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Evolution of Floristic Composition and Structural Parameters between Two Management Inventories in a Tropical Forest in the East Cameroon Region

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Abstract

The realization of two management inventories in 2003 and 2020 on the same forest concession made it possible to characterize the floristic composition and to describe some structural parameters on three sites established according to the period of exploitation. Due to the change in the orientation of the lines, it was noted that respectively 82 and 85 species from the first inventory are not found in the second and inversely. A total of 311 species were identified in 2003, compared to 314 in 2020. The density varies from 111 to 140 stems/ha for all the individuals, 19 to 25 for the main species and 15 to 20 for the most exploited species. The decrease in the basal area between the two phases of 12% for all the species and 13% for the main species on the site exploited before the first inventory indicates a persistence of the disturbance for years after logging. It is proposed to supplement the management plans decisions with annual measures based on more complete inventories and to ensure the application of reduced impact logging measures.

Keywords

Tropical Forest, Floristic Composition, Density, Basal Area

1. Introduction

The sustainable management of central African forests has been identified as an avenue for improving unsustainable logging practices in tropical forests (Nasi et al., 2012). It is governed by international commitments and forest policies which are articulated at the level of a legal document commonly called a management plan (Eba'a Atyi, 2001; Karsenty & Ferron, 2017). The management measures required by the concessionaires have their origin in the literature and scientific trials, most of which focus on the reconstitution of the exploited massifs. The reconstitution of exploited stands in the congo basin countries is determined using a formula defined by De Madron and Forni (1997). This formula considers some structural parameters of the exploited species (minimum diameter of exploitation, average annual growth). Also, several other parameters such as felling damage and mortality are taken into account with rates that do not reach consensus among researchers. The central indicator of this formula is the rotation that represents the period assumed for the potential exploited in a forest to be reconstituted by at least 50%. It varies from 20 to 30 years between the countries in central Africa, and applies to a species or a group of species. A 30-year rotation was chosen by Cameroon with a minimum of twenty species chosen by the forest manager among the main ones called managed species (MINEF, 2001; Leroy et al., 2013; BAD, 2018). The need to replenish resources over the long term is a major issue for forest management. Timber production is threatened and because it is not profitable enough, a forest concession runs the risk of being abandoned by the company that operates it. The massif could then be transformed into an agricultural area, thus eliminating most of the functions it fulfills (DYNAFAC, 2022). In addition to this species reconstitution, the protection and sustainable management of the forests requires a better understanding of their heterogeneity, the environmental drivers of their composition and their vulnerability to climate change (Lewis et al., 2013).

According to De Madron and Daumerie (2004), the methods for calculating forest possibility and reconstitution are based on empirical thresholds and jeopardize the regeneration of exploited forests. They were established within pilot research projects as decision-making aid tools for planners. Many observers denounce the increased risks of depletion of exploited resources if current management standards and practices are maintained (Zimmerman & Kormos, 2012). Adding to that, almost half (47%) of 2000 verified reconstruction calculations were incorrect and often significantly overestimated (Wilson, 2013). Also, the application of reconstitution rates on certain species has not changed a single harvest parameter for certain historically exploited and vulnerable species (Pérez et al., 2005; Cerutti et al., 2008). The evaluation of the gaps between the forecasts of the management plans and the effectiveness on the ground remains very little documented after twenty years of implementation. Several studies effectively reveal that the renewal of a commercial volume would be lower after the first rotation and forest would present a great degradation (Biwolé et al., 2012; Gourlet-Fleury et al., 2013; Doucet, 2003). An assessment of the effect of logging-related disturbance on forest structure and dynamics shows that the timber stock has slowly been rebuilt. It is essential in the framework of the revision of the standards that underlies the second generation of forest management (DYNAFAC, 2022).

Questions remain on the effectiveness of reconstitution formulas, the maintenance of diversity indices and other parameters such as density, basal area and diameter structure in a perspective of the implementation of sustainable forest management (Bolia et al., 2019). Studies on the variability of forest structure and diversity between different sites of the same forest according to local conditions are rare and poorly documented (Gérard et al., 2016). However, these parameters are essential in determining the indicators of the dynamics of forest ecosystems, an essential basis in their development. To this must be added the spatial structure of species, which is one of the key parameters for understanding ecological processes and the functioning of forest ecosystems (Gourlet-Fleury, 1998).

The objective of this study is to describe the evolution of the floristic composition and the structural parameters in a forest concession after fifteen years of implementation of the management plan.

2. Material and Methods

2.1. Material

Study Area

The study area is a production forest in which two management inventories were carried out respectively in 2003 and 2020 in Cameroon, in the East region, department of Boumba-et-Ngoko (**Figure 1**). The climate is tropical type with two dry seasons (early June to end of July and from mid-November to mid-March) and two rainy seasons (from mid-March to early June and from August to mid-November). The average annual rainfall is 1367 ± 208 mm. The average monthly temperature is 23.9˚C ± 0.7˚C with an average relative humidity of 76.4% ± 2.2%. The relief of the massif is relatively uneven with extreme altitudes varying between 506 and 801 m. There are some swamps, sometimes very extensive. On the surface, the soils mainly encountered are of the ferralitic type, deriving from the alteration of the metamorphic source rocks.

