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Full Length Research Paper

Trees species diversity and above ground biomass in three tropical forest types in Azaguié area, Côte d'Ivoire

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It is often assumed that diversity, floristic composition, and structural parameters vary according to forest management types. The current study was conducted in three tropical rain forests which are distinguished by their type of management in Azaguié area: Yapo protected forest, a Natural Voluntary Reserve and community forests. The main objective was to assess the aboveground biomass (AGB) and diversity of tree species in these forests. The data consisted of dbh measurement of all tree individuals with dbh ≥ 10 cm in plots of 500 m^2. Species richness, Shannon diversity index, Pielou evenness, stem density, basal area, and AGB were calculated for each forest type and compared using one-way ANOVA. A total of 2375 stems and 164 tree species with diameter ≥10 cm were recorded in these forests. The Shannon diversity index was significantly higher in Yapo protected forest (5.78) and natural voluntary reserve (5.06) than in community forests (4.64). Evenness did not differ between Yapo protected forest (0.81) and community forests (0.83) but it's differed significantly in natural voluntary reserve (0.71). Mean AGB values were significantly higher in Yapo protected forest (347.17 ± 101.70 $t.ha^{-1}$) and natural voluntary reserve (245.09 ± 31.68 $t.ha^{-1}$) than in community forests (35.69 ± 17.12 $t.ha^{-1}$). For the three forests, structure described by diameter distribution was inverse J-shaped. This study showed that in Azaguié area, trees species in community forests were most equitable than protected area which have higher stems density and AGB. Further researches are needed to explain causes of these variations.

Keywords: Tropical forest; climate change, sustainable management, aboveground biomass, Côte d'Ivoire

INTRODUCTION

Species extinction and climate change are two important components of global change. These two components degrade the quality of both environment and human well-being. If these phenomena are considered normal during a long time, they are often exacerbated by human pressure. Today, in international negotiations, interest has increased particularly to find global strategies to reduce CO_2 emissions and biodiversity conservation (Scheldeman and van Zonneveld, 2012) in tropical forests.

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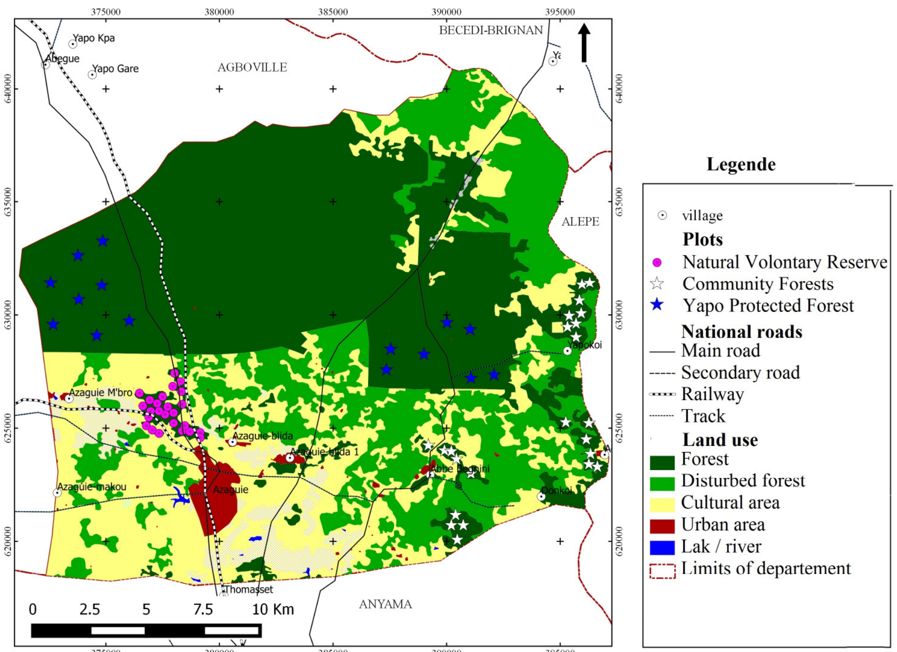

