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Research article

Diversity, above-ground biomass, and vegetation patterns in a tropical dry forest in Kimbi-Fungom National Park, Cameroon

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ABSTRACT

Research highlights: This study is one of few detailed analyses of plant diversity and vegetation patterns in African dry forests. We established permanent plots to characterize plant diversity, above-ground biomass, and vegetation patterns in a tropical dry forest in Kimbi-Fungom National Park, Cameroon. Our results contribute to long-term monitoring, predictions, and management of dry forest ecosystems, which are often vulnerable to anthropogenic pressures.

Background and objectives: Considerable consensus exists regarding the importance of dry forests in species diversity and carbon storage; however, the relationship between dry forest tree species composition, species richness, and carbon stock is not well established. Also, simple baseline data on plant diversity are scarce for many dry forest ecosystems. This study seeks to characterize floristic diversity, vegetation patterns, and tree diversity in permanent plots in a tropical dry forest in Northwestern Cameroon (Kimbi-Fungom National Park) for the first time.

Materials and methods: We studied associations between above-ground biomass and species composition, and how different vegetation types vary in terms of species composition, diversity, and carbon storage, in a dry forest in Kimbi-Fungom National Park, Cameroon. Vegetation was inventoried in 17 permanent 1-ha plots. Allometric equations were used to calculate above-ground biomass and carbon.

Results: We found an average of 269.8 tree stems ha^{-1} and 43.1 species ha^{-1}. Five vegetation types: semi-deciduous, gallery, mixed vegetation, secondary and the grassland/woody savanna forest were classified using TWINSPAN analysis. The five vegetation types had an average above-ground biomass of 149.2 t ha^{-1} and 74.6 tC ha^{-1} of carbon in the 17 ha analyzed. Canonical correspondence analysis (CCA) showed the importance of semi-deciduous forest over grassland/woody savanna forest.

Conclusions: This study demonstrated that the forest of the Kimbi-Fungom National Park is poor in plant diversity, biomass, and carbon, highlighting the need to implement efficient management practices. Fine-scale inventory data of species obtained in this study could be useful in developing predictive models for efficient management of tropical dry forests.

1. Introduction

Forest inventory and monitoring are key tools in understanding the structure, composition, diversity, above-ground biomass, and carbon storage of different vegetation types and habitats, and are also key in achieving targets for international agreements [1]. Dry forests rank among the most threatened ecosystems globally, creating a need for detailed assessments of biodiversity hotspots, carbon stocks, and the extent and preservation of these forests [2, 3]. Anthropogenic factors, such as agriculture, pastoral nomadism, and population expansion, are reducing dry forest extents, and natural factors like drought and fire also affect this biome; these ecosystems appear highly vulnerable even to small increases in temperature [4].

Cameroon, situated at the juncture of West and Central Africa, holds important extents of Lower Guinean forest [5, 6], holding rich biodiversity totaling around 9000 species, 1800 genera, and 230 families of vascular plants [7, 8, 9]. Cameroon holds three main biomes: dry savanna, moist savanna, and tropical rain forest. Dry savanna covers the

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northern parts of the country, and moist savanna and tropical rainforest form a mosaic across much of the rest of the country, except for montane areas. The dry savanna and moist semi-deciduous forest of Kimbi-Fungom National Park (KFNP), in the northwestern part of the country, are assumed to be relatively species-poor, albeit based on few studies [10, 11]. Indeed, fewer than 70 herbarium sheets, representing fewer than 60 plant species/100 km^2, have been collected from the KFNP area [8, 9, 12]. Although the vegetation of the Bamenda Highlands has been studied extensively [13, 14, 15], much remains to be understood regarding forest structure, species composition, species diversity, distribution, and carbon stocks across different vegetation types [10, 11]. Furthermore, few or no studies on carbon storage have been undertaken in dry forests in this region.

Generally, the vegetation of the newly-established KFNP remains poorly understood; since this park represents an important conservation effort in the region, a detailed understanding of its vegetation and biodiversity is paramount. A preliminary assessment of forest cover in KFNP during 1979–2015 based on images from the sensor revealed potential significant forest cover reduction through deforestation (Figure 1), further prioritizing research attention to this area. Hence, in this study, we aimed to determine the forest structure, composition, and abundance, and estimate existing biomass and carbon storage. Results are discussed in terms of carbon storage, and are placed in the context of other vegetation types in central Africa.

2. Materials and Methods

2.1. Study site

The study site lies in the Bamenda Highlands, in the North West Region of Cameroon, at latitude 6.5–6.9°N and longitude 9.8–10.5°E (Figure 2), covering 953.8 km^2. This site holds a mixture of humid semi-evergreen forest, woody savanna, grassland savanna, and gallery forest of the Sudano-Zambazien forest ecosystem [16] including habitats such as swampy *Pandanus* forest, *Raphia* forest, and inselberg. KFNP is surrounded by several other protected areas: Mt Oku, Mbembe Forest Reserve, Mt Tabenken, Nkom-Wum Forest Reserve, Mbi Crater, Kagwene Wildlife Sanctuary, Bali Ngemba Forest Reserve, and Bafut Ngemba Forest Reserve.

The climate of KFNP has two seasons within the Equatorial Cameroon climate type [11], with a dry season in November through mid-March with <100 mm; December to February are the driest months. The rainy season occurs