Located in the Guineo-Congolese domain, the flora consists of semi-deciduous dense humid forest with *Sterculiaceae* and *Ulmaceae* (Letouzey, 1968; Letouzey, 1985).

2.2. Methods

2.2.1. Sampling

In the study area, three sites were identified and named:

- Ame: which is a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020);
- NonAme: which was exploited before the first management inventory;
- NonExpl: where no exploitation has been carried out since the production forest was granted as a concession (**Figure 1**).

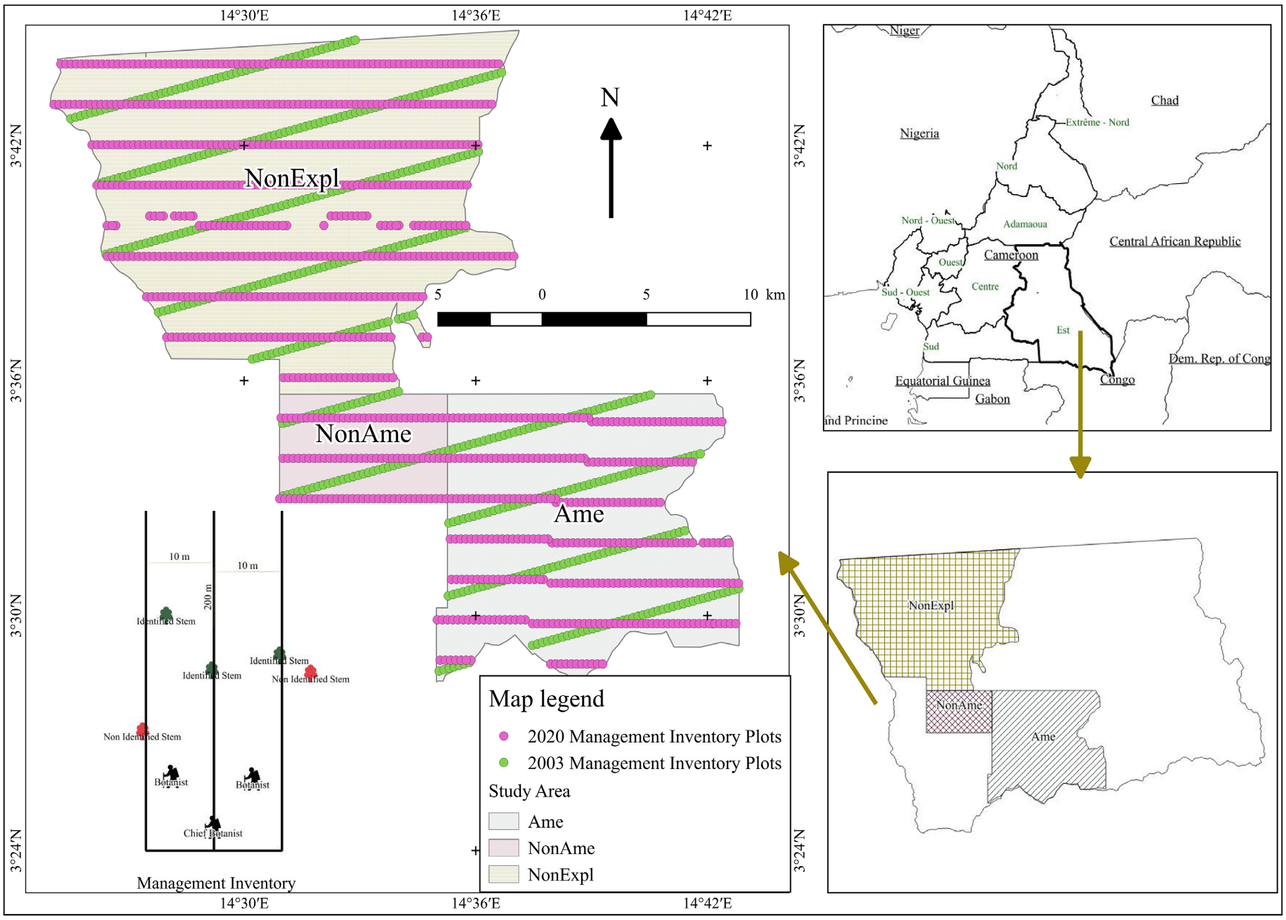

Figure 1. Location of the study area and presentation of the management inventory device. Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession.

2.2.2. Data Collection

The data was collected in 2003 and 2020 on plots positioned in the study area (see Figure 1).

On each plot consist of 250 m long and 20 m wide (i.e. 0.5 ha) positioned on equidistant lines, where all trees over 20 cm in diameter at chest height (DHP) have been inventoried. For each tree, the species was identified and the DBH was measured using a tape. Then on a sheet where information was given to identify the line, it was added on each line the common name of the species identified, a corresponding code, the class of DBH and in some cases a code indicating the quality of the tree.

Once this information has been computed following the line number, a link was established with a database of all known species to add scientific name, genus, family, group (main species composed of recognized by the administration as exploitable for wood or others) and the minimum management felling diameter (DMA). Depending on the line number, the different sites (Ame, NonAme and NonExpl) have been added, with their total area and their surveyed area. The two databases thus constituted were grouped together with precision in the first column of the inventory year (2003 or 2023). A comparison between the DBH class and the DMA made it possible to add a status for each species (exploitable for those with at least the DMA or No). It was also distinguished among these species those which are part of the 17 most exploited species identified on the basis of the analysis of production in Cameroon from 2007 to 2018.

