 7 species, or 31.81%, have a special status. Among these species, 5, namely Afzelia *Africana* Smith ex Pers*, Khaya anthotheca* (Welw.) DC., *Khaya ivorensis A. Chev.*, *Nauclea diderrichii* (De Wild. & T. Durand) Merr. and *Vitellaria paradoxa C.* F. Gaertn. are vulnerable. They represent 23% of all species. The results also show one endangered species (*Pterocarpus erinaceus* Poir.) and another near threatened species (*Mitragyna stipulosa (*DC.) O. Ktze) (Table 3). It appears that 70.68% of species with special status are found in teak plantations less than 15 years old, compared to 29.32% in teak plantations more than 15 years old.

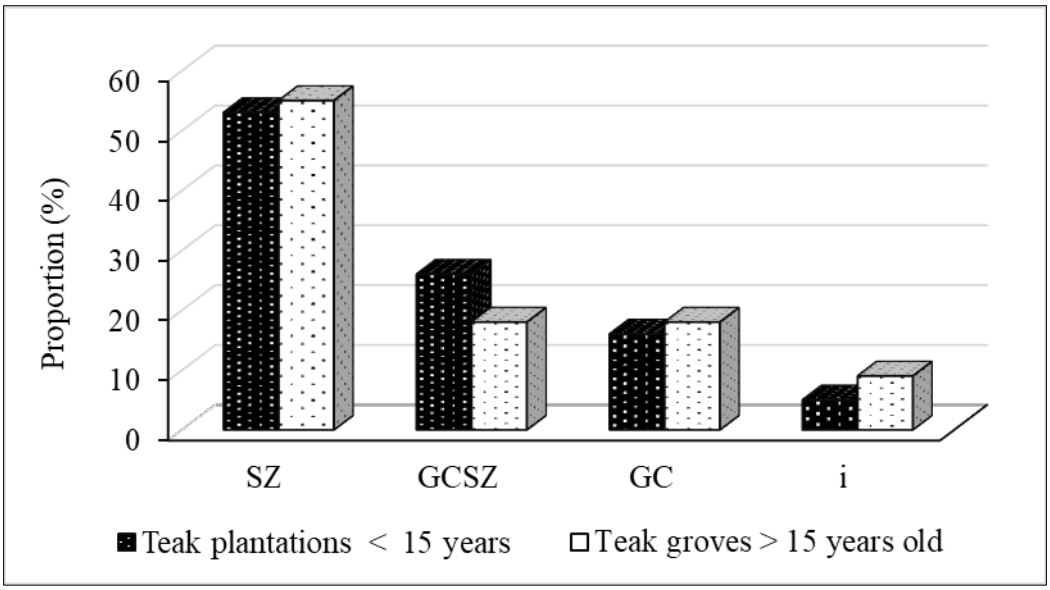

Figure 5 Phytochory of species inventoried in teak plantations

Table 3 Species with special status inventoried

No.	Species	Plantation less than 15 years old	Over 15 years old	IUCN status
1	*Afzelia Africana* Smith ex Pers	X		VU
2	*Khaya anthotheca* (Welw.) DC.	X		VU
3	*Khaya ivorensis* A. Chev.	X		VU
4	*Mitragyna stipulosa* (DC.) O. Ktze	X		NT
5	*Nauclea diderrichii* (De Wild. & T. Durand)		X	VU
6	*Pterocarpus erinaceus* Poir.	X	X	EN
7	*Vitellaria paradoxa* C. F. Gaertn.		X	VU

VU = vulnerable; NT = near threatened; EN = endangered

4. Discussion

4.1. Diversity of species associated with teak plantations

Our study identified 21 species in the teak plantations of the Boundiali department. These tree species were also discovered by [10] in their work on the Boundiali department. According to these authors, the vegetation of the Boundiali department is characterized by the presence of dense dry forest, gallery forest, dry open forest, wooded savanna, and shrubland. Each of the species encountered belongs to one of these types of vegetation formation. This is the case, for example, with *Afzelia africana, Lophira lanceolata* Van Tiegh. ex Keay, *Sarcocephalus latifolius (*Sm.) Bruce, etc., in the Sudanese zones of Côte d'Ivoire [25], Benin [26], Cameroon [27], Mali [28], etc. The abundance of these species in the environment could be due to their ecology, which allows them to adapt better to these areas. Contrary to our findings, *Cedrela odorata, Gmelina arborea*, and *Ficus exasperata* are the most abundant species in the Téné Forest Reserve located in central Côte d'Ivoire. The predominance of these species is due to their ecology, which allows them to thrive in both dry and wet areas [29]. In addition, this number of species indicates low biodiversity conservation in the region, unlike the Téné Classified Forest located in central Côte d'Ivoire, where 158 plant species have been recorded . As for the Atlantic department in southern Benin, 444 species have been recorded in the teak plantations. This variable number of species is thought to be due to the original plant formations with varying densities of plant species on which the teak trees were planted.

