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Research paper

Plant species diversity and structure in tree plantations at Téné Protected Forest (Côte d'Ivoire)

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ABSTRACT This study assessed flora establishment in the exotic tree plantations. The old and young *Tectona grandis* L.f. plantations, mixed-species plantations (*Tectona grandis* L.f, *Gmelina arborea* Roxb., *Cedrela odorata* L.) and a neighbouring unmanaged forest were inventoried in Téné Protected Forest. In each habitat type, all vascular plant species were recorded and tree species with diameter at breast height ≥ 10 cm were measured and counted. The conservation value was determined through the listing of rare, threatened or endemic species. The diversity, the structure, and aboveground biomass have been estimated for comparison. The results showed that, plant species richness and diversity decreased significantly from unmanaged forest to mixed-species plantations and teak plantations, while, tree density, basal area and biomass were similar between the four habitat types. This study suggests that the value of forest plantations for plant diversity varies considerably depending on whether the exotic tree species are planted as mixed-species or monocultural plantations.

KEYWORDS: Forest plantation, timber production, aboveground biomass, Côte d'Ivoire.

Introduction

Forests host about 75% of terrestrial species (Chaffard-Sylla 2007). These have the potential important environmental benefits and services if effectively managed (Vroh et al. 2017). However, forest ecosystems are under serious threats. The annual rates of deforestation have been estimated at 4.2 million ha from 1990 to 2000 and, at 2.7 million ha from 2000 to 2015, only in the tropic (FAO 2016).

Contrary to the deforestation rhythm in natural forest, the average annual rate of forest plantation establishment is 5 million ha (FAO 2014).

Indeed, the global forest plantation area increased from 17.8 million ha in 1980 to 187 million ha in 2000, an increase of about 950% (Onyekwelu et al. 2006).

By 2014, global forest plantation area had risen to 264 million ha and accounts for 7% of total global forest estates (FAO 2014). In the tropic, while natural forest losses occur continuously, the extent of forest plantations has increased by 69% over the last 25 years (MacDicken 2015). These tree plantations play a vital role in meeting the global demands for wood, paper, pulp and timber products. Because of this economic role, there are indications that, the area of forest plantations will continue to increase. This fact makes it necessary to assess its potentials to fulfil ecological purposes (e.g., biodiversity conservation, stock of biomass) in addition to wood production. Indeed, while plantations are known for high timber productivity, little is known about their potential to conserve and harbour biodiversity.

The establishments of forest plantations were often based on exotic species. In 2010, 117 countries, representing 67% of the total global forest area, reported the use of exotic economic species in planted forests (FAO 2010). However, exotic species can be difficult to control and may interfere with restoration projects, although these exotic species reforestations have generally yielded positive economic and employment benefits (Niskanen and Saastamoinen 1996). Also, their impacts on biodiversity conservation and recovery have been viewed negatively, especially where exotic species are involved (Barlow et al. 2007, Makino et al. 2007). The question remains whether plantations of economic and exotic tree species can harbour biodiversity like that in surrounding natural forests (Carnus et al. 2006). Thus, a critical issue for future plantation forests is how to create a synergy between management of plantations for the production of high-value timber and biodiversity conservation.

In a country like Côte d'Ivoire, agriculture and forest resources are the primary and often the only viable sources of income (Aké-Assi 1998). Yet, the country's forest cover declined from 7.85 million ha in 1990 to 5.09 million ha in 2000, with an annual loss rate of 4.32%. In 2015, forests covered 11% of the country (3.4 million ha), with an annual deforestation rate of 2.69% between 2000 and 2015 (Mondelèz International 2017). Despite legal protections, protected forest managed by the Forest Development Society (SODEFOR), saw the impacts of deforestation. Indeed, the area covered by protected forest declined from 2.13 million ha in 1990 to 0.84 million ha in 2015. The annual deforestation rate in protecting forests reached 4.2% during the period between 2000 and 2015.