This database was used for the various simulations.

2.2.3. Data Analysis

1) Floristic composition

The floristic composition represented by the number of each taxon (family, genus and species) found in the population. It is independent of the number of individuals represented in the taxon. This composition was determined for each management inventory phase, for all the sites and for each site individually, with all the species or only the main species, and taking all the individuals (TI) or only the exploitable individuals i.e. individuals with DBH greater than or equal to DMA (IE). It was also a question of highlighting the elements of the taxa which are in one phase of the inventory, but not in the other.

2) Density

Density is the number of individuals per ha. It was calculated according to the three sites (Ame, NonAme and NonExpl). It was calculated according to the formula:

$$D_i = N_i / S_i$$

where: D_i: Density in Site i; N_i: Number of individuals in Site i; S_i: Sampling area of Site i (equal to the multiplication of the number of plots in Site I time 0.5 ha).

3) Basal area

The basal area (m^2/ha) is the cumulative sum of the ratio of the area occupied by the base of the trunks to the area of the site. It was calculated according to the formula:

$$G = \sum_{i=1}^{n} N_i \left(\pi dm_i^2 / 4 \right)$$

where: G: basal area; π: 3.14; i: DBH class (Class 1 includes stems from 20 to 30 cm… Class 13 stems from 140 to 150 cm…); N_i: Number of individuals of class i; dm_i: Median diameter of the class ($dm_1 = 25$… $dm_{13} = 145$…).

2.2.4. Statistical Analyzes

The analyses of variances (ANOVA) were carried out using Fisher's test ($p < 0.05$) using Python 3.11.

3. Results

The study carried out made it possible to highlight the floristic composition and some structural parameters on the three sites according to the period of exploitation.

3.1. Floristic Composition

The floristic composition of all the species inventoried and of the main species was observed for the two inventories on all the sites on the one hand and on each site on the other.

The inventoried individuals were grouped in terms of species, genus and family as presented in Table 1.

Data from management inventories show 36,615 individuals belonging to 311 species, 210 genera and 61 families over a surveyed area of 277 ha during the first inventory in 2003, 61,647 individuals belonging to 314 species, 223 genera and 58 families over a surveyed area of 501 ha during the second inventory in 2020. The main species are made up of 43 species belonging to 34 genera and 15 families in the first inventory, and to 35 genera and 16 families during the second inventory.

This specific composition is not exactly the same when it is observed at the level of the three sites, both for all the species and for the main species.

The area surveyed during the first inventory (2003) is 94.5 ha for the Ame site, 27.5 ha for the NonAme site and 155 ha for the NonExpl site. It is, for the second inventory (2020) respectively 166 ha, 48.5 ha and 286.5 ha.

The floristic composition for the species inventoried on the different sites is presented in Table 2.

It is noted that none of the three sites bears all of the families found during each inventory. The number of species between the first and the second inventory is higher in the "NonExpl" site for all individuals (273 and 291 respectively for the 2003 and 2020 inventory phases), and for exploitable individuals (192 and 214). This number of species is lower in the "NonAme" site.

The most represented genus in all three sites is *Polyalthia* (Annonaceae). The genera *Celtis* (Ulmaceae) and *Terminalia* (Combretaceae) are also among the five most represented in all the sites, but at different frequencies.

Table 1. Number of individuals, families, genera and species listed according to the all the species and for main species. TI = All individuals; IE = Exploitable individuals. Percentage is the proportion of main species within all species.

Inventory Phase	Setting	All species		Main species		Percentage	
		IT	IE	IT	IE	IT	IE
2003	Stem	36,615	5813	6239	1434	17.04%	24.67%
	Species	311	216	43	36	13.83%	16.67%
	Gender	210	155	34	32	16.19%	20.65%
	Family	61	45	15	15	30.36%	41.46%
2020	Stem Total	61,647	9067	10,169	2325	16.50%	25.64%
	Species	314	228	43	37	13.69%	16.23%
	Gender	223	173	35	32	15.70%	18.50%
	Family	58	47	16	14	35.85%	42.22%

Table 2. Number of individuals, families, genera and species for the species inventoried on the three sites. TI = All individuals; IE = Exploitable individuals; Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession.

Inventory Phase	Setting	Study zone					
		Ame		NonAme		NonExpl	
		IT	IE	IT	IE	IT	IE
2003	Stem	13,256	2318	3626	580	19,733	2915
	Species	258	160	175	98	273	192
	Gender	184	120	134	82	185	139
	Family	55	43	49	32	51	41
2020	Stem	19,341	2927	5406	963	36,900	5177
	Species	256	174	211	126	291	214
	Gender	191	133	156	101	206	161
	Family	54	41	47	37	54	46

Observation of the data shows that for all individuals:

- On the Ame site, Erythropalaceae family is found in the first inventory, but not in the second. The families Huaceae and Simaroubaceae are found in the second inventory, but not in the first.
- On the NonAme site, Families Asteraceae, Flacourtiaceae and Salicaceae are found in the second inventory, but not in the first.
- On the NonExpl site, the families Araliaceae and Primulaceae are found in the first inventory, but not in the second. And families Zygophyllaceae, Chrysobalanaceae, Ochnaceae, Salicaceae and Simaroubaceae are found in the second inventory, but not in the first.