Analyses have revealed that the older the plantations, the less diverse they are. This result can be explained by the fact that several native species, sometimes considered useless, are cut down before teak is planted. The remaining trees are gradually cut down by the agents in charge of managing these areas for the development of teak, which is the species to be exploited [30]. In addition, the rapid growth of this species could hinder the development of several other native species in its undergrowth that are less tolerant of shade due to their need for light to grow.

The Shannon and Pielou's equitability indices, which are close to 0, clearly demonstrate the dominance of a small number of species (*Lophira lanceolata*, *Afzelia africana*, and *Sarcocephalus latifolius*) over the others. The dominance of these three (03) species can be explained by their predominance in the study area and their use by the populations of northern Côte d'Ivoire. For example, *Lophira lanceolata* is an excellent source of firewood, *Afzelia africana* is an excellent source of timber, and *Sarcocephalus latifolius* is used in traditional medicine [31]. Species diversity decreases as plantations age, which is common in all agricultural operations and has also been revealed by several authors, including [29] and [32]. Furthermore, the largest diameters are found in teak plantations over 15 years old, unlike those under 15 years old, which have a low number of large-diameter species. The predominance of relatively large diameters in teak plantations over 15 years old can be explained by the relatively long time it takes for trees to grow. In addition, various silvicultural practices, especially thinning, are a factor in tree growth [33].

The low diversity of native species in teak plantations reflects the destruction of a large number of species that could provide several ecosystem services for the well-being of populations. Indeed, several species could be used by populations in several areas such as food, medicine, etc. These secondary plant formations are also conservation areas for several species with special status.

4.2. Conservation value of teak plantations

In terms of chorology, the study highlights a predominance of species (51%) belonging to the Sudano-Zambesian zone. Sudano-Zambesian species are abundant because this is their preferred habitat. This is the case with *Daniellia oliveri*, a species typical of savanna areas. It is a tree with a cylindrical trunk, capable of reaching large diameters, notable for its smooth, light-colored bark, which exudes a fragrant oleoresin [34]. In addition, trees also have socio-cultural value for local populations. This is the case with *Vitellaria paradoxa* and *Parkia biglobosa.* In the customs of the peoples of this area of Côte d'Ivoire, it is strictly forbidden to cut them down, under penalty of sanctions. There is also the fact that the fruits of these trees (shea and néré) are part of the dietary habits of the peoples of the area. *Daniellia oliveri* is used in local medicine. *Afzelia africana* and *Pterocarpus erinaceus* are highly prized forest species. For example, lingué is widespread in the northern part of Côte d'Ivoire in dense semi-deciduous forests [35]. It is a timber generally used in exterior carpentry, parquet flooring, heavy construction, and furniture manufacturing [34]. In the study area, *Anogeissus leiocarpus* is one of the best energy woods [10]. It is used both for charcoal production and as firewood.

The teak forests of the Boundiali department are home to five species classified as vulnerable according to the red list of [22]. These are *Nauclea diderrichii, Afzelia africana, Khaya anthotheca*, and *Khaya ivorensis*. In this part of the country, [36] identified 11 vulnerable species. With the exception of *Nauclea diderrichii, [*37] recorded the four other species with the same special status in the arboretum of the National Floristic Center in Abidjan. Thus, the teak plantations in the department of Boundiali contribute to the conservation of vulnerable species. In total, the study identified 20 individuals of vulnerable species in teak plantations less than 15 years old, compared to 12 in teak plantations over 15 years old.

5. Conclusion

Floristic inventories carried out in the teak plantations of the Boundiali department reveal the presence of 21 species classified into 20 genera belonging to 12 families. However, this diversity of flora tends to disappear as the plantations age. The impact of silvicultural activities on flora diversity can be observed through several parameters, including floristic richness, species diversity, the number of species with special status, and species density. These parameters have low values in old plantations compared to young plantations. In addition, the presence of large-diameter local species in teak plantations over 15 years old shows that teak plantations could be favorable environments for biodiversity conservation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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