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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 m². 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 CO₂ emissions and biodiversity conservation (Scheldeman and van Zonneveld, 2012) in tropical forests.

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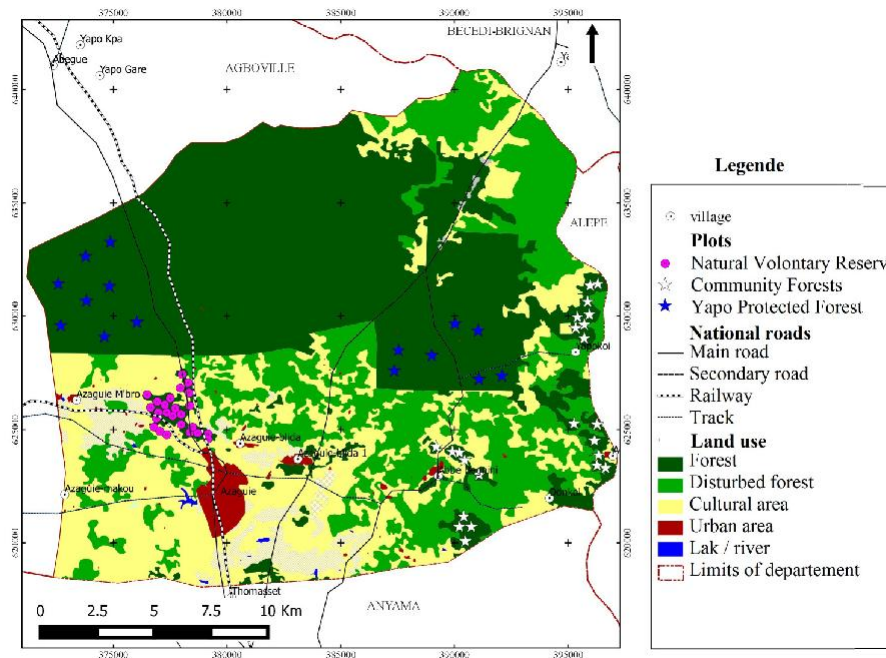


Figure 1 Map of land use and location of survey plots in Azaguié area (Source: Poorter *et al* 2004)

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 CO₂ (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 CO₂ 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 m² 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:

$$B = \rho \exp[-1.499 + 2.148 \ln(D) + 0.207 \ln(D^2) - 0.0261 \ln(D^3)]$$

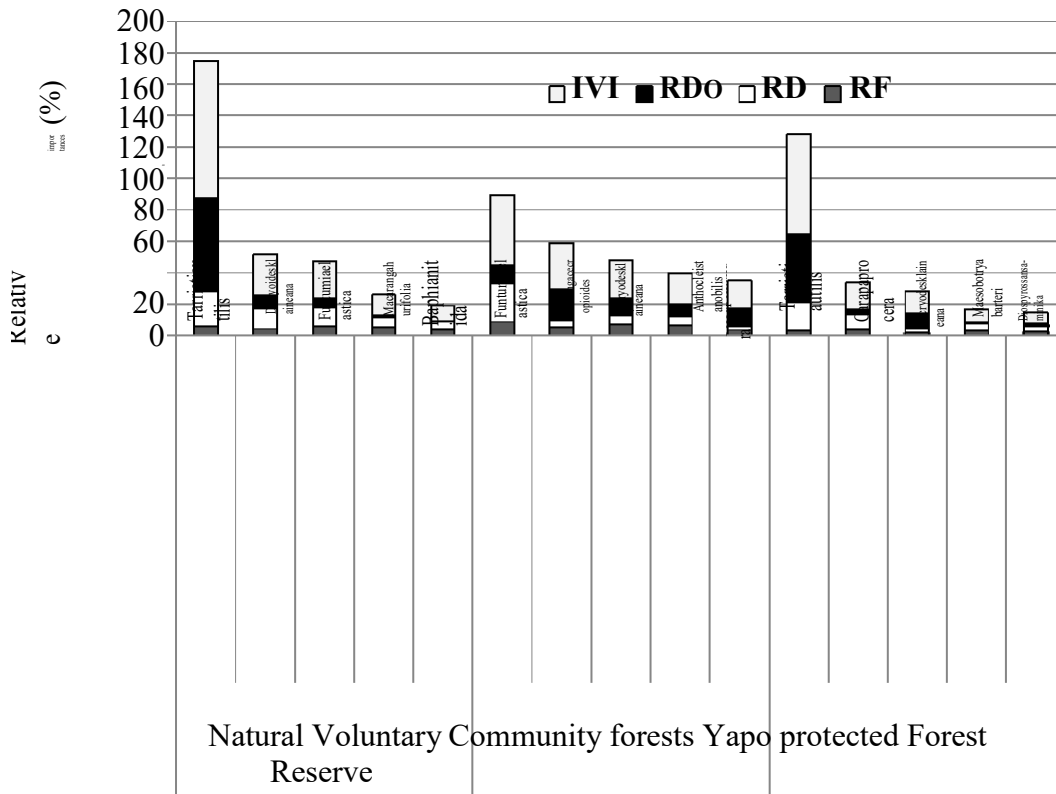


Figure 2 Preponderant species with at least 5 % of all IVI in three forests

Where 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 ($\rho = 0.58 \text{ g}/\text{cm}^3$) 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 elastica*. *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 *Dacryodes 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 relative 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
<i>Albizia ferruginea</i>	Fabaceae	-	Vu	-	-	-	+
<i>Anthocleista nobilis</i>	Gelsemiaceae	-	-	GCW	+	+	+
<i>Baphia pubescens</i>	Fabaceae	-	-	GCi	+	-	+
<i>Bombax brevicuspe</i>	Malvaceae	-	Vu	-	+	-	-
<i>Calpocalyx brevibracteatus</i>	Fabaceae	1	-	-	+	-	-
<i>Cleistanthus libericus</i>	Annonaceae	-	-	GCW	+	-	+
<i>Cola caricaefolia</i>	Malvaceae	1	-	GCW	-	-	+
<i>Dialium aubrevillei</i>	Fabaceae	1	-	GCW	-	-	+
<i>Dicranolepis persei</i>	Thymelaeaceae	1	-	GCW	-	-	+
<i>Diospyros cooperi</i>	Ebenaceae	1	-	GCW	+	-	-
<i>Drypetes aylmeri</i>	Phyllanthaceae	1	-	GCW	+	-	+
<i>Drypetes ivorensis</i>	Phyllanthaceae	-	-	GCW	+	-	-
<i>Entandrophragma cylindricum</i>	Meliaceae	-	Vu	-	-	-	+
<i>Entandrophragma utile</i>	Meliaceae	-	Vu	-	-	-	+
<i>Lepalea cedrata</i>	Meliaceae	-	Vu	-	+	-	+
<i>Hymenostegia aubrevillei</i>	Fabaceae	-	-	GCW	+	-	+
<i>Maesobotrya barteri</i>	Phyllanthaceae	-	-	GCW	+	-	+
<i>Maranthes aubrevillei</i>	Chrysobalanaceae	1	-	GCW	+	-	-
<i>Milicia excelsa</i>	Moraceae	-	LR	-	-	+	-
<i>Millettia lane-poolei</i>	Fabaceae	1	-	GCW	-	+	-
<i>Millettia takou</i>	Fabaceae	1	-	GCi	+	-	-
<i>Napoleonaea vogelii</i>	Lecythidaceae	-	-	GCW	+	-	+
<i>Nauclea diderrichii</i>	Rubiaceae	-	Vu	-	-	-	+
<i>Octoknema borealis</i>	Olacaceae	1	-	GCW	+	-	+
<i>Placodiscus attenuatus</i>	Sapindaceae	1	EN	GCW	-	-	+
<i>Placodiscus pseudostipularis</i>	Sapindaceae	1	EN	GCW	+	-	+
<i>Robynsia glabrata</i>	Rubiaceae	1	Vu	-	+	-	-
<i>Samanea dinklagei</i>	Fabaceae	-	-	GCW	-	-	+
<i>Scaphopetalum amoenum</i>	Malvaceae	1	-	GCW	+	-	+
<i>Tarrietia utilis</i>	Malvaceae	1	Vu	GCW	+	-	+
<i>Terminalia ivorensis</i>	Combretaceae	-	Vu	-	-	+	+
<i>Vitex rivularis</i>	Verbenaceae	-	-	GCW	+	-	+
<i>Xylopia villosa</i>	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 IUCN red list and surveyed only in Yapo protected forest.

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

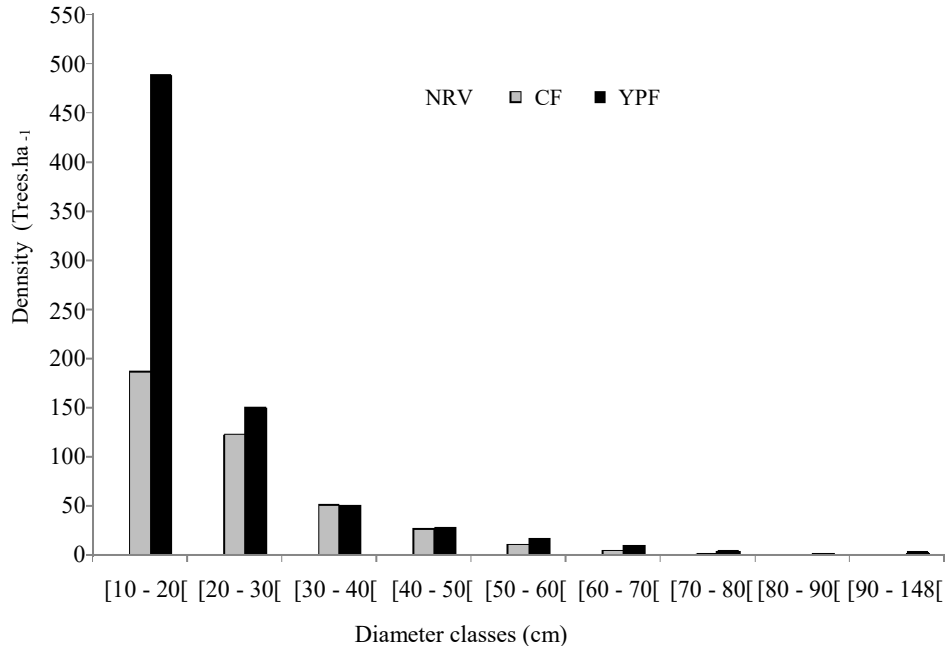


Figure 3 Histogram of stems distribution in diameter classes in sampled forests
 NRV = Natural Voluntary Reserve; CF = Community forests; YPY = Yapo protected forest

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 NRV forest Shannon index was equal to 5.06. Average value of Shannon diversity index was significantly higher in Yapo protected forest ($H' = 4.6 \pm 0.09$) and NRV forest ($H' = 3.68 \pm 0.14$) than in community forests ($H' = 2.68 \pm 0.10$.) (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 ($J = 0.92 \pm 0.01$ and $J = 0.88 \pm 0.01$) 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 ($J = 0.81 \pm 0.02$.) 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 NRV forest and Yapo protected forest. We observed the higher basal area ($49.01 \text{ m}^2/\text{ha}$) in Yapo protected forest than in NRV ($34.41 \text{ m}^2/\text{ha}$) and community forests ($5.72 \text{ m}^2/\text{ha}$). 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 NRV 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 $35.69 \pm 17.12 \text{ t.ha}^{-1}$ in Yapo protected forest, NRV 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. NRV 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 of 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 NRV 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 \geq 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 m²/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 m²/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 m²/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 (Scoupe, 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 Salenave (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 \pm 101.70 t/ha) and the NVR forest (245.09 \pm 31.68 t/ha) were significantly higher than that of community forests (35.69 \pm 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.

BIBLIOGRAPHY

- Aké-Assi L (2001). Flore de la Côte d'Ivoire 1, catalogue, systématique, biogéographie et écologie. *Boisseries*, 57:396.
- Aké-Assi L (2002). Flore de la Côte d'Ivoire 2, catalogue, systématique, biogéographie et écologie. *Boisseries*, 58:441.
- Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Fölster H, Fromard F, Higuchi N, Kira T, Lescure J-P, Nelson BW, Ogawa H, Puig H, Riéra B, Yamakura T (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145:87-99.
- Chave J, Riéra B, Dubois MA (2001). Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability. *J Trop Ecol*, 17:79-96.
- Chisholm AR, Muller-Landau HC, Rahman KA, Bebbler DP, Bin Y, Bohlman SA, Bourg NA, Brinks J, Bunyavejchewin S, Butt N, Cao H, Cao M, Cardenas D, Chang LW, Chiang JM, Chuyong G, Condit R, Dattaraja HS, Davies S, Duque A, Fletcher C, Gunatilleke N, Gunatilleke S, Hao Z, Harrison RD, Howe R, Hsieh CF, Hubbell SP, Itoh A, Kenfack D, Kiratiprayoon S, Larson AJ, Lian J, Lin D, Liu H, Lutz JA, Ma K, Malhi Y, McMahon S, McShea W, Meegaskumbura M, Razman SM, Morecroft MD, Nyctch CJ, Oliveira A, Parker GG, Pulla S, Puchi-Manage R, Romero-Saltos H, Sang W, Schurman J, Su SH, Sukumar R, Sun I-F, Suresh HS, Tan S, Thomas D, Thomas S, Thompson J, Valencia R, Wolf A, Yap S, Ye W, Yuan Z, Zimmerman JK (2013). Scale-dependent relationships between tree species richness and ecosystem function in forests. *J. of Ecology*, 1-11.
- Corthay R (1996). *Analyse floristique de la forêt sempervirente de Yapo (Côte d'Ivoire)*. Travail de diplôme, Université de Genève, 152.
- Cottam G, Curtis JT (1956). The use of distance measures in phytosociological sampling. *Ecology* 37:451-460.
- Day M, Baldauf C, Rutishauser E, Sunderland TCH (2013). Relationships between tree species diversity and above-ground biomass in Central African rainforests: implications for REDD. *Environmental Conservation*:1-9.
- Djuikouo MNK, Doucet JL, Charlemagne KN, Lewis SL, Sonké B (2010). Diversity and above ground biomass in three tropical forest types in the Dja Biosphere Reserve, Cameroon. *African J. of Ecology* 48:1053-1063.
- Faucon M P (2009). *Ecologie et biologie de la conservation des métallophytes. Le cas de Crepidorhopalon perennis et C. tenuis (Scrophulariaceae) des sols cupro-cobaltifères du Katanga*. Thèse d'Université Libre de Bruxelles Faculté des Sciences, 192.
- Gentry AH (1988). Trees species richness of upper Amazonian forests. *Ecology* 85:156-159.
- Ghazoul J, Sheil D (2010). *Tropical rain forest ecology, diversity, and conservation*. Oxford University press, 516.
- Gourlet-Fleury S, Mortier F, Fayolle A, Baya F, Ouédraogo D, Bénédet F, Picard N (2013). Tropical forest recovery from logging: a 24 year silvicultural experiment from Central Africa. *Philosophical transactions*: 1-10.
- Guillaumet JL (1967). *Recherche sur la végétation et la flore de la région du Bas Cavally (Côte d'Ivoire)*. Mémoire ORSTOM 20. Paris, France.
- Hawthorne WD (1996). Holes and the sums of parts in Ghanaian forest: regeneration, scale and sustainable use. *Proceedings of the Royal Soc. Edinburgh* 104:75-176.
- IUCN (2014). Red List Website. <http://www.iucnredlist.org/>.
- Jennings S, Nussbaum R, Judd J, Evans T (2003). *The High Conservation Value Forest Toolkit* Edition 1, Pro Forest, 27.
- Kearsley E, de Haulleville T, Hufkens K, Kidimbu A, Toirambe B, Baert G, Huygens D, Kebede Y, Defourny P, Bogaert J, Beeckman H, Steppe K, Boeckx P, Hans Verbeeck H (2013). Conventional tree height-diameter relationships significantly overestimate aboveground carbon stocks in the Central Congo Basin. *Nature communication*: 1-8.
- Khan F (1982). *La reconstitution de la forêt tropicale humide Sud-ouest de la Côte d'Ivoire*. ORSTOM, collection mémoires 97, Paris, 151.
- Kouamé NF (1998). *Influence de l'exploitation forestière sur la végétation et la flore de la forêt classée du Haut Sassandra (Centre-Ouest de la Côte d'Ivoire)*. Thèse Doctorat. 3e cycle, UFR Biosc., Université de Cocody- Abidjan, 227.
- Lewis SL, Sonké B, Sunderland T, Begne SK, Lopez-Gonzalez G, van der Heijden GMF, Phillips OL, Affum-Baffoe K, Baker TR, Banin L, Bastin FJ, Beeckman H, Boeckx P, Bogaert J, Cannière DC, Chezeaux E, Clark CJ, Collins M, Djangbletey G, Djuikouo MNK, Droissart V, Doucet JL, Ewango CEN, Fauset S, Feldpausch TR, Foli EG, Gillet JF, Hamilton AC, Harris DJ, Hart TB, de Haulleville T, Hladik A, Hufkens K, Huygens D, Jeanmart P, Jeffery KJ, Kearsley E, Leal ME, Lloyd J, Lovett JC, Makana J-R, Malhi Y, Marshall AR, Ojo L, Peh KS-H, Pickavance G, Poulsen JR, Reitsma JM, Sheil D, Simo M, Steppe K, Taedoum HE, Talbot J, Taplin JRD, Taylor D, Thomas SC, Toirambe B, Verbeeck H, Vleminckx J, White LJT, Willcock S, Woell H, Zomagho L (2014). Above-ground biomass and structure of 260 African tropical forests. *Philosophical transactions*:1-14.
- Magurran AE (2004). *Measuring biological diversity*. Blackwell Sciences, Ltd, New York.
- Mangenot G (1955). Etude sur les forêts des plaines et plateaux de la Côte d'Ivoire. *Etudes éburnéennes* 4 :5-61.
- Martinot-Lagarde P (1961). Le Niangon en plantation serrées sous forêt en Côte d'Ivoire. *Bois et Forêts des tropiques* 80:13-26.
- Montagnini F, Nair PKR (2004). Carbon sequestration: an under-exploited environmental benefit of agroforestry systems. *Agroforest Syst*, 61:281-298.
- Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA (2011). A large and persistent carbon sink in the world's forests. *Science*, 333:988-993.
- Parmentier I, Malhi Y, Senterre B, Whittaker RJ, Alonso A, Balinga MPB, Bakayoko A, Bongers F, Chatelain C, Comiskey JA, Cortay R, Djuikouo MNK, Doucet JL, Gautier L, Hawthorne WD, Issembé YA, Kouamé FN, Kouka LA, Leal ME, Lejoly J, Lewis SL, Nusbaumer L, Parren MPE, Peh KSH, Phillips OL, Sheil D, Sonké B, Sosef MSM, Sunderland TCH, Stropp J, ter Steege H, Swaine MD, Tchouto MGP, van Gemerden BS, van Valkenburg JLCH, Wöll H (2007). The odd man out? Might climate explain the lower tree a-diversity of African

- rain forests relative to Amazonian rain forests? *J. Ecol.* 95:1058–1071.
- Pascal J-P (2003). Notions sur les structure et dynamique des forêts tropicales humides. *Rev. For. Fr.* LV - Numéro special: 118-130.
- Pearson TRH; Brown S, Birdsey L, Richard A (2005). *Measurement guidelines for the sequestration of forest carbon*. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 42.
- Piélou EC (1966). Species diversity and pattern diversity in the study of ecological succession. *J. Theor. Biol.*, 10:370-383.
- Poorter L, Bongers F, Kouamé FN, Hawthorne WD (2004). *Biodiversity of West African Forests: An Ecological Atlas of Woody Plant Species*. CABI Publishing, Nederland, Pays-Bas, 521.
- Reyes G, Brown S, Chapman J, Lugo AE (1992). *Wood densities of tropical tree species*. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 15pp.
- Salennave P (1961). Niangon de Côte d'Ivoire et Niangon du Gabon. *Bois et forêts des Tropiques* 76:45-54.
- Scheldeman X, van Zonneveld M (2012). *Manuel de formation à l'analyse spatiale de la diversité et de la distribution des plantes*. Bioversity International, Rome, Italia. 186.
- Schroeder JM, Oke DO, Onyekwelu JC, Yirdaw E (2010). Secondary Forests in West Africa a Challenge and Opportunity for Management. *Forests and society responding to global drivers of change*: 335-353.
- Scoupe M (2011). *Composition floristique et diversité de la végétation de la zone Est du Parc National de Taï (Côte d'Ivoire)*. Master Université de Genève. 194.
- Shannon C E (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27:379-423.
- Sheil D, Puri RK, Basuki I, van Heist M, Wan M, Liswanti N, Sardjono MA, Samsodin I, Sidiyasa K, Permana E, Angi EM, Gatzweiler F, Johnson B, Wijaya A (2004). *A la découverte de la biodiversité, de l'environnement et des perspectives des populations locales dans les paysages forestiers. Méthodes pour une étude pluridisciplinaire du paysage*. Center for International Forestry Research, 97.
- Slik FJWS, Arroyo-Rodríguez V, Aiba S-I, Alvarez-Loayza P, Alves LF, Balvanera P, Bastian ML, Bellingham PJ, van den Berg E, da Conceição Bispo P, Blanc L, Böhning-Gaese K, PBoeckx P, Bernacci L, Bongers F, Bradford M, Brearley FQ, Hockemba MB-N, Bunyavechewin S, Matos DCL, Castillo-Santiago M, Catharino ELM, Chai S-L, Colwell RK, Robin CL, Clark C, Clark DB, Clark DA, Damas K, Dattaraja HS, Dauby G, Davidar P, DeWalt SJ, Ashton P, Boyle B, Chen Y, Culmsee H, Duque A, Durigan G, Eichhorn KAO, Eisenlohr PV, Eler E, Farwig N, Feeley KJ, Ferreira L, Field R, de Oliveira Filho AT, Doucet J-L, Ewango C, Forshed O, Franco G, Fredriksson G, Gillespie T, Gillet J-F, Griffith DM, Grogan J, Gunatilleke N, Harris D, Harrison R, Homeier J, Imai N, Itoh A, Jansen PA, Joly CA, Fletcher C, Amarnath G, Hector A, de Jong BHJ, Kartawinata K, Kearsley E, Kelly DL, Kenfack D, Kessler M, Kitayama K, Kooyman R, Larney E, Laumonier Y, Laurance S, Laurance WF, Lawes MJ, do Amaral IL, Letcher SG, Lu X, Mansor A, Marjokorpi A, Martin EH, Lindsell J, Meilby H, Montero DJMJC, Medjibe VP, Metzger JP, de Morisson Valeriano M, Mugerwa B, Millet J, Mohandass D, Nagamasu H, Ochoa-Gaona S, Page N, Parolin P, Parren M, Melo FPL, Nilus R, Parthasarathy N, Paudel E, Permana A, Piedade MTF, Pitman NCA, Poulsen AD, Poulsen J, Powers J, Prasad RC, Poorter L, Puyravaud J-P, Razafimahaimodison J-C, Reitsma J, dos Santos JR, Spironello WR, Romero-Saltes H, Rovero F, Rozak M, Ruokolainen K, Rutishauser E, Saiter F, Saner P, Santos BA, Santos F, Satdichanh M, Schmitt CB, Schöngart J, Schulze M, Sarker SK, Suganuma MS, Sheil D, Eduardo da Silva EP, Sist P, Stevart T, Sun I-F, Sunderand T, Suresh HS, Suzuki E, Tabarelli M, Targhetta N, Theilade I, Thomas DW, Tchouto P, Sukumar R, Hurtado JTJ, Valencia R, van Valkenburg JLCH, Do TV, Vasquez R, Adekunle V, Vieira SA, Webb CO, Whittfield T, Verbeeck H, Wich SA, Williams J, Wittmann F, Wöll H, Yang X, Adou Yao CY, Yap SL, Yoneda T, Zahawi RA, Zakaria R, de Assis RL, Luize BG, Venticinque EM, Zang R (2015). An estimate of the number of tropical tree species. *Proc. Natl Acad. Sci. USA (PNAS)*: Early Edition 1-10.
- Stahl J, Christopherson T (2010). La convention sur la diversité biologique et son programme forestier. *OIBT*, 18(1):3-7.
- Tchouto MGP (2004). *Plant diversity in central African rain forest. Implications for biodiversity conservation in Cameroon*. PhD thesis, Wageningen University, Wageningen, The Netherlands. 208.
- Van Gemerden BS (2004). *Disturbance, diversity and distributions in Central African rain forest*. Ph-D. Thesis, Wageningen University, 199.
- White F (1983). The vegetation of Africa, a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. UNESCO, *Natural Resources Research* 20:1–356.
- Woodall CW, D'Amato AW, Bradford JB, Finley AO (2011). Effects of Stand and Inter-Specific Stocking on Maximizing Standing Tree Carbon Stocks in the Eastern United States. *Forest Science*, 57(5):365-378.
- Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J (2009). Global wood density database. *Dryad. Identifier*.