Since the issue of forest management is the sustainable exploitation, it is important to pay particular attention to the main species for exploitation.

The floristic composition for the main species at the farm on the different sites is presented in Table 3.

Table 3 shows that the number of main species recorded during the first and second inventories is higher on the NonExpl site (41 and 40 respectively), followed by the Ame site (39 and 36) and finally the NonAme site (28 and 34).

The most important species recorded in the two inventories appear in all the study sites: *Terminalia superba* Engl. & Diels (Fraké/Limba), *Alstonia boonei* De Wild (Emien), *Mansonia altissima* A. Chev.(Bété), *Triplochyton scleroxylon* K. Schum (Ayous/Obeche), *Entandrophragma cylindricum*(Sprague) Sprague (Sapelli), *Erythropleum ivorense* A. Chev. (*Tali*). *Pericopsis elata* (Harms) Meeuwen no longer appears in the second inventory in the Ame site.

Observation of the data shows that for all individuals:

Table 3. Number of individuals, families, genera and species recorded for the main species on the three sites. TI = All individuals; IE = Exploitable individuals; Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession.

Inventory Phase	Setting	Study sites					
		Ame		NonAme		NonExpl	
		IT	IS	IT	IS	IT	IS
2003	Stem	2391	658	698	151	3150	625
	Species	39	29	28	18	41	32
	Gender	31	25	24	17	31	28
	Family	14	12	10	8	14	14
2020	Stem	3495	725	969	262	5705	1338
	Species	36	33	34	27	40	35
	Gender	29	29	29	25	32	29
	Family	12	12	11	11	15	13

- On the Ame site, the species *Afzelia pachyloba Harms*, *Aningeria robusta* (*A. Chev.*) *Aubr. & Pellegr.*, *Baillonella toxisperma Pierre*, *Fagara heitzii Aubr. & Pellegr.*, *Gambeya africana* (*A.DC.*) *Pierre* (*1891*), *Khaya grandifoliola C. DC.*, *Antrocaryon klaineanum Pierre* (Rutaceae and Anacardiaceae) are found in the first inventory, but not in the second. The species *Autranella congolensis* (*De Wild.*) *A. Chev.*, *Gambeya lacourtiana* (*De Wild.*) *Aubrév. & Pellegr.* (*1961*), *Gambeya perpulchra* (*Mildbr. ex Hutch. & Dalziel*) *Aubrév. & Pellegr.* (*1961*), *Khaya ivorensis A. Chev.* are found in the second inventory, but not in the first.
- On the NonAmé site, the species *Afzelia pachyloba*, *Aningeria robusta*, *Fagara heitzii*, *Gambeya africana*, *Khaya grandifoliola* are found in the first inventory, but not in the second. The species *Aningeria altissima* (*A. Chev.*) *Aubr. & Pellegr.*, *Entandrophragma angolense* (*Welw.*) *C.DC*, *Entandrophragma utile* (*Dawe & Sprague*) *Sprague*, *Milicia excelsa* (*Welw.*) *C. C. Berg*, *Autranella congolensis*, *Canarium schweinfurthii Engl.*, *Daniellia ogea* (*Harms*) *Rolfe ex Holl*, *Desbordesia glaucescens* (*Engl.*) *Van Tiegh.*, *Gambeya lacourtiana*, *Gambeya perpulchra*, *Pterygota macrocarpa K. Schum. are* found in the second inventory, but not in the first.
- On the NonExpl site, the species *Afzelia pachyloba*, *Aningeria robusta*, *Gambeya africana*, *Khaya grandifoliola*, *Antrocaryon klaineanum* are found in the first inventory, but not in the second. The species *Antrocaryon micraster A. Chev. & A. Guillaum.*, *Entandrophragma congoense* (*De Wild.*) *A. Chev.*, *Gambeya lacourtiana*, *Maranthes gabunensis* (*Engl.*) *Prance* are found in the second inventory, but not in the first.

Similarly, it is noted for exploitable individuals:

- On the Ame site, the species *Aningeria robusta*, *Fagara heitzii*, *Gambeya africana*, *Guarea thompsonii Sprague & Hutch.* are found in the first inventory, but not in the second. The families *Aningeria altissima* (*A. Chev.*) *Aubr. & Pellegr.*, *Entandrophragma utile*, *Khaya anthotheca* (*Welw.*) *C. DC.*, *Lovoa trichilioides Harms*, *Autranella congolensis* (*De Wild.*) *A. Chev.*, *Desbordesia glaucescens*, *Gambeya lacourtiana*, *Staudtia kamerunensis* (*Warb.*) *R. Fouilloy* are found in the second inventory, but not in the first.
- On the NonAmé site, the species *Aningeria robusta*, *Entandrophragma candollei Harms*, *Gambeya africana*, *Nesogordonia papaverifera* (*A. Chev.*) *R Capuron*, *Pericopsis elata* are found in the first inventory, but not in the second. The species *Afzelia bipindensis Harms*, *Aningeria altissima* (*A. Chev.*) *Aubr. & Pellegr.*, *Entandrophragma angolense*, *Guarea cedrata* (*A. Chev.*) *Pellegr.*, *Guarea thompsonii Sprague & Hutch.*, *Khaya anthotheca* (*Welw.*) *C. DC.*, *Autranella congolensis*, *Canarium schweinfurthii*, *Daniellia ogea* (*Harms*) *Rolfe ex Holl.*, *Desbordesia glaucescens*, *Gambeya lacourtiana*, *Nauclea diderrichii* (*De Wild. & Th. Dur.*) *Merrill*, *Pycnanthus angolensis* (*Welw.*) *Warburg*, *Staudtia kamerunensis* are found in the second inventory, but not the first.
- On the NonExpl site, the species *Aningeria robusta*, *Fagara heitzii*, *Gambeya africana*, *Antrocaryon klaineanum* are found in the first inventory, but not in the second. The species *Aningeria altissima*, *Guarea cedrata*, *Guarea thompsonii*, *Antrocaryon micrasler*, *Entandrophragma congoense*, *Gambeya lacourtiana*, *Pterygota macrocarpa* K. Schum. are found in the second inventory, but not in the first.

The floristic composition shows some differences between two inventories and the three sites. To better understand the evolution of forest stand, the structural parameters need to be observed.

3.2. Structural Parameters

The structural parameters studied are density and basal area.

3.2.1. Density

The densities of all the individuals were calculated taking into account all the individuals with a DBH greater than or equal to 20 cm and the so-called exploitabl individuals, i.e. those with a DBH greater than or equal to at DMA. They are shown in **Table 4**.

The results of the first inventory show an average density for all the individuals of 132 stems/ha with 21 stems/ha for exploitable individuals (≥DMA). It decreases significantly ($P < 0.05$) by 9 stems/ha within the framework of the second inventory with 3 stems/ha for exploitable individuals. A significant decrease ($P < 0.05$) in density between the first and second inventory is observed in Amé and NonAme sites. The most important difference is recorded in the Ame site with 24 stems/ha of which 7 stems/ha are represented by exploitable individuals. This decrease represents 20 stems/ha in the NonAme site with 1 stem/ha for exploitable

Table 4. Density of all individuals of species inventoried by study site (stems/ha). TI = All individuals; IE = Exploitable individuals; Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession; on the same column, the densities followed by the same letter mean that there is no significant difference ($P < 0.05$).

Inventory Phase	Density (stems/ha)							
	Ame		NonAme		NonExpl		Total	
	TI	EI	TI	EI	TI	EI	TI	EI
2003	140.275[a]	24.529[a]	131.855[a]	21.091[a]	127.310[a]	18.806[a]	132.184[a]	20.986[a]
2020	116.512[b]	17.633[b]	111.464[b]	19.856[b]	128.796[a]	18.070[a]	123.048[b]	18.098[b]

individuals. It increases in the NonExpl site by one stem per hectare in the second inventory.

Considering the fact that not all the species are exploited, the evolution of the density on the main species of the exploitation have to be observed.

The densities of all individuals and of exploitable individuals are presented in Table 5.

Table 5 shows that the total density of the main species is 23 stems/ha during the first inventory is significantly different ($P < 0.05$) from that of the second inventory (20 stems/ha). This significant difference ($P < 0.05$) is observed at the level of Ame and NonAme sites, but not at the level of NonExpl site.

By looking at the exploitable individuals in this same group, a significant difference ($P < 0.05$) is noted between the results of the two inventories only at the level of the Ame site.

To go further, observations have been made on the most exploited species.

According to the analysis of exploitation data in Cameroon from 2007 to 2018, 17 species were identified as the most exploited in forest concessions. Among these species, three species are not found on our study sites. There are *Distemonanthus benthamianus* Baill. (Movingui) and *Brachystegia cynometrioides* Harms (Naga) which are not found in the concession and *Lophira alata* Banks ex Gaertn. (Azobé) who is found in the concession, but not in the study sites.

The evolution of the densities of the most exploited species out of the remaining 14 species and two other main species that are mostly represented in the inventories (*Mansonia altissima* A. Chev (Bété) and *Alstonia boonei* De Wild (Emien)) is presented in Table 6.

The distribution of the density of the most exploited species varies according to the study sites. *Terminalia superba* and *Triplochyton scleroxylon* show the highest densities for the two inventories on Ame and NonAme sites (which have already experienced a period of logging). Between the two inventories, it is noted for these two species a decrease in density on Ame and NonAme sites and an increase in NonExpl site.

Table 5. Density of all individuals of the main species inventoried by study site (Stems/ha). TI = All individuals; IE = Exploitable individuals; Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession; on the same column, the densities followed by the same letter mean that there is no significant difference ($P < 0.05$).

Inventory Phase	Density (stems/ha)							
	Ame		NonAme		NonExpl		Total	
	TI	EI	TI	EI	TI	EI	TI	EI
2003	25.302[a]	6.963[a]	25.382[a]	5.491[a]	20.323[a]	4.032[a]	22.523[a]	5.177[a]
2020	21.054[b]	4.367[b]	19.979[b]	5.402[a]	19.913[a]	4.670[a]	20.297[b]	4.641[b]

Table 6. Density of all individuals of the most exploited species inventoried by study site (stems/ha). Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession.