With the intense population pressure along with limited economic opportunities, the use of fast-growing species with high economic value has been a popular choice in previous national forest re-

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habilitation programs by SODEFOR. Indeed, SODEFOR has a long history of using native species and fast-growing exotic tree species in its effort to recreate the immediate forest cover in at least 145,686 ha (BNETD 2015). In protected forest managed by SODEFOR, the exotic species teck (*Tectona grandis* L.f.) represented 40% of the total forest plantations. Two indigenous species fraké (*Terminalia superba* Engl. & Diels) and framiré (*Terminalia ivorensis* A. Chev.) with both 40% have been the most used tree species in forest plantations. Many other exotic tree species such as gmelina (*Gmelina aroborea* Roxb.), cedrela (*Cedrela odorata* Roxb. ex Rottler & Willd.) and native species such as samba (*Triplochiton scleroxylon* K.Schum.), niangon (*Tarrietia utilis* Sprague), makoré (*Tieghemella heckelii* Pierre ex A. Chev.), kotibé (*Nesogordonia papaverifera* A. Chev.), represented 20% of the reforested area (Eblin and Amani 2015).

These tree plantations have become an important resource for the country's forestry industry and timber needs, thus providing an immediate alternative to reduce the pressure on remaining natural protected forests. The largest areas of these plantations are in Téné Protected Forest (TPF), which is considered as the pioneer in timber production and industrial tree plantation development in the country. However, in this protected forest, native tree plantation such as *Terminalia ivorensis* and or *Triplochiton sclerxylon* no longer exist since the last exploitation in 2000. There are only exotic monospecific plantations of *Tectona grandis* or mixed-species plantations, including *Tectona grandis*, *Gmelina arborea* and *Cedrela odorata* in this protected forest. These tree plantations have been sometimes established on land previously covered by natural semideciduous forests (Sangne et al. 2008). However, an improved understanding of their potential of plant diversity conservation and biomass stock would be critical to the development of ecologically sustainable policy measures. In Téné forest and other protected forests of the country, published quantitative data demonstrating the positive effects of exotic tree plantations on plant diversity and aboveground biomass establishment is still very limited, although this information is critical in deciding whether tree plantations can be a valuable component in the country's indigenous forest rehabilitation and the Reducing Emissions from Deforestation and Forest Degradation (REDD+) programs.

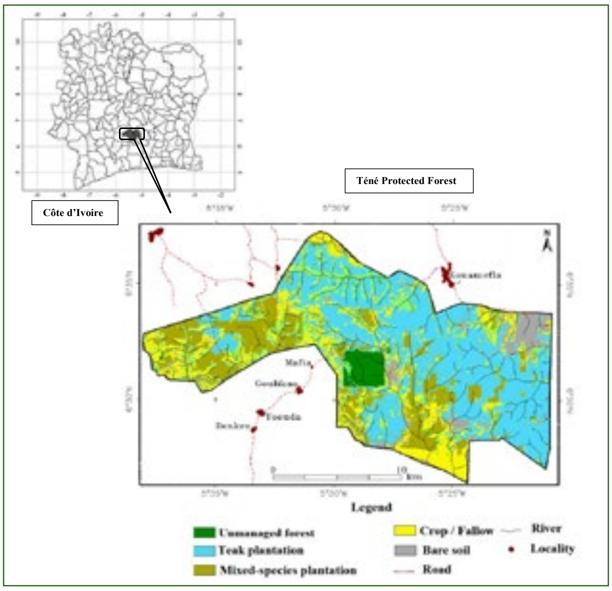
The main aim of this study was to evaluate the effects of plantation forestry on plant species diversity within the planted forests, considering two types of *Tectona grandis* plantations (young and old), one type of mixed-species (*Tectona grandis*, *Gmelina arborea*, *Cedrela odorata*) plantation, and the surrounding unmanaged forest. Specifically, the study compared (1) plant species richness and diversity (exotic and native species richness), (2) the structure of vegetation (stem density, basal area, aboveground biomass).

Methods

Study area

The study was conducted in the Téné Protected Forest (TPF) managed by the Government agency (SODEFOR) since 1973. The site is located in the Oumé department (6°27' - 6°37' N and 5°20' - 5°40'0, the above sea level elevations ranging from 31 to 226 m) (Fig. 1) (Miellot and Bertauld 1980).

Figure 1 - Map of land use type in the Téné Protected Forest in Côte d'Ivoire (Source: Adapted of Sangne 2009).



The mean annual rainfall in the department is 1,200 mm of precipitation, while the mean annual temperature is of 25 °C (Kouadio et al. 2018).

The vegetation is characterized by a mosaic of Guinean savannahs and semi-deciduous forests. The dominant species in the latter are *Celtis* spp; and *Triplochiton sclexylon* K. Schum.

The TPF cover 29,400 ha, of which 22,000 ha are forest plantations. In the site, SODEFOR established two tree forest types: the monospecific *Tectona grandis* forest and the mixed-species tree forest based on *Tectona grandis*, *Gmelina arborea* and *Cedrela odorata* (Fig. 1). These two trees plantation types are characterized by short rotation periods (less than 40 years) and are intended especially for plantations with commercial use. Various spacings are used for these plantation establishment: 2.5 x 2.5 m for monocultural teak and 6 x 6 m for mixed species. The plantations of *T. grandis* under 10 years old (young plantations) are subject to regular cutting operations. In more than ten years (10-40 years), thinning and selective tree cutting is done to ensure a better solar illumination and to favor the increase of the tree's diameter (SODEFOR 2014).

Betwen these tree plantations, there are some unmanaged forest patches wich have been highly degraded by the early 1980s. Indeed, a wildfire destroyed these parts of the natural forest in 1981-1982 (Dupuy et al. 1997).

Data collection

Inventories were carried out through stratified sampling method. Four habitat types were investigated; each one was considered as a stratum: young monospecific teak plantations with of 5-10 years, old monospecific teak plantations with more than 10 years, mixed-species plantations with 25-35 years and an unmanaged forest patche selected as controls of natural vegetation. This unmanaged forest is a part of the natural spaces destroyed by a wildfire; there is 40 years ago.

A total of 31 plots of 2,500 m^2 (50 m x 50 m) was sampled and inventoried in the unmanaged forest (n = 6 plots), the young teak plantations (n = 6 plots), the old teak plantations (n = 6 plots), and the mixed-species plantations (n = 13 plots).

First, in each plot, all vascular plants (with no stem dimensions) were recorded. Secondly, all trees stem with dbh ≥ 10 cm were counted. Indeed, the overstory plants (dbh ≥ 10 cm) are the only one able to impact the tropical forest physiognomy (Kessler et al. 2005). Also, the overstory plants include mainly mature trees able to future production of fruits and seedling for forest recovery.

During the study, the identification was made on the field with the research team. Undetermined specimens (less than 3%) were identified by comparison to those of the National Herbarium of Côte d'Ivoire (*Herbarium ivorensis* UCJ).

Data analysis

Firstly, for each recorded species, the botanical family was determined. Secondly, the conservation status of all recorded species in the forest types was checked using the IUCN Red List of Threatened Species (IUCN 2020), the local threatened species list (Aké-Assi 1998), and regional endemic lists of West African forests (White 1983, Poorter et al. 2004). These statuses allowed to assess the conservation value of each forest type.

Thirdly, to illustrate tree species shared between the different habitats (beta-diversity), a Venn diagram was drawn with the Bioinformatics & Evolutionary Genomic Tool (http://bioinformatics.psb.ugent.be/webtools/Venn/). This diagram generated a textual output indicating which species were in each intersection or were unique to a habitat (Vroh et al. 2017).

Fourtly, the Renyi diversity profile was calculated (Morris et al. 2014). The Renyi diversity profile is one of the techniques for diversity ordering and specifically designed to rank communities from low to high diversity (Kindt et al. 2006). Renyi diversity profile values ($H\alpha$), based on 100 randomisations, have been calculated (Kindt and Coe 2005) and the ouput has been represented graphically. The mathematical formula of $H\alpha$ is:

$$H\alpha = \frac{\ln \sum (p\hat{i})\alpha}{1-\alpha} \quad \text{(eq. 1)}$$

In this formula, pi is the abundance of species i and α is a scale parameter. Legendre and Legendre (1998) have demonstrated that the values of the Renyi profile at the respective scales of 0, 1, 2 and ∞ are related respectively to species richness, the Shannon diversity index, the Simpson diversity index, and the Berger–Parker diversity index (Berger and Parker 1970).

Considering the comparison based on the Renyi diversity profile, a community A is more diverse than a community B if the diversity profile of community A is everywhere above the diversity profile for community B (Kindt et al. 2006). Communities that have intersecting profiles have the same diversity level.

Fifthly, the Importance Value Index (IVI, Cottam and Curtis 1956) was determined in each forest. The IVI indicates the relative ecological importance of the woody species in the study area. It is determined from the summation of the relative values of density, frequency, and dominance of each species. The IVI varied from 0 (absence of dominance) to 300 (monodominance). A species is ecologically dominant when IVI is greater than 10 (Fobane et al. 2017).

Regarding the structural characterization, basal area, stems density and aboveground biomass were calculated in each plot and forest averages of stem density, basal area and aboveground biomass were compared between the four forest types.

The allometric equation developed by Chave et al. (2005) was used for aboveground biomass estimation. The equation is:

$$GB = \rho exp^{[-0.667+1.784\ln(D)+0.207\ln(D^2)-0.0281\ln(D^3)]} \quad \text{(eq. 2)}$$

In this formula AGB = aboveground biomass (kg), D = the diameter at breast high (cm), ϱ = specific wood density. This pantropical equation of Chave et al. (2005) is recommended for tropical forest when site-specific equations are missing for aboveground biomass estimation (Madountsap et al. 2018).

Data (AGB, plant density and basal area) not confirming to the assumptions of parametric tests, Krustals-Wallis test was performed on the measured and calculated parameters using the R software.

Finally, the diameter structures based on diameter classes and stems density, were analyzed to characterize the vegetation structure of each habitat type.

Results

Richness and composition of woody species

The 31 plots included 158 vascular plant species (tree, shrub, liana, and herb) belonging to 124 genera and 50 botanical families. The unmanaged forest recorded 109 species belonging to 91 genera and 44 families. The most frequent genera were *Clerodendrum* (5 species), *Albizia* and *Vitex* (3 species each one). The most represented botanical families in the forests were Fabaceae (12 species) and Malvaceae (9 species). In the mixed-species plantations, 104 species belonging to 61 genera and 32 families were recorded. This richness decreases in the young teak plantations (72 species, 59 genera and 29 families) and in the old teak plantations (70 species, 56 genera and 42 families).

Out of the 158 species, seven (7) were listed on the IUCN threatened list as vulnerable (Tab. 1). *Milicia regia* and *Nesogordonia papaverifera* were present in all habitat types, while *Afzelia africana*, *Afzelia bella* and *Khaya ivorensis* were recorded only in the unmanaged forest, *Entandrophragma cylindricum* and *Terminalia ivorensis* (recorded in the mixed-species plantations). At the local level of threatened plant species, three species were listed: *Sphenocentrum jollyanum* (in the four forest types), *Turraea heterophylla* in the unmanaged forest and mixed-species plantations, and *Milicia excelsa* which was the most common threatened species (Tab. 1).

According to endemic level, out of the 158 species, three were endemic to West African forests (GCW) and found in all habitats: *Hippocratea vignei*, *Milicia regia* and *Napoleonaea leonensis*. *Milicia regia* is both vulnerable, according to the IUCN red list and endemic to West African forests.

Tree species diversity

By considering only tree species, a total of 6,305 individuals with dhb ≥ 10 cm belonging 56 species, was inventoried in the study area. In the unmanaged forest 42 species (75%) were recorded, the mixed-species plantations harboured 28 species (50%), the old teak plantations included 10 species (17.9%), and young teak plantations 6 species (10.7%).

The Nonsymmetric Venn diagram (Fig. 2) showed that two species (3.5%) were shared by all the four habitat types. Indeed, *Cedrela odorata* and *Ficus exasperata* were found in all habitats.

Three species (5.3%) were shared by the unmanaged forest, the mixed-species and old teak plantations: *Baphia nitida*, *Cola gigantea* and *Manguifera indica*.

In the remaining unmanaged forest, 23 (54.7%) species were exclusively present and in the mixed-species plantations, 7 species (25%) were found.

The unmanaged forest and the mixed-species plantations shared 18 species (32%). Only one species was exclusive to young teak plantations (*New-*

Table 1 - List of tree species in each stand with their family, conservation attributes, number of stems.

Species	Family	Ecological statut	Number of observed stem			
			Unmanaged forest	Young teak plantations	Mixed-species plantations	Old teak plantations
Afzelia africana Sm. ex Pers.	Fabaceae	Vu	4	-	-	-
Afzelia bipindensis Harms	Fabaceae	Vu	64	-	-	-
Baphia nitida Lodd.	Fabaceae	LC	40	-	28	24
Cnestis corniculata Lam.	Connaraceae	HG	73	21	3	61
Cola caricaefolia (G.Don) K.Schum.	Malvaceae	GCW	13	-	8	-
Commelina erecta L.	Commelinaceae	LC	2	-	-	-
Entandrophragma cylindricum (Sprague) Srague	Meliaceae	Vu	-	-	12	-
Hippocratea vignei Hoyle	Celastraceae	GCW	17	2	7	3
Khaya ivorensis A.Chev	Meliaceae	Vu	8	-	-	
Milicia excelsa (Welw.) Berg	Moraceae	LR/nt, AA	21	8	-	9
Milicia regia (A.Chev.) Berg	Moraceae	Vu, GCW	14	4	7	5
Napoleonaea leonensis Hutch. & Dalz.	Lecythidaceae	GCW	32	2	1	1
Nesogordonia papaverifera (A.Chev.) Cap.	Malvaceae	Vu	5	-	-	2
Sphenocentrum jollyanum Pierre	Mennispermaceae	AA	72	3	2	1
Terminalia ivorensis A.Chev.	Combretaceae	Vu	-	-	6	-
Triplochiton scleroxylon K.Schum.	Malvaceae	LR/nt	-	-		5
Turraea heterophylla Sm.	Meliaceae	AA	7	-	11	-

Note: LC = least concern; LR/nt = lower risk ; VU = vulnerable; AA = rare species according to Aké-Assi; GCW = West African Guineo-Congolian species *bouldia laevis*) and old teak plantations (*Distemonanthus benthamianus*).

The diversity profiles of each habitat type are presented in Figure 3. Results from the comparison based on the diversity profile, showed that all habitat types have a clear bend towards low values of H-alpha at higher scales of alpha (Fig. 3). The forest was more diverse than the other habitats. But young and old teak plantations have intersecting profiles for Berger–Parker diversity index at H ($\alpha = \infty$) and cannot be ordered in diversity.

In the unmanaged forest, *Cedrela odorata* (83%), *Triplochiton scleroxylon* (27%), *Nesogordonia papaverifera* (24.2%), *Trichilia monadelpha* (18.7%), and *Celtis zenkeri* (13.9%) had higher values of IVI. In the mixed-species plantations, the predominant

Figure 2 - Nonsymmetric Venn diagram showing the number of species shared between the different habitat types.

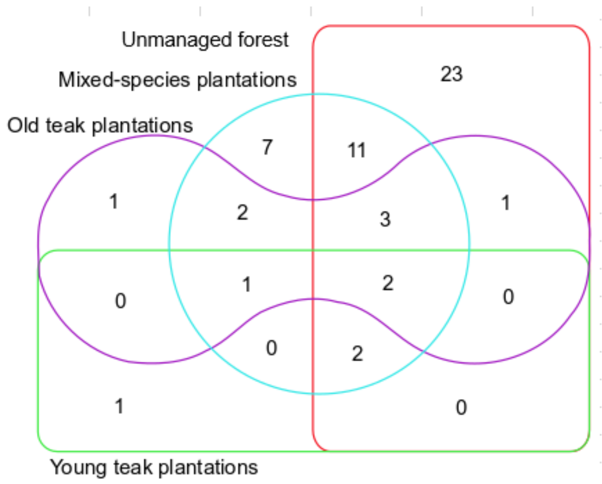


Figure 3 - Comparison of Rényi diversity profiles for the separate habitat types.

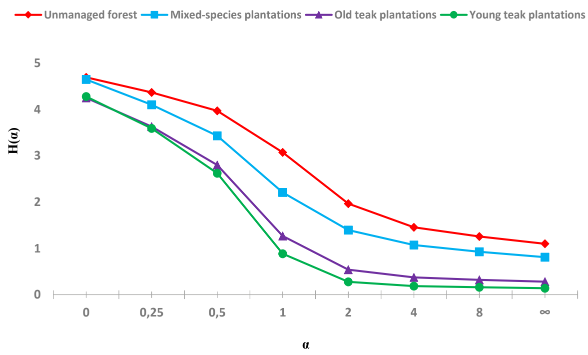


Table 2 - Population characteristics of the five most important tree species in the four habitat types.

	Tree species	Family	RF (%)	RDo (%)	RD (%)	IVI (%)
		Unmanaged forest				
1	*Cedrela odorata*	Meliaceae	6.6	37.2	39.2	83.0
2	*Triplochiton scleroxylon*	Malvaceae	6.6	5.9	14.5	27.0
3	*Nesogordonia papaverifera*	Malvaceae	4.4	7.4	12.3	24.2
4	*Trichilia monadelpha*	Meliaceae	5.5	10.0	3.2	18.7
5	*Celtis zenkeri*	Cannabaceae	4.4	4.1	5.4	13.9
		Mixed-species plantations				
1	*Cedrela odorata*	Meliaceae	15.7	44.2	36.5	96.4
2	*Gmelina arborea*	Verbenaceae	9.6	22.4	37.3	69.4
3	*Tectona grandis*	Verbenaceae	12.0	14.0	8.9	34.9
4	*Triplochiton scleroxylon*	Malvaceae	8.4	7.8	5.3	21.6
5	*Terminalia superba*	Combretaceae	6.0	5.1	7.9	19.0
		Old teak plantations				
1	*Tectona grandis*	Verbenaceae	26.1	97.2	75.9	199.2
2	*Cedrela odorata*	Meliaceae	26.1	0.4	20.8	47.2
3	*Gmelina arborea*	Verbenaceae	21.7	0.9	2.4	25.1
4	*Baphia nitida*	Fabaceae	4.3	0.7	0.3	5.4
5	*Albizia zygia*	Fabaceae	4.3	0.2	0.2	4.7
		Young teak plantations				
1	*Tectona grandis*	Verbenaceae	54.5	96.9	94.8	246.3
2	*Ficus exasperata*	Moraceae	9.1	1.4	2.2	12.8
3	*Cedrela odorata*	Meliaceae	9.1	1.0	1.7	11.8
4	*Terminalia superba*	Combretaceae	9.1	0.4	0.5	10.0
5	*Ficus sur*	Moraceae	9.1	0.1	0.7	9.9

species were *Cedrela odorata* (96.4%), *Gmelina arborea* (69.4%), *Tectona grandis* (34.9%), *Triplochiton scleroxylon* (21.6%), and *Terminalia superba* (19%).

In the young and old teak plantations the most important species were respectively *Tectona grandis* (246.3% and 199.2% respectively), *Cedrela odorata* (Tab. 2). The other important species were *Terminalia superba*, *Ficus exasperata* and *Ficus sur* in the young teak plantations, *Baphia nitida* and *Albizia zygia* in the old teak plantations.

Forest stand structure

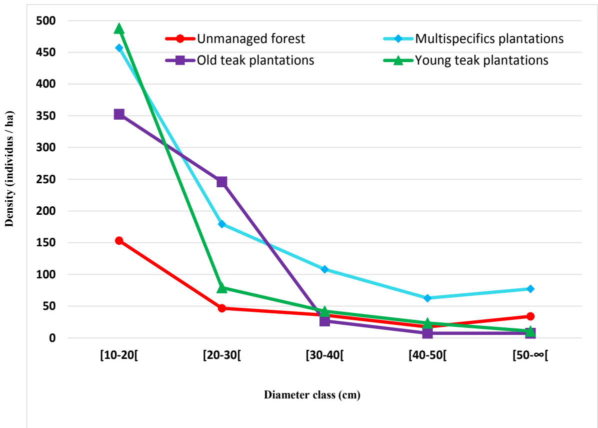
The mean density was ranked from 698 individuals/ha (in mixed-species plantations) to 934 individuals/ha (in old teak plantations). The average basal area of tree stems was decreasing from teak plantations to mixed-species plantations and forest (Tab. 3). However, as founded for the density, the basal area was not statistically different between the four habitat types. The aboveground biomass varied from 189 t/ha in the young teak plantation, to 283 t/ha in the unmanaged forest (Tab. 3).

The diametric structure of stems, in the four forest types, had a decreasing exponential form (reversed J) showing that the number of individus/ha decreased with increasing diameter (Fig. 4).

Table 3 - Density, basal area and aboveground biomass (AGB) in different habitat types.

Biotopes	Density (individus/ha)	Basale area (m²/ha)	AGB (t/ha)
Unmanaged forests	749 ± 271.94a	29.52 ± 11.41a	283.95 ± 138.63a
Young teak plantations	865.33 ± 240.41a	23.92 ± 7.72a	189.90 ± 57.71a
Mixed-species plantations	698.46 ± 312.82a	29.18 ± 14.55a	232.02 ± 128.12a
Old teak plantations	934 ± 298.22a	24.04 ± 16.54a	214.94 ± 200.36a

Figure 4 - Diametric structures of trees in the different habitat types.



Discussion

In Côte d'Ivoire, tree plantations have been identified and developed to enable ecologically sustainable restoration and forest management framework. The present study discussed the diversity of plant species, aboveground biomass and structural characteristics of these woody production systems, comparing monospecific and mixed-species plantations to unmanaged forest.

The study showed that tree plantations (monospecies and mixed species) have a lower diversity and richness of vascular plant species than the unmanaged forest. This could be due to the fact that most of the plantations were monocultures or mixed plantations of some exotic tree species. Indeed, exotic tree species like *Tectona grandis*, *Gmelina arborea* and *Cedrela odorata* are not adapted to the hard competitive conditions in natural tropical forest. In plantations based on these exotic species, other species such as native understorey and overstorey plants are usually eliminated during weeding. In the case of SODEFOR plantations, the planted trees grow with little or no understorey recruitment, resulting in low species diversity in the overstorey at later stages of development. These results are similar to those obtained by Barlow et al. (2007) and Makino et al. (2007).

However, the lower richness and diversity of plants would be nuanced when considering monospecies and mixed-species tree plantations. In the mixed-species plantations, indeed, we have observed more plant species and a high diversity which can be related to high recruitment of native species. These mixed-species plantations may generally indirectly protect natural biodiversity (plants and wildlife) by allowing greater wood production from smaller and intensively managed areas, as argued by Rudel (1998). On the other hand, plantations of monospecific trees, such as *Tectona grandis* plantations, are characterized by certain constraints resulting from their more intensive management (Harikrishnan et al. 2012). These teak plantations are most favorable to ruderal plants than native species with long life. Thus, enhanced biodiversity outcomes are expected with plantations that utilize mixed species as demonstrated by Hartley (2002). Other authors like Brockerhoff et al. (2008), recommended the use of native tree species to improve biodiversity outcomes.

Few rare or threatened species have been reported from tree plantations. This could be related to human disturbance caused during the plantation management practices, such as weeding, salvage logging and thinning. According to Brockerhoff et al. (2003), these species are often the most sensitive to land-use change. But some notable cases of occurrence of such species exist in the tree plantations inventoried at Téné Protected Forest. For example, large populations of threatened species such as *Entandrophragma cylindricum*, *Milicia regia*, *Nesogordonia papaverifera*, *Terminalia ivorensis* and *Triplochiton scleroxylon* inhabit old and young teak plantations and also mixed species plantations. *Turraea heterophylla*, another endangered species endemic to the Upper Guinean Forest (Poorter et al. 2004) are highly threatened locally (Aké-Assi 1998), due to its useprimarily as a male sex stimulant in many areas of the country. These occurrences are significant findings and must be taken into account for the management of tree plantations. According to Brown et al. (2013), the presence of a single species can be sufficent to qualify a site as High Conservation Value (HCV 1). On this basis, the occurrences of these 6 threatened species allow to classify these forest plantations as High Conservation Value (HVC1). The presence of some flightless endemic plant species, such as *Cola caricaefolia*, *Hippocratea vignei and Napoleonaea leonensis*, is also a challenge for tree plantation managers, as shown by Brockerhoff et al. (2001).

Regarding only tree species with a dbh ≥ 10 cm, the young and old teak plantations and the unmanaged forest exhibited low similarity (less than 5%) in the composition of indigenous woody species despite uniform climatic conditions. Also, there is a lower smilarity (5.3%) between teak plantations and mixed species plantations. In contrast, we have recorded a relative high similarity (32%) between mixed-species plantations and the unmanaged forest. This finding provides evidence to support the claim that the more tree species in the same plantations, the more diverse the native plants (Li 2010). The relatively high similarity of plant species between the unmanaged forest and mixed species plantations could mean that this remaining forest was highly disturbed. Indeed, this disturbance could be linked to the persistent effects of the fire that destroyed this space in early 1980s (der Meersch et al. 2020). Also, others human activities like logging, hunting, harvesting of toothpicks could cause the disturbance of this unmanaged forest, as reported by Vroh et al. (2017) in other Ivorian protected forests managed by SODEFOR. The high disturbance of this remaining forest has been also demonstrated by the importance value index of *Trichilia monadelpha*, anunderstory and pioneer species (Fatimoh et al. 2017). In the remaining forest, the high importance value index of some commercial native species such as *Nesogordonia papaverifera and Triplochiton scleroxylon*, are related to the old plantations of these species in the Téné Protected Forest.

The lower similarity between the unmanaged forest and teak plantations (monoculture) concurs with any previous investigation based mainly on overstory species (Senbeta et al. 2002) and indicating that forest plantations become an 'ecological desert' (Brockerhoff et al. 2008). According to Gibson et al. (2011), by comparison to plantation stands (farms and tree plantations), forests are irreplaceable for sustaining tropical biodiversity in the tropic.

However, the comparison of plant diversity index of unmanaged forests and tree plantations has been done in this study, mainly based on overstory levels (trees with diameter at breast height of 10 cm and above). Given that the understories of tropical forests may be as rich in species as their overstories (Tchouto et al. 2006), we believe that taking into account the diversity of understory tree species could contrast these results as repported by Tulod et al. (2017).

In the case of Téné Protected Forest, the high occurrence of the exotic species *Cedrela odorata* in the unmanaged forest may be attributed to the lasting effects of the wildfire which destroyed more than 65% of this space in 1980's (der Meersch et al. 2020). Others biological characteristic could also favour the abundance of this species in this remaining forest. Indeed, according to Cintron (1990), the germination of *Cedrela odorata* is rapid, usually completed within 2 to 4 weeks and trees of this species begin to fruit at an age of 10 to 12 years. At this moment, the other planting trees, including teak, are still growing. In the unmanged forest at Téné Protected Forest, we have observed high seedling densities and many individuals with a dhb under 10 cm (relative density = 39 %). In other countries like South Africa, this timber tree has become invasive in some areas, especially those disturbed by cutting (GISD 2015). Then, regarding spatial distribution, *Cedrela odorata*-based tree plantations can potentially have negative effects on adjacent communities because of the potential for invasive natural regeneration of this species in adjacent habitats.

Regarding to structural characteristics, the AGB value of the studied unmanaged forest (283.95 t/ha) was being in the range (240 – 426 t/ha) obtained by Lewis et al. (2013) in Ivorian forests. But the AGB in teak and mixed-species plantations were lower than the minimum determined for Ivorian forests. These results mean that mixed-species plantations can have some structural characteristics (density, basal area and biomass) observed in close tropical forests. But in monospecies teak plantations these structural characteristics change.

The structure described by a diameter distribution of the four habitat types presented an inverse J-shaped. This J-shaped distribution does not demonstrate the stability (climax) as generally in tropical forests (Ige et al. 2013). Due to various human activities in these habitats, this study explains the good regeneration capacity of tree species (exotic plants and native species).

Conclusion

The plant richness and diversity of the young and old teak (*Tectona grandis*) plantations were poorer in tree species diversity and richness compared to the mixed species (*Tectona grandis*, *Cedrela odorata* and *Gmelina arborea*) plantations and the unmanaged forest at Téné protected Forest. However, the density, basal area and aboveground biomass of the monospecific *Tectona grandis* plantations were comparable to those obtained in mixed-species plantations and unmanaged forest. The high number of tree species in the mixed species plantations indicates that, these plantations can harbour high species richness.

However, a higher attention is necessary when choosing tree species for plantation because some exotic species such as *Cedrela odorata* can become invasive in the adjacent landscape. The presence of some rare, endemic and threatened species in the two plantation types (mono and mixed species) suggests that tree plantations in Téné Protected Forest have the ability to conserve biodiversity. Much of the plant diversity conservation benefit obtained in the tree plantations in this study was gained by chance rather than design, since biodiversity conservation was not part of the initial management objective(s) of SODEFOR. Thus, tree plantations will conserve higher plant diversity if biodiversity conservation is included in the initial management objectives of SODEFOR. In the Ivorian tree plantations, further enhancement of biodiversity is possible through greater attention to using native species or mixed species in the same plots. Thus, management of plantations of economic tree species must seek to strike a balance (synergy) between timber production and biodiversity conservation.

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