# PLANT SPECIES DIVERSITY AND FOREST STAND STRUCTURE OF TREE PLANTATIONS IN TENE GAZETTED FOREST (COTE D'IVOIRE)

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**ABSTRACT**

This study assessed the impacts of tree plantations on plant species diversity, biomass and structure in the Téné Gazetted Forest (TGF). Plots were inventoried in old and young teak plantations (*Tectona grandis* L.f.), mixed-species plantations (*Tectona grandis, Gmelina arborea* Roxb., *Cedrela odorata* L.) and a remaining forest. All vascular plant species were counted and stems with a diameter at breast height (dbh) greater or equal to 10 cm were counted. Diversity index, biomass and structural parameters were determined by the habitat type. A total of 158 species was found in all habitat types. Among them, 56 are tree species with stems having a dbh e» 10 cm. The richness of these tree species is greater in forests (42 species) and mixed-species plantations (28 species) than in teak plantations (6 - 10 species). The diversity profile shows that tree diversity was decreasing from remaining forest to mixed-species plantations and monospecific teak plantations. *Cedrela odorata* was the most important species with an Importance Value Index ranging from 47 to 96% in older habitats. Tree density is greater in teak plantations (943 - 865.3 stems / ha) than in forest (749 stems / ha) and mixed-species plantations (698 stems / ha). However, the biomass is greater in forest (283.9 t / ha) and in mixed-species plantations (232.01 t / ha) than in teak plantations (189.9- 214.9 t / ha). The study shows that for better conservation of native species and high biomass production in forest plantations based on exotic species, the mixed-species plantations would be favoured.

**Keywords:** Forest plantation; timber production; aboveground biomass; Côte d'Ivoire.

***RESUME***

***DIVERSITE ET STRUCTURES DES ESPECES VEGETALES DANS LES PLANTATIONS FORESTIERES DE LA FORET CLASSEE DE TENE (COTE D'IVOIRE)***

*La présente étude a permis de comprendre les effets des plantations forestières sur la diversité végétale et les stocks de biomasse dans la Forêt Classée de Téné (FCT). Des parcelles ont été inventoriées dans des vieilles et jeunes plantations de teck (*Tectona grandis *L.f.), des plantations de mélange d'espèces (*Tectona grandis*,* Gmelina arborea *Roxb.,* Cedrela odorata *L.) et un fragment de forêts résiduelles. Toutes les espèces de plantes vasculaires ont été recensées et les tiges avec un diamètre à hauteur de poitrine (dhp) supérieur ou égal à 10 cm ont été comptées. Des indices de diversité, la biomasse et des paramètres structuraux ont été déterminés par type d'habitat. Les résultats montrent que sur 158 espèces présentes dans tous les types d'habitat, 56 sont des espèces arboresentes dont les tiges ont un dhp e» 10 cm. La richesse de ces espèces arborecentes est plus grande en forêt (42 espèces) et en plantation mixtes (28 espèces) que dans les teckeraies (6 à 10 espèces). Le profile de diversité montre que la diversité des arbres diminue de la forêt résiduelle aux plantations mixtes et aux plantations monospécifiques de teck. L'espèces* Cedrela odorata *présentait un Indice de Valeur d'Importance allant de 47 à 96 % dans les habitats plus âgés. La densité des arbres est plus grande dans les teckeraies (943 à 865,3 tiges / ha) que dans la forêt (749 tiges / ha) et les plantations mixtes (698 tiges / ha). Par contre la biomasse est plus grande en forêt (283,9 t/ha) et en plantatons mixtes (232,01 t/ha) que dans les teckeraies (189,9 à 214,9 t/ha). L'étude montre que pour*

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*une meilleurs conservation des espèces indigènes dans les plantations forestières à base d'espèces exotiques, il faut privilégier les plantations mixtes.*

***Mots clés**: plantation forestière, Production de bois, biomasse végétale aérienne, Côte d'Ivoire*

## INTRODUCTION

The global forest plantation area increased about 95% from 1980 to 2000 (Onyekwelu *et al*., 2006). In the tropic, the extent of forest plantations has increased by 69% over the last 25 years (MacDicken, 2015). Because their economic role, there are indications that, the area of forest plantations will continue to increase.

The establishment of forest plantations was often based on exotic species. In 2010, 117 countries, representing 67% of the total global forest area, reported using exotic economic species in plants forests (FAO, 2010). However, exotic species can be difficult to control (Niskanen and Saastamoinen, 1996) and their impacts on biodiversity conservation and recovery have been viewed negatively (Makino *et al.*, 2007). Thus, the question remains whether plantations of economic and exotic tree species can harbour biodiversity similar to that in surrounding natural forests.

In Côte d'Ivoire, the Forest Development Company (SODEFOR), is the main government institution investing in the creation of forests plantations. 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.) represented 20% of the reforested area (Eblin, and Amani, 2015).

The largest areas of these plantations are in Téné Gazetted Forest (TGF), which is considered as the pioneer in timber production and industrial tree plantation development in the country. However, in this protected forest, there are only exotic monospecific plantations of *T. grandis* or mixed-species plantations, including *T. grandis, G. arborea* and *C. odorata* in this protected forest.

In Téné forest and other protected forests of the country, published quantitative data to demonstrating the facilitating role 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 *T. grandis* plantations (young and old), one type of mixed-species (*T. grandis, G. arborea, C. odorata*) plantations, and the surrounding remaining forests. Specifically, the study compared (1) plant species richness and diversity, including exotic and native species, (2) the structural parameters of the vegetation and the aboveground biomass.

## METHODS

### STUDY AREA

The Téné Gazetted Forest (TGF; Figure 1) located in the Center of Côte d'Ivoire, cover 29 000 ha, of which 22 000 ha is forest plantations (Kouassi *et al*., 2015). In this study, were concerned the monospecific planted forests (*T. grandis*), mixed-species timber (*T. grandis, G. arborea,* and *C. odorata*) and a remaining natural old-growth forest. During the study period, the mixed-species timber plantations were all at least 25 years old. These tree plantations have been sometimes established on land previously covered by natural semideciduous forests (Sangne *et al*., 2008). The remaining parts of natural forest have been highly degraded by the early 1980s. This parts of old-growth forest (900 ha) is currently used as an experimentation site for seedling production.

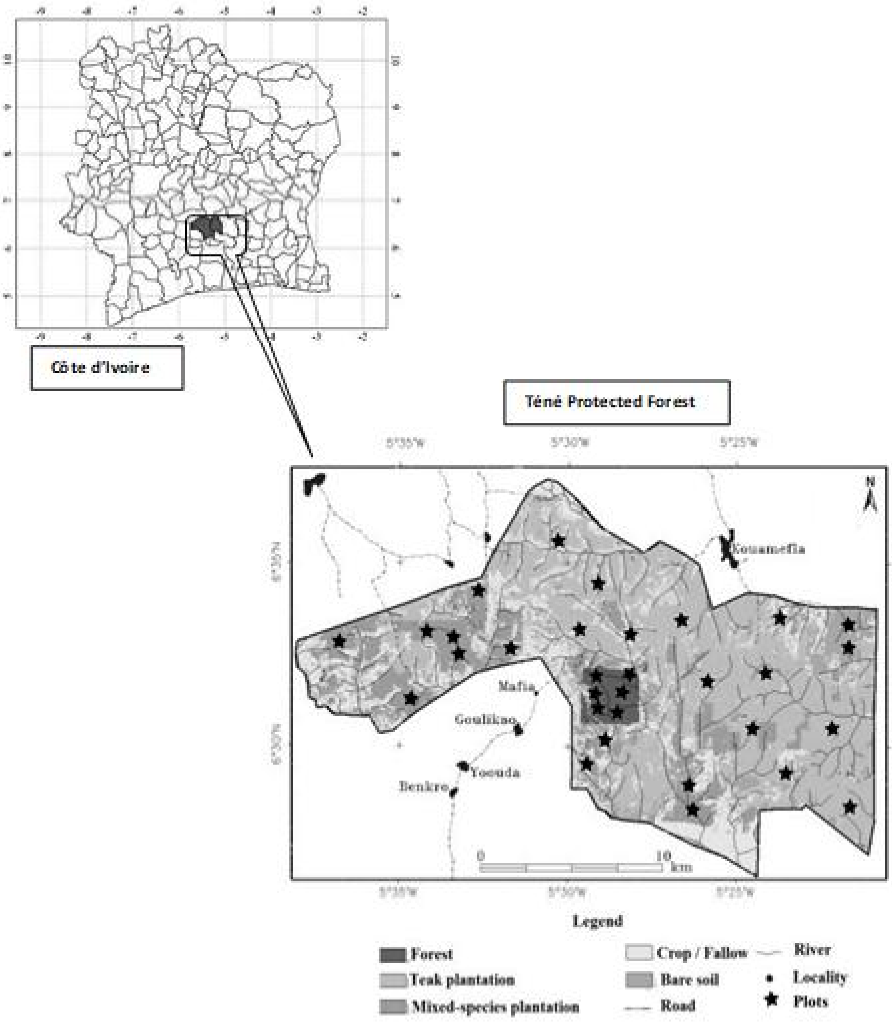


**Figure 1 :** Map of land use type in the Téné Gazetted Forest in Côte d'Ivoire.

*Carte des types d'occupation du sol dans la Forêt Classée de Téné.*

All the plantations established, 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.

DATA COLLECTION

Inventories were carried out through stratified sampling method. Each type of plant forest and remaining natural forest were considered as a stratum and plots were randomly set up. The plants forests included young (5-10 years) and old (> 10 years) teak plantations and mixed-species plantations (25-35 years). The sole remaining natural old-growth forest was additionally selected as controls.

A total of 31 plots of 2500 $m^2$ (50 m x 50 m) was sampled and inventoried in the remaining 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). More plots were chosen in the mixed forest because this habitat type occuped more space in the TGF.

In each plot, all vascular plants were recorded. The tree stems with diameter at breast high greater or equal to 10 cm (dbh ≥10 cm) have been counted and focused. In fact, the overstory plants (dbh ≥ 10 cm) are the only one able to impact the tropical forests physiognomy (Kessler *et al*., 2005). Identification of species was made according to Cronquist (1981) classification system.

DATA ANALYSIS

The conservation status of all recorded species in the forest types was checked using the IUCN Red List of Threatened Species (IUCN, 2020), the locally threatened species list (Aké-Assi, 1998), and the regional endemic lists of West African forests (White, 1983; Poorter *et al*., 2004).

To illustrate tree species shared between the different habitats, a Venn diagram was drawn with the Bioinformatics & Evolutionary Genomic Tool (http://bioinformatics.psb.ugent.be/webtools/Venn/).

Using the package Biodiversity R (Kindt and Coe, 2005), the Renyi diversity profile ($H\alpha$ ) was calculated. Legendre and Legendre (1998) have demonstrated that, the values of the Renyi profile at the respective scales of 0, 1, 2 and $\infty$ are related respectively to species richness, the Shannon diversity index, the Simpson diversity index and the Berger–Parker diversity index. 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).

The information about the proportions of each species were provided through the Importance Value Index (IVI; Cottam and Curtis, 1956) determined in each forest type. A species is ecologically dominant when its IVI > 10 (Fobane *et al*., 2017).

Basal area, stems density and aboveground biomass were calculated in each plot and were compared between the four forest types. The data collected and the area of TGF verify the validity conditions for allometric equation developed by Chave *et al.* (2005): stems with dbh between 5 and 156 cm, annual rainfall from 1500 to 4000 mm with one to five months of dry season (Pearson *et al*., 2005). Then the allometric equation developed by Chave *et al.* (2005) was used for biomass estimation. The equation is:

$$AGB = \rho\, exp^{[-0.667+1.784\ln(D)+0.207\ln(D^2)-0.0281\ln(D^3)]}$$

In this formula AGB = aboveground biomass (kg), D = the diameter at breast high (cm), $\rho$ = specific wood density, ln = natural logarithm.

## RESULTS AND DISCUSSION

The 31 plots included 158 vascular plant species (tree, shrub, liana, and herb), recorded in the four forest types. Out of the 158 species, seven (7) were listed on the IUCN (2020) threatened list: *Afzelia africana* Sm. ex Pers *Afzelia bipindensis* Harms, *Entandrophragma cylindricum* (Sprague) Srague, *Khaya ivorensis* A.Chev, *Milicia regia* (A.Chev.) Berg, *Nesogordonia papaverifera* (A.Chev.) Cap, *Terminalia ivorensis* A.Chev. (Table 1). Only *Entandrophragma cylindricum, Milicia regia, Nesogordonia papaverifera and Terminalia ivorensis* were recorded in tree plantations. The lower number of threatened species in tree plantations 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* (Sprague) Sprague, *Milicia regia* (A. Chev.) C.C.Berg, *Milicia excelsa* (Welw.) C.C. Berg. and *Terminalia ivorensis* inhabit old and young teak plantations and also mixed-species plantations. *Turraea heterophylla* Sm. another endangered species (Aké-Assi, 1998), is endemic to the Upper Guinean Forest (Poorter *et al*., 2004). This species is used primarily as a male sex stimulant in many areas of the country (Vroh *et al.,* 2016). These occurrences are significant findings and must be taken into account for the management of tree plantations as shown by Brockerhoff *et al.* (2001).

**Table 1:** List of taxon with particular status in the different habitat types.

*Liste des taxons à statut particulier dans les différents types d'habitats.*

| Species | Family | Ecological statut | Number of observed stem | | | |
|---|---|---|---|---|---|---|
| | | | Forests | Young teak plantations | Mixed-species plantations | Old teak plantations |
| *Afzelia africana* Sm. ex Pers. | Fabaceae | Vu | 4 | - | - | - |
| *Afzelia bipindensis* Harms | Fabaceae | Vu | 64 | - | - | - |
| *Cnestis corniculata* Lam. | Connaraceae | HG | 73 | 21 | 3 | 61 |
| *Cola caricaefolia* (G.Don) K.Schum. | Malvaceae | GCW | 13 | - | 8 | - |
| *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 | - |
| *Turraea heterophylla* Sm. | Meliaceae | AA | 7 | - | 11 | - |

Vu = vulnerable (IUCN, 2020); LR/nt = near threatened (IUCN, 2020); AA = rare species according to Aké-Assi (1998); GCW: endemic of Guineo-Congolian West forests; HG = endemic of Upper Guinean Forest

By considering only tree species, a total of 6 305 individuals with dhb≥ 10 cm belonging 56 species, was inventoried in the study area. The young and old teak plantations and the remaining forest exhibited low similarity (less than 5%) in the composition of indigenous woody species compared to the similarity between this forest and the mixed-species plantations (Figure 2). Also, there is a lower similarity (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 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; Vroh *et al.*, 2017).

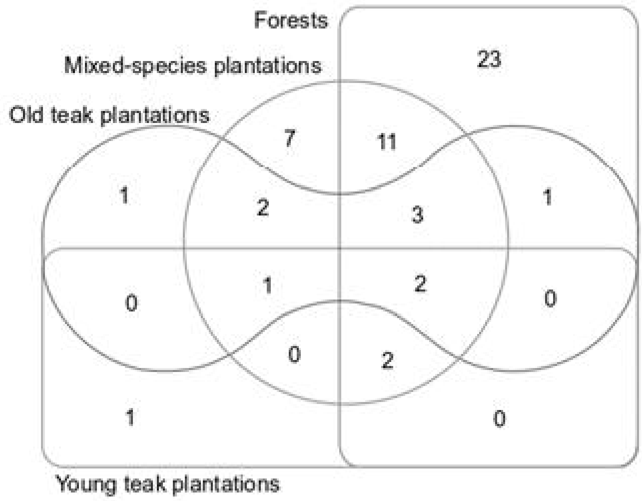


**Figure 2 :** Nonsymmetric Venn diagram showing the number of species shared between the different habitat types.

*Diagramme non symétrique de Venn montrant les nombres d'espèces communes aux différents habitats.*

Results from the comparison based on the diversity profile (Figure 3), showed that, the profile curve of the remaining natural forest was above the others for all values of alpha. This result shows that the forest was more diverse than the other habitats. This could be due to the fact that in plantations the shade of planted trees is not favorable to the recruitment of several indigenous plant species. .

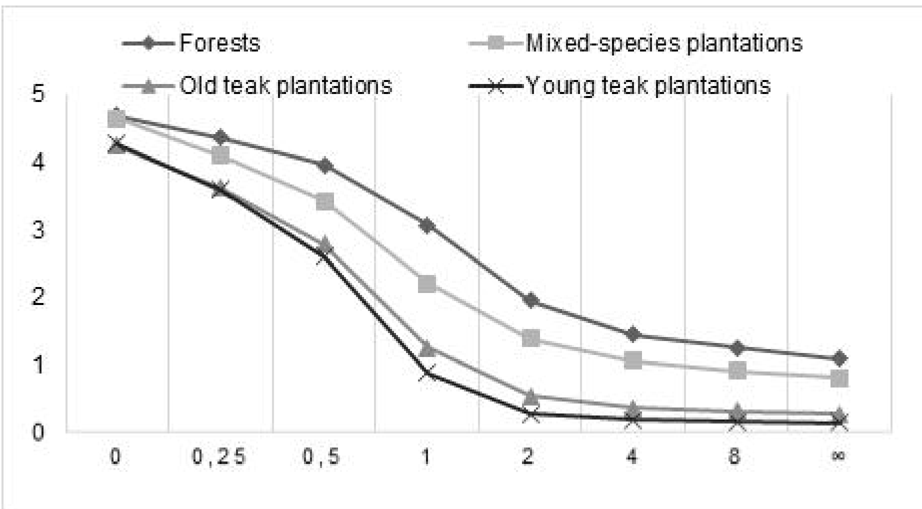


**Figure 3 :** Comparison of Rényi diversity profiles between the habitat types.

*Comparaison des profils de diversité de Rényi entre les types d'habitat.*

However, the lower richness and diversity of plants would be nuanced when considering monospecies and mixed-species tree plantations. In the mixed-species plantations, we have observed more plant species and a high diversity which can be related to high recruitment of native species than the *T. grandis* plantations. The 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 Sedjo and Botkin (1997). On the other hand, plantations of monospecific trees, such as *T. grandis* plantations, are characterized by certain constraints resulting from their more intensive management (Harikrishnan *et al*., 2012).

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

Even if young and old teak plantations the most important species were respectively *Tectona grandis* (246.3% and 199.2% respectively), *Cedrela odorata* (Table 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.

**Table 2:** Importance Value Index (IVI) of the five most important tree species in each habitat type.

*Indices de Valeur d'Importance (IVI) des 5 espèces les plus importantes dans chaque type d'habitat.*

| | Tree species | Family | RF (%) | RDo (%) | RD (%) | IVI (%) |
|---|---|---|---|---|---|---|
| | **Forests** | | | | | |
| 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 |

RF: relative frequency; RDo: relative dominance; RD: relative density; IVI: importance value index.
*RF : fréquence relative ; RDo : dominance relative ; RD : densité relative; IVI: indice de valeur d'importance.*

At TGF level, the high occurrence of the exotic species *C. odorata* in the remaining forest and the mixed-species plantations may be attributed to the abundance of seed-producing trees of this species in the vicinity of the forest, to seed dispersal mode or to the nature of dispersing agents (Cintron, 1990). In other countries like South African, this timber tree has become invasive in some areas (GISD, 2015). Then, this study warns that, SODEFOR must pay special attention to the invasive characteristics of this species.

In the remaining forest and the mixed-species plantations, stems density (749 and 698 individuals/ha respectively) and corresponding basal area (29.52 and 29.18 $m^2$/ha respectively) were comparable to intervals defined by Pascal (2003) and Slik *et al.* (2015) for tropical forests. Then, the density of stems in the young (865.33 individuals/ha) and old (934 individuals/ha) teak plantations were higher than the upper margin of the density interval. But the basal areas (23.9 and 24 $m^2$/ha respectively) were lower than the minimum defined for tropical forests. This could means that the old stems of *T. grandis* are lower diameter than those of the others planted or indigenous species.

The AGB were 283.9 t/ha (remaining forest), 232.02 t/ha (mixed-species plantations), 214.9 t/ha (old teak plantations) and 189.9 t/ha (Young teak plantations). The AGB value of the studied remaining forest was in the range (240 – 426 t/ha) obtained by Lewis *et al.* (2013) for Côte d'Ivoire. 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 and basal area) observed in close tropical forests. But in mono-species teak plantations all these structural characteristics change with a decrease for basal area and aboveground biomass.

## CONCLUSION

This study shown that the richness of tree species is greater in forests (42 species) and mixed-species plantations (28 species) than in teak plantations (from 6 to 10 species). Accorind to the diversity profile, tree diversity was decreasing from remaining forest to mixed-species plantations and monospecific teak plantations. Among the planted species, *Cedrela odorata* was the most important with an Importance Value Index ranging from 47 to 96 % in older habitats including the remaining forest. Tree density is greater in teak plantations (from 943 to 865.3 stems / ha) than in forest (749 stems / ha) and mixed-species plantations (698 stems / ha). However, the biomass is greater in forest (283.9 t / ha) and in mixed-species plantations (232.01 t / ha) than in teak plantations (189.9- 214.9 t / ha). The presence of some rare, endemic and threatened species in the two plantations types suggests that tree plantations in TGF, have the ability to conserve plant diversity. 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. Future studies will be necessary in order to assess the invasive potential of this species in the Téné Gazetted Forest area.

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