Scientific species name	Common Name	Density (stems/ha)					
		Ame		NonAme		NonExpl	
		2003	2020	2003	2020	2003	2020
Terminalia superba Engl. & Diels	Fraké/Limba	4.70	3.76	5.09	3.96	3.54	4.22
Alstonia boonei De Wild.	Emien	2.38	2.14	3.24	1.44	2.65	2.59
Mansonia altissima A. Chev.	Bété	2.32	2.31	3.16	2.37	1.19	1.47
Triplochyton scleroxylon K. Schum.	Ayous/Obéché	2.19	1.75	2.58	2.49	0.57	0.87
Erythrophleum ivorense A. Chev.	Tali	1.65	1.16	1.93	1.77	2.05	1.27
Entandrophragma cylindricum (Sprague) Sprague	Sapelli	1.88	1.49	1.60	1.34	1.29	1.35
Pterocarpus soyauxii Taub.	Padouk rouge	1.33	0.86	0.62	0.64	1.08	1.58
Pericopsis elata (Harms) Meeuwen, 1962	Assamela/Afrormosia	1.53	1.11	1.78	1.13	0.36	0.06
Eribroma oblongum (Mast.) Bodard	Eyong	0.92	0.82	1.45	1.09	0.74	0.94
Piptadeniastrum africanum (Hook. f.) Brenan	Dabéma	0.31	0.53	0.15	0.12	0.26	0.23
Staudtia kamerunensis (Warb.) R. Fouilloy	Niove	0.30	0.22		0.12	0.24	0.19
Pycnanthus angolensis (Welw.) Warburg	Ilomba	0.26	0.29	0.04	0.04	0.19	0.22
Cylicodiscus gabonensis Harms	Okan	0.38	0.25	0.04	0.06	0.12	0.13
Nauclea diderrichii (De Wild. & Th. Dur.) Merrill	Bilinga	0.06	0.13	0.22	0.08	0.22	0.22
Entandrophragma candollei Harms	Kossipo	0.04	0.03	0.11	0.02	0.04	0.05
Milicia excelsa (Welw.) C. C. Berg	Iroko	0.02	0.02		0.02	0.02	0.03
Total		20.29	16.86	22.00	16.72	14.55	15.42

It is noted on Ame site that *Entandrophragma candollei*, *Nauclea diderrichii* and *Piptadeniastrum africanum* have seen their density increased. The same for *Piptadeniastrum africanum*, *Pterocarpus soyauxii*, *Terminalia superba* and *Trip-*

lochyton scleroxylon on the NonAme site.

In the NonExpl control site, the density of certain species decreases. These are *Entandrophragma cylindricum*, *Milicia excelsa*, *Pycnanthus angolensis* and *Staudtia kamerunensis*.

The densities giving the number of stems can mask an important aspect of the development which is the growth of the species. The basal area was calculated to get an idea of the cover.

3.2.2. Basal Area

Basal area is used to characterize forest stands because it is directly related to the volume of standing timber and its increment is therefore a measure of timber production. It is a theoretically unitless number (ratio of two surfaces), but in practice the results are expressed in m^2/ha.

Table 7 presents the variations in basal areas between the two inventories.

The basal area of all the species found represents 269 m^2/ha during the first inventory in 2003 and is reduced to 225 m^2/ha in 2020 during the second inventory. It decreases between the first and second inventory and varies according to the study areas.

It is noted a reduction in the basal area in Ame site between the first and the second inventory, respectively of 30% and 35% for all the species inventoried and for the main species. This difference is also found in NonAme site (respectively 12% and 13%).

The most exploited species will best illustrate the impact of the basal area.

Table 8 show the evolution of the basal area on the different sites between two management inventories according to the most exploited species.

The most exploited species present a basal area representing respectively 68% and 69% of that of the main species between the inventories of 2003 and 2020 on the one hand, and 26% of all the species inventoried. The main exploited species are mostly abundant in the massif studied.

Overall, the basal area decreased between the years 2003 to 2020 according to the results of the management inventory. However, an increase is recorded for *Pterocarpus soyauxii*, *Piptadeniastrum africanum*, *Staudtia kamerunensis*, *Nauclea diderrichii* and *Milicia excelsa*

This increase base area varies according to species and study areas. In the

Table 7. Evolution of the basal area on the different sites between two management inventories according to the identified and main species. Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession; diff% represents the percentage of the difference in the basal areas between the two inventories compared to the first inventory.

Basal area (m^2/ha)	Ame			NonAme			NonExpl		
	2003	2020	Diff%	2003	2020	Diff%	2003	2020	Diff%
All species	103,213	72,213	30%	87,656	77,380	12%	78,128	75,571	3%
Main species	41,539	27.023	35%	35,082	30,364	13%	25,735	26,238	−2%

Table 8. Evolution of the basal area on the different sites between two management inventories according to the most exploited species. Ame: a site grouping annual felling zone exploited after the first management inventory (2003) and at least 10 years before the second (2020); NonAme: site that was exploited before the first management inventory; NonExpl: site where no exploitation has been carried out since the production forest was granted as a concession; diff% represents the percentage of the difference in the basal areas between the two inventories compared to the first inventory.

Basal area (m^2/ha)	Ame		NonAme		NonExpl	
Inventory year	2003	2020	2003	2020	2003	2020
Scientifics species names						
Terminalia superba Engl. & Diels	9.34	6.04	6.87	5.84	5.54	6.88
Triplochyton scleroxylon K. Schum.	7.34	4.23	6.63	7.46	1.27	2.05
Alstonia boonei De Wild.	5.35	2.88	3.93	2.06	4.38	3.83
Erythrophleum ivorense A. Chev.	3.48	2.10	3.19	3.16	3.03	2.14
Entandrophragma cylindricum (Sprague) Sprague	4.05	2.18	2.98	1.76	2.14	2.36
Mansonia altissima A. Chev.	1.84	1.86	2.31	1.91	0.87	1.33
Pericopsis elata (Harms) Meeuwen, 1962	2.25	1.50	2.35	1.92	0.39	0.09
Pterocarpus soyauxii Taub.	1.13	0.76	0.56	0.59	0.92	1.37
Eribroma oblongum (Mast.) Bodard	0.56	0.45	1.06	0.85	0.59	0.70
Piptadeniastrum africanum (Hook. f.) Brenan	0.55	0.61	0.26	0.33	0.45	0.41
Cylicodiscus gabonensis Harms	0.64	0.51	0.15	0.06	0.22	0.25
Pycnanthus angolensis (Welw.) Warburg	0.17	0.15	0.01	0.06	0.27	0.20
Nauclea diderrichii (De Wild. & Th. Dur.) Merrill	0.09	0.11	0.07	0.12	0.19	0.15
Staudtia kamerunensis (Warb.) R. Fouilloy	0.07	0.12		0.11	0.18	0.10
Entandrophragma candollei Harms	0.05	0.06	0.22	0.00	0.05	0.10
Milicia excelsa (Welw.) C. C. Berg	0.05	0.03		0.05	0.06	0.05
Total	36.97	23.57	30.57	26.29	20.55	22.01

"Ame" site there are represent by *Piptadeniastrum africanum*, *Staudtia kamerunensis*, *Nauclea diderrichii*, *Entandrophragma candollei*. In the "NonAme" site, it increases for four species: *Triplochyton scleroxylon*, *Pterocarpus soyauxii*, *Piptadeniastrum africanum*, *Nauclea diderrichii*. It decreases for half of the fourteen in the "NonExpl" site represented by: *Erythropleum ivorense*, *Pericopsis elata*, *Piptadeniastrum africanum*, *Pycnanthus angolensis*, *Staudtia kamerunensis*, *Nauclea diderrichii* and *Milicia excelsa*.

4. Discussion

The inventory data for this massif are in accordance with the phytogeographical descriptions of Letouzey (1968). Indeed, the forest formations encountered are identified as dense semi-deciduous humid forests. The five most represented families in terms of number of species (55%) of inventoried individuals are made up by order of magnitude of Annonaceae (13 genera), Fabaceae (48 genera), Euphorbiaceae (19 genera), Sterculiaceae (11 genera) and Apocynaceae (6 genera). Among the main species, *Terminalia superba* (Fraké) and *Alstonia boonei* (Emien) are the most important, and represent 30% of the individuals recorded in the first inventory, and 31% in the second.

One of the fundamental characteristics of dense tropical forests is the large number of representative species (DYNAFAC, 2022). A consequence of this diversity is that individuals of a given species generally only occur at very low densities. However, this can vary a lot from one area to another (De Madron, 2004; Choula et al., 2017). In addition, only 17% of the inventoried stems are proposed for exploitation as main species according to Cameroonian regulations, of which only 25% are exploitable. This result indicates a low valorization of existing species in our forest ecosystems.

The first and second inventories carried out on the same sites but with a different positioning of the survey plots reveal that the layout of the survey plan makes it possible to capture species or lose species. Indeed, 82 of the 311 species identified in the 2003 inventory data are not found in that of 2020. The same is true for 31 genera and 3 families (Simaroubaceae, Zygophyllaceae Chrysobalanaceae). Conversely, 85 of the 314 species identified in the 2020 inventory data, are not found in that of 2003. The same is true for 44 genera and 2 families (Erythropalaceae, Primulaceae).

The analysis of the specific diversity in the three sites studied shows that the diversity of the species varies according to the sites. Indeed, after the first management inventory, the number of species on the Ame site (258) is lower than that on the NonExp site (273) which has not been exploited since the allocation of the studied massif. This difference can also be justified by the previous exploitation of the forest that occurred between 1969-1995, during licensed cuts (GRUMCAM, 2020). The decrease and or increase of species between the two inventories in the same studied site which could be due to the difference in the positioning of the inventory layout. It could also be justified by the passage of the exploitation which reduced the potential available in the exploited zone.

It can be established that the result of a 1% survey does not provide the complete floristic composition of a site. There are taxa that can appear or disappear depending on the device of the sampling plan used.

The density differs according to the zones exploited or not. The density of species varies from 140 to 127 stems/ha in the first inventory and from 129 to 111 stems/ha in the second inventory depending on the study areas. This density is lower than that found by the studies of the DynAfFor network project, which alone cover most of the variability identified in the forests of the Congo Basin from 323 to 674 stems/ha (DYNAFAC, 2022). It corresponds to that found in the Central African tropical forests on a hundred per hectare which was considered lower than that of the forests of the Amazon with nearly 300 species per ha (wa Lisingo, 2016).

The distribution of species or specific richness within the same concession and in the same type of forest is very disproportionate. Indeed, the density is higher in the "Amé" zone (140 stems/ha) followed by the NonAme zone (132 stems/ha) and lower in the "NonExpl" zone (127 stems/ha) under the first inventory. This variation in distribution could reveal the fact that the operator favors the richest areas for exploitation during the plot and the provisional agreement (Gérard et al., 2016).

The decrease in density in the second inventory is normal on the Ame site, but not on the NonAme site. This result could be justified in the Ame zone by the transition to mining on average 10 years ago before the second inventory. This correlates with the results of Rechul (2022) which show that in the Congo Basin, logging in unexploited areas remains more or less stable and undisturbed as they have reached the climax, hence the slight variation in the density between the first and the second inventory.

Basal area (G) is an indicator of competition between trees and an indicator of stand quality. The basal area is strongly linked to the density of species. It is higher by 269 m^2/ha during the first inventory in 2003 and for all the species inventoried, and is reduced to 225 m^2/ha during the second inventory of 2020. In the context of the first inventory, the basal area on the Ame site was respectively 103.213 and 41.539 m^2/ha for all the species listed and the main species. It was lower on the NonExpl site, respectively by 78.128; 25.735 m^2/ha. These densities are much greater than those described by Gourlet-Fleury (1998), which has a basal area of 35.12 m^2/ha on average. Choula et al. (2013) found that values vary from 17 to 26 in Yingui forest. The largest area is observed between 1800 - 2400 m altitude (66.71 m^2/ha) and the smallest between 2400 - 2600 m (14.18 m^2/ha).

The main species occupy a significant proportion compared to all the other inventoried species of 38% in 2003 and is reduced to 37% in 2020. The species *Terminalia superba* remains the species with the largest basal area followed in descending order by *Triplochyton scleroxylon* (15 and 14 m^2), *Entandrophragma cylindricum* (9 and 6 m^2) and *Erythropleum ivorense* (10 and 7 m^2) respectively between the first and the second inventory. Certain theoretical developments of the last two decades allow us to conclude that it is now time to go beyond the use of the basal area to characterize the competitive environment of trees, in particular with respect to the light resource. The theory even tells us that the good performance, in some cases, of the basal area would only be fortuitous and linked to very specific conditions (Cordonnier, 2022).

Between the two inventories, it is noted for these two species a decrease in density on the Ame site and an increase on the NonAme and NonExpl sites. This can be explained by an overexploitation of the said species due to selective exploitation. *Triplochyton scleroxylo* being the most exploited species in Cameroon for more than 20 years of the implementation of the principles of management and even well before (Zimmerman & Kormos, 2012; Rechul, 2022).

The mostly dense species *Alstonia boonei* (Emien) and *Mansonia altissima* (Bété) appeared at de second and third position after *Terminalia superba* but their density decreased. This is due for their anthropological origine (Fayolle et al., 2015; Réjou-Méchain et al., 2021).

According to Morin-Rivat et al. (2014), several heliophiles species dominate the forest canopy of Central Africa due to the human action of these environments over the previous centuries. Some are of great commercial importance (*Triplochyton scleroxylon*, *Pericopsis elata*, *Terminalia superba*, *Erythropleum ivorense*, *Entandrophragma cylindricum*, *Milicia excelsa*, *Cylicodiscus gabonensis*, etc.). The impact of human action on the forest, when controlled, is therefore not always negative. In this case, it has contributed to the high current economic value of these environments. Such a model of forest enrichment should be integrated into the reflections on the sustainable management of tropical forests (DYNAFAC, 2022).

Result found during this study corroborate with Putz et al. (2012) with stated that logged forest closed to further logging for a century or more after the first harvest cannot, in practical terms, be renewed. Species diversity may increase temporarily as a result of these changes, but it could also decrease regionally when species in production forests become more homogeneous (Nasi et al., 2012).

5. Conclusion

The floristic composition between two phases of the management inventory shows variations on the sites studied which cannot be attributed to the modification of the positioning of the line which carries the plots. On the site which had not experienced any felling, it is noted an increase of the number of individuals counted from 19,733 to 36,900. More generally, more than 80 species found in one phase were not meet in the other. Thus, this inventory carries out at a reduced rate (0.5% to 1%), which serves as a basis for the management plans, does not provide any guarantee as to the identification of all the resources. It would be desirable to set up annual management decision that improves the sustainable management of forest.

Density and basal area decreased on the site which had been exploited before the first inventory and did not experience any felling between the two inventories, dropping respectively from 132 to 112 stems/ha and from 88 to 77 m^2/ha. It is therefore possible that disturbances on the forest stand will continue several years after logging has taken place, hence the need for greater rigor in the implementation of reduced-impact logging techniques.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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