Figure 1 Map of land use and location of survey plots in Azaguié area (Source: Poorter *et al* 2004)

Tropical forests have the most tree species diversity around the world (Poorter et al., 2004; Sheil et al., 2004; Schroeder et al., 2010 ; Stahl and Christopherson, 2010 ; Ghazoul and Sheil, 2010). These forests harbor some of the highest levels of biodiversity on earth as well as the largest number of species threatened with global extinction (Parmentier et al., 2007). At the same time, tropical forests play a crucial role in the terrestrial greenhouse gas balance by carbon storage in above- and belowground forest vegetation (Chave et al., 2001; Chave et al., 2005). After fossil fuel use, tropical deforestation and forest degradation represent the second largest source of carbon emissions, contributing about 12–20 % of the annually released CO_2 (Pan et al*.,* 2011). Accordingly, conservation of tropical forests and reforestation of formerly forested habitats are viewed as important components of global strategies to reduce CO_2 emissions. This dual role of tropical forests as carbon and biodiversity repositories presents a potential win-win situation, in which management of habitats for carbon storage may, in parallel, result in biodiversity conservation (Day et al., 2013).

However, over the last decade, human-impacted ecosystems including agricultural areas and forest management types play a crucial role both in carbon and biodiversity management (Montagnini and Nair, 2004). In addition, aboveground biomass of trees and corresponding carbon storage vary according to how forests were managed (Woodall et al., 2011). In Côte d'Ivoire there is a sustainable forest management program established as national parks, forest reserves, protected forests and community forests in rural areas. We compared effects of these management types on biodiversity conservation and aboveground biomass.

This study was conducted in three forests under different management types, in agricultural areas of Azaguié. There were Yapo protected forests managed by SODEFOR, a Natural Voluntary Reserve (NVR) with a status of individual and private forest and community forests managed by local people without any protection low. The main objective was to compare effects of these management types on biodiversity conservation and aboveground biomass. Specifically, we assessed the aboveground biomass (AGB) and multiple measures of trees species diversity in these forests. We tested this hypothesis: different management types influence trees species diversity, stem density and above ground biomass.

MATERIALS AND METHODS

Study Area

The study took place around the village of Azaguié in the southeast of Côte d'Ivoire (Figure 1), in three forest types: Yapo protected Forest (YPF), a Natural Voluntary Reserve (NVR) and four community forests, differently managed. Yapo protected forest is one of the few rainforest remains in area of Azaguié. It was subjected to logging with enrichment in some compartments (experimental plots) which resulted in changes in its vegetation and natural flora (Corthay, 1996). These enhancements have contributed to the subdivision of the forest in multiple non-contiguous compartments. In the case of the present study, only forest compartments with logging activities and enrichment, were carefully selected and inventoried. In rural area of Azaguié, many other forest patches exist. They are constantly penetrated by people for various reasons and had become therefore relatively poor in species that may interest them. Since 2002, the law N° 2002-102 of February 11th 2002 authorized the creation of Natural Voluntary Reserves through individual initiatives to protect priority forest patches. The private forest considered in this study is an example of these NVR then, in this area any intervention of local people was prohibited since 2005. Four community forest fragments were also inventoried (Figure 1). These were old growth forests of 40 to 45 years old, which were considered by local farmers as "black forest" (humid forest areas depending on their perceptions). In these forests, the farmers' activities of harvesting non-timber forest products (NTFPs) were uncontrolled and difficult to measure.

Rainfall and temperature database from 1996 to 2009 show that climate regime for this area had four seasons: two dry and two rainy seasons. The duration of the dry season was less than 5 months. Annual rainfall varied between 1500 and 2000 mm.

In 1907, Chevalier was the first botanist who inventoried in this area (Corthay 1996). The vegetation of the area is characterized by *Diospyro-Mapanietum* association (Mangenot, 1955). The main vegetation is evergreen rainforest (Guillaumet, 1967) that is being replaced by disturbed biotopes such as farms, fallows and secondary forests.

Data Collection

We surveyed plant species using stratified sampling method. Each forest type was considered as a stratum. Due to difficulties to have large integral patch in community forests and the fact that it is better to have many little plots than few large ones to estimate biomass and biodiversity (Magurran, 2004), in these forests, we selected 63 rectangular plots of 500 m^2 according to a random block design: Yapo protected forest (15 plots), NVR forest (25 plots) and community forests (23 plots). Also, according to Chisholm *et al.* (2013), this size is similar to typical scale forest survey (0.04 ha).

In each plot, all trees with a diameter greater than or equal to 10 cm at breast height (dbh), were identified. We included only trees ≥ 10 cm dbh because trees of this size contribute the vast majority of aboveground biomass (Chisholm et al., 2013). Identification of species was made on field. Undetermined specimens (less than 2%) were identified by Laurent Ake-Assi and by comparison to those of the National Herbarium of Côte d'Ivoire (*Herbarium ivorensis* UCJ).

Plant Species Diversity and Structural Heterogeneity

Species richness for each quadrat at each spatial grain was calculated by summing the number of tree species with stem ≥ 10 cm dbh in the quadrat.

In each forest type and for each species, the Importance Value Index (IVI, Cottam and Curtis, 1956) was determined. This index allowed combination of all data collected about species: number of individuals, frequency and importance depending on the basal area. This index is the sum of three quantitative biometric factors values: relative dominance which is representative of the basal area, relative frequency which is representative of occurrence and relative density representing the importance of the species in terms of individuals' number.

For each forest type, its conservation value was assessed by counting special status species or species with high conservation value: West African Guineo-Congolian (GCW) species which are endemic of West African forests (White, 1983), endemic species of Upper Guinean Forest (Poorter et al., 2004), and endemic species of Ivorian flora (Aké-Assi, 2001-2002). Also, endangered, rare and threatened species were identified according to the red list of International Union for Conservation of Nature (IUCN, 2014).

We quantified diversity with three commonly used indices: species richness (S), Shannon (1948) entropy (H') and Pielou (1966) index of evenness (J) which measures how close in terms of number of stems species are. These indices were calculated for each plot and average values per forest types in order to assess their floristic diversity.

We counted all stems with dbh ≥ 10 cm to calculate stems density and basal areas for each forest and by plot. Average values per plot of density of individuals and basal area of all individuals were then determined for forest types. Stems distribution curves based on diameter classes were analyzed to defined forest structures.

Estimation of the Above Ground Biomass (AGB)

We used generic algometric equations for moist tropical forests (Chave et al*.,* 2005) for AGB estimation. Total AGB for each quadrat at each spatial grain was calculated by summing AGB for all stems in a quadrat. Data collected and area of Azaguié verify validity conditions of this equation: dbh between 5 and 156 cm for rainforest species (Chave et al., 2005), annual rainfall from 1500 mm to 4000 mm with one to five months dry season (Pearson et al., 2005). This equation is defined as follows:

$$B = \rho \; exp^{[-1{,}499+2{,}148 \ln(D)+0{,}207 \ln(D^2)-0{,}0281 \ln(D^3)]}$$

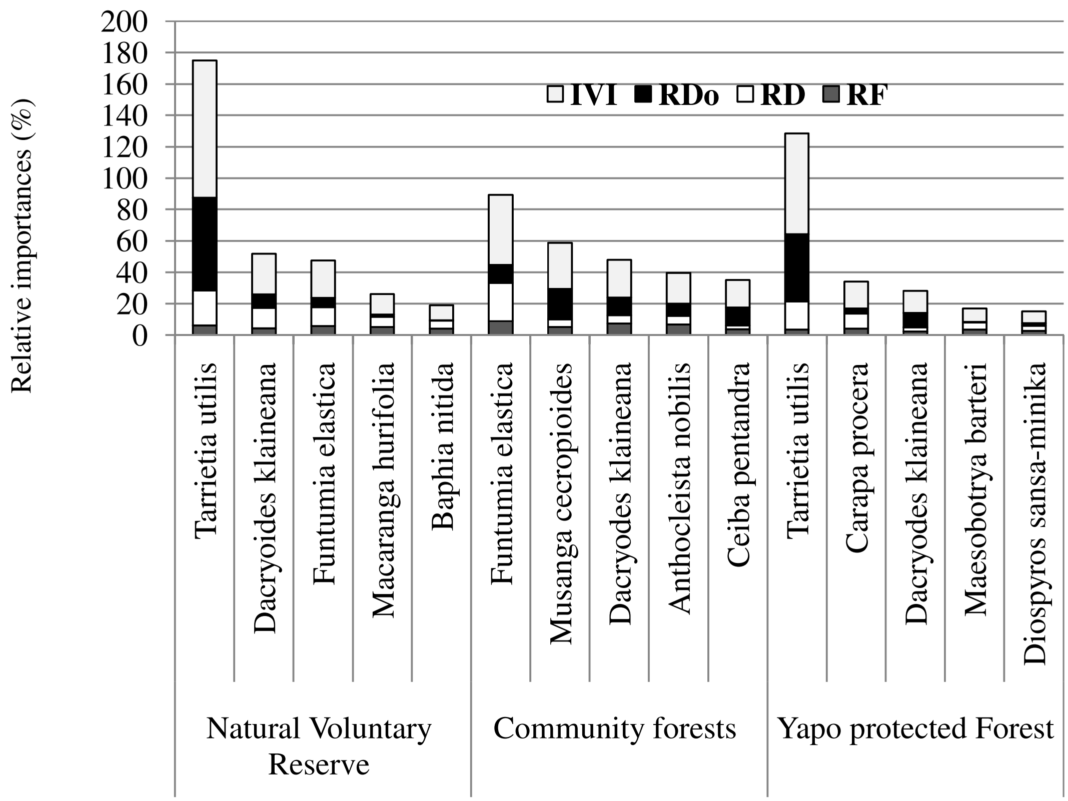

Figure 2 Preponderant species with at least 5 % of all IVI in three forests

Were B is AGB measured (tones/ hectare), D is the dbh (cm); ρ the specific gravity of a species (g/cm^3). Specific gravity was identified using the basic wood density Global database (Zanne et al., 2009) which includes 205 references. When specific gravity of a species and corresponding genus did not exist in the database, we used the default value (ρ = 0.58 g/cm^3) for African tropical forests (Reyes et al., 1992). This latter case concerned 31 species (18.9%) represented by 258 stems.

Statistical Analysis

For each forest type, averages of species Richness, diversity index, basal area, stem density and AGB were calculated and compared to another. We use analysis of variance tests for these comparisons. Before application of the analysis of variance test, normality of distributions was verified using Shapiro-Wilk test and the Homogeneity of variance was tested by Bartlett's test. If differences between averages of parameters were significant (*p* value < 0.05), a post-hoc test using Turkey's test, was performed. This test allowed us to identify differences between pairs of averages. Statistical analysis was performed with R.

RESULTS

Richness, Diversity and Floristic Composition

A total of 2375 stems and 164 tree species with diameter ≥10 cm were recorded in three forest types. They were 105 species in the NVR forest, 39 species in all community forests and 110 species in Yapo protected forest.

In NVR forest, preponderant species with at least 5 % of all IVI were in decreasing order: *Tarrietia utilis, Dacryodes klaineana* and *Funtumia elastic*. *Tarrietia utilis* had high value because its high

important relative dominance (61.55% of all basal areas) compared to other species (Figure 2). Stem density and frequency values of this species were also biggest in this forest. In NVR, IVI of *Tarrietia utilis* reached 126.62 (42.2% of all species IVI). In community forests four species had their IVI representing at least 5% of all indexes: *Funtumia elastica, Musanga cecropioides, Anthocleista nobilis* and *Dacryoides klaineana*. In these forests, *Funtumia elastica* had both highest number of stems (42.85 %) and frequency (27.73 %). In Yapo protected forest, *Tarrietia utilis* and *Dacryodes klaineana* with RDo, RD and RF are respectively relatives values of dominance, stems density and frequency; IVI = Importance Value Index Respectively 22.8 and 5.19%

Table 1 List of special status species recorded in the three forest types

Species	Family	Special status			Forest types		
		HG	IUCN	GCW / GCi	NVR	CF	YPF
Albizia ferruginea	Fabaceae	-	Vu	-	-	-	+
Anthocleista nobilis	Gelsemiaceae	-	-	GCW	+	+	+
Baphia pubescens	Fabaceae	-	-	GCi	+	-	+
Bombax brevicuspe	Malvaceae	-	Vu	-	+	-	-
Calpocalyx brevibracteatus	Fabaceae	1	-	-	+	-	-
Cleistanthus libericus	Annonaceae	-	-	GCW	+	-	+
Cola caricaefolia	Malvaceae	1	-	GCW	-	-	+
Dialium aubrevillei	Fabaceae	1	-	GCW	-	-	+
Dicranolepis persei	Thymelaeacaeae	1	-	GCW	-	-	+
Diospyros cooperi	Ebenaceae	1	-	GCW	+	-	-
Drypetes aylmeri	Phyllanthaceae	1	-	GCW	+	-	+
Drypetes ivorensis	Phyllanthaceae	-	-	GCW	+	-	-
Entandrophragma cylindricum	Meliaceae	-	Vu	-	-	-	+
Entandrophragma utile	Meliaceae	-	Vu	-	-	-	+
Leplaea cedrata	Meliaceae	-	Vu	-	+	-	+
Hymenostegia aubrevillei	Fabaceae	-	-	GCW	+	-	+
Maesobotrya barteri	Phyllanthaceae	-	-	GCW	+	-	+
Maranthes aubrevillei	Chrysobalanaceae	1	-	GCW	+	-	-
Milicia excelsa	Moraceae	-	LR	-	-	+	-
Millettia lane-poolei	Fabaceae	1	-	GCW	-	+	-
Millettia takou	Fabaceae	1	-	GCi	+	-	-
Napoleonaea vogelii	Lecythidaceae	-	-	GCW	+	-	+
Nauclea diderrichii	Rubiaceae	-	Vu	-	-	-	+
Octoknema borealis	Olacaceae	1	-	GCW	+	-	+
Placodiscus attenuatus	Sapindaceae	1	EN	GCW	-	-	+
Placodiscus pseudostipularis	Sapindaceae	1	EN	GCW	+	-	+
Robynsia glabrata	Rubiaceae	1	Vu	-	+	-	-
Samanea dinklagei	Fabaceae	-	-	GCW	-	-	+
Scaphopetalum amoenum	Malvaceae	1	-	GCW	+	-	+
Tarrietia utilis	Malvaceae	1	Vu	GCW	+	-	+
Terminalia ivorensis	Combretacaeae	-	Vu	-	-	+	+
Vitex rivularis	Verbenaceae	-	-	GCW	+	-	+
Xylopia villosa	Annonaceae	1	-	-	+	-	+

Special status HG endemic of Upper Guinean Forest ; GCi ; endemic of Ivorian flora ; GCW : endemic of West Guineo-Congolian , Vu : Vulnerable ; EN : Endanger; LR : Lower risk; NVR = Natural Voluntary Reserve; CF = Community forests; YPF = Yapo protected forest; + present; - absen

Of IVI, were the most important species. In this forest, *Tarrietia utilis* had highest dominance relative (43.10%) and stem density (18.20%).

Globally 33 species (20.12% of all recorded species) can be qualified as special status species (Table 1). NVR forest had most endemic species: 20 endemic species to West Africa (GCW), 16 endemic species to Upper Guinea (HG) and 2 endemic species of Ivorian flora (CGi). Yapo protected forest had 10 GCW species, 12 HG species and 2 CGi species. In community forests, there were very few endemic species (Table 1). According to the IUCN red list we surveyed 11 plant species in Yapo protected forest, 9 in NVR forest and 7 in community forests. *Baphia pubescens* (Fabaceae) was the only one endemic species to Ivorian flora which was recorded in these three forests. *Millettia takou* (Fabaceae), another endemic species of Ivorian flora was surveyed only in both protected forests. *Albizia ferruginea* (Mimosaceae) *Entandrophragma cylindricum* and *Entandrophragma utile* (Meliaceae) were three species on the UICN red list and surveyed only in Yapo protected forest.

The higher average value of species richness was significantly different in Yapo protected forest (S = 23.33 ± 1.79 species) and in NVR forest (S = 15.16 ± 1.45) than community forests (S = 5.96 ± 0.65 species) (ANOVA, F = 38.9, p *value* < 0.0001; df = 62).

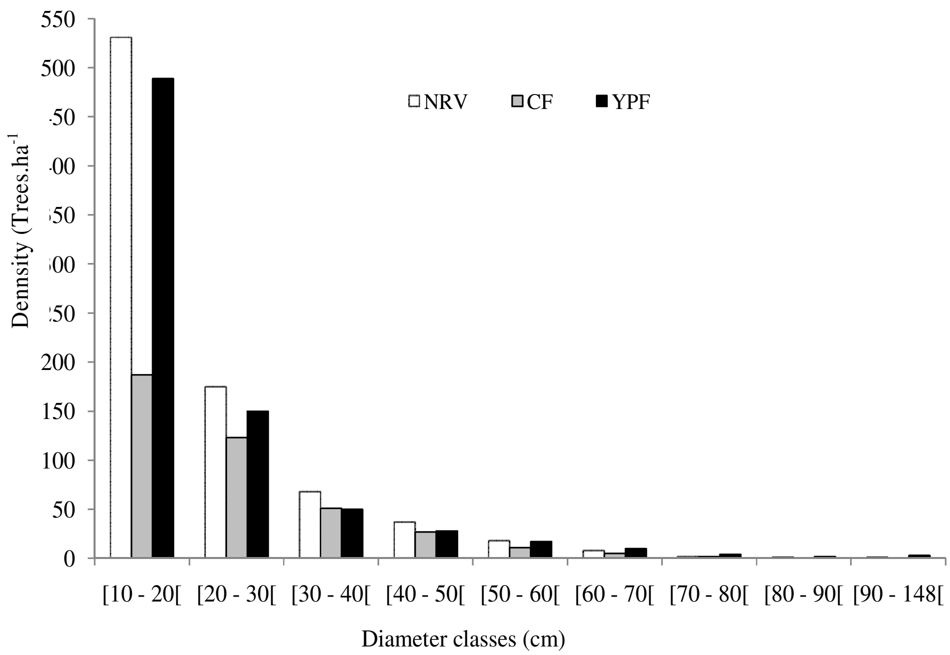

Figure 3 Histogram of stems distribution in diameter classes in sampled forests
NVR = Natural Voluntary Reserve; CF = Community forests; YPY = Yapo protected forest

We observed the higher Shannon index (H' = 5.78) in Yapo protected forest, and the lower Shannon index (H' = 4.64) in community forests. In NVR forest Shannon index was equal to 5.06. Average value of Shannon diversity index was significantly higher in Yapo protected forest (H' = 4.6 ± 0.09) and NVR forest (H' = 3.68 ± 0.14) than in community forests (H' = 2.68 ± 0.10.) (ANOVA, F = 52.81, *p value* <0.0001; df = 62).

Total evenness index was higher (J = 0.83) in community forests. This index decreased in Yapo protected forest (J = 0.81) and NRV (J = 0.71). Means of this index was higher (J = 0.92 ± 0.01 and J = 0.88 ± 0.01) respectively in community forests and Yapo protected forest. There was no significant difference between these two means of evenness obtained in these two forests. But evenness mean was lower significantly in NRV (J = 0.81 ± 0.02.) than Yapo protected forest and community forests (ANOVA, F = 13.976, *P value* <0.0001, *df* = 62).

Forest Structures and Aboveground Biomass

In community forests, number of living trees ≥ 10 cm dbh were 406 trees/ha. This value was lower than 841 trees/ha and 753 trees/ha recorded respectively in NVR forest and Yapo protected forest. We observed the higher basal area (49.01 m^2/ha) in Yapo protected forest than in NVR (34.41 m^2/ha) and community forests (5.72 m^2/ha). Diameter distribution showed that higher proportions of the trees were in the smaller diameter classes (Figure 3). In other words, there was a decline in the number of stems with increasing size classes. In Yapo protected forest and NVR forest, number of stem in smallest dbh class (10-20 cm), was the triple of upper class (20-30 cm). In community forest this proportion was lower and did not reach the double. The size-class distribution for the three forests decreased gently with increasing size class (Figure 3) and overall, structure described by diameter distribution was inverse J-shaped.

Mean AGB were respectively, 347.17 ± 101.70, 245.09 ± 31.68 and 35.69 ± 17.12 t.ha^{-1} in Yapo protected forest, RNV forest and community forests. There was significant difference between the groups of plots assigned to the three forests (ANOVA, F = 27.31, *p value* < 0.0001; *df* = 62).

DISCUSSION

Three forest types distinguished by their management mode have been surveyed. Yapo protected forest is managed by State body, via SODEFOR. NVR forest is private site and community forests are managed by local people without any protection law. Are these different management types impacted the conservation value of plant species in Azaguié area?

Generally, a forest with high richness and high level f endemic, rare or threatened species has priority attention for conservation (Hawthorne, 1996; Jennings et al., 2003; Tchouto, 2004). Some results of this study showed observations comparable to this criterion. In NVR forest 105 were recorded in 25 plots with 500 m^2 (84 trees species per hectare). In community forests there were 33

Trees species per hectare and in Yapo protected forest Yapo, 146 trees species per hectare. According to Gentry (1988), the number of tree species (dbh ≥ 10 cm) in tropical forests generally is between 120 and 200 species per hectare. So only species richness in Yapo protected forest was comparable to those tropical forests. This forest had also higher value of Shannon index. These results have a link with differences in managing of these three forests. Those were subjected to different human pressure. Because of its status, controlled loggings were regular in Yapo protected forest by SODEFOR. Effects of this operation have been less harmful to plant species diversity according to Shannon index and species richness values than to those in community forests and NVR forest. Since 1960s, in all Ivorian protected forests, timber were cut only if their diameters (dbh) were between 70 and 80 cm (Kouamé, 1998). This explains the remarkable drop in stems density after 70 cm dbh in these three forests. But because logging and timber exploitation are controlled in Yapo protected forest, stem density (753 trees/ha) and basal area (49.01 m^2/ha) were comparable respectively to intervals defined by Pascal (2003) for tropical forests. According to this author, in tropical forest stems density and basal area are respectively between 450-750 trees/ha and 25-50 m^2/ha.

NVR forest had not a final legal status before the study. First protective measures for this forest have been taken in 2005. Before this date NVR was under human pressures such as timber logging, hunting, harvesting of toothpicks and of other non timber forest products. Effects of all these uncontrolled activities could have reduced plant diversity and stem density as observed also in community forests. Those were free access space. They were so regularly disturbed by local people activities: harvesting of many plants for various purposes, for hunting and timber. These activities were intense and uncontrolled with severe impacts on diversity (decrease in number of tree species, stem density and basal area). In community forests, basal area (5.72 m^2/ha) and stem density (406 trees/ha) were far from those determined by Pascal (2003) and Silk et al. (2015) for tropical dense forests.

However, the structure described by diameter distribution of the three forest types presented inverse J-shaped. Due to diverse human activities in these forests, this J-shaped do not demonstrate the stability (climax) as generally in tropical moist forests. In this study it explains a good regenerative capacity of trees. The low rate of endemic, endangered, rare and threatened species listed by Aké-Assi (2001-2002) and Poorter et al. (2004) for Ivorian forests hosted by the studied forest could be due to the diverse human activities. Indeed, these species are most sensitive to human disturbances (Tchouto, 2004; Van Gemerden, 2004) and were often absent in degraded habitats, where they do not find suitable ecological drivers for their establishment and development (Faucon, 2009).

For evenness index, this study showed that in Azaguié area, trees species in community forests were most equitable than protected area which had higher stem density and ABG. It would mean that in both Yapo protected forest and NVR forest, the functioning of ecosystems, has guided by small number of tree species which were common. Many other tree species were uncommon or rare in these protected forests. As in most tropical rainforests both forest types had high proportion of rare species represented by a single occurrence. This observation is regular in other Ivorian protected forests such as Taï National Park (Scouppe, 2011). The same findings have been made in Paracou (Guyane) and Uppangala forest (Indian) (Collinet, 1997; Pascal and Pelissier, 1996). In the present study, the same observation has been made and was related to the high preponderance of *Tarrietia utilis* (Sprague) Sprague (Malvaceae) in both protected forests. Corthay (1996) demonstrated the dominance of this species in Yapo protected forest in which this species was replanted to enrich its vegetation in 1930s. The gregarious behavior of *Tarrietia utilis* mentioned by Aké-Assi (2001; 2002) in the study area could be one of the reasons that explain this observation. According to Salennave (1961) and Martinot-Lagarde (1961), Azaguié area is a natural habitat where this species grows. In community forests, *Tarrietia utilis* was absent because these forests were younger than Yapo protected forest and the NVR (more than 60 years old). In these secondary forests fewer 40 years, as mentioned by Khan (1982) individuals with large diameters were rare.

We compared AGB of each forest type with values of other tropical forests. The AGB of Yapo protected forest (347.17 ± 101.70 t/ha) and the NVR forest (245.09 ± 31.68 t/ha) were significantly higher than that of community forests (35.69 ± 17.12 t/ha). The differences between AGB in forest types could be explained by the variability in the proportions of large diameter stems. Indeed, in community forests, the range of diameter was not wide (70 - 80 cm). Only 5 and 2 stems exceeding 80 cm dbh respectively in Yapo protected and NVR forests have been recorded. Many larger stems played an important role in increasing AGB because the allometric equation (Chave et al., 2005) used during this study is a function of stem diameter. Studies focused on the quantification of AGB in the West African area were rare. One of these data relating to Ivorian forests concerned studies conducted by Lewis et al. (2014) who considered AGB in 12 African countries. According to these authors, in South-east Côte d'Ivoire / West Ghana, AGB ranged from 240 to 335 t/ha. AGB value of the NVR forest was between these two values. In Yapo protected forest, AGB was over estimated the maximum value (335 t/ha) gave by Lewis et al. (2014). In community forests, AGB value was very low and below the minimum value determined for south-eastern of Côte d'Ivoire. The same authors reported for the Southwest of Côte d'Ivoire, AGB ranging

From 336 to 426 t/ha. Only Yapo protected forest was within this range. However, largest AGB in Yapo forest was lower than the average for all dense humid forests (395.7 ± 117.4 t/ha, Lewis et al*.,* 2014) and those obtained in Central Africa (Djuikouo et al., 2010; Gourlet Fleury et al., 2013; Kearsley et al., 2013).

CONCLUSION

This study assessed diversity, floristic composition, and structural parameters according to three forest management types in Côte d'Ivoire: a protected forest managed by State body, an individual and private forest, and community forests managed by local people. The main result was that trees species in community forests are most equitable than protected area which have higher species richness, stem density, and aboveground biomass. For the three forests, structure described by diameter distribution was inverse J-shaped, explaining a good regenerative capacity of trees. Further researches will be necessary to explain the causes of variations on floristic and structural parameters, and to test possible relationships between aboveground biomass and trees diversity in these forest types. These researches could help to better understand the trade-offs between biodiversity and climate change for sustainable forest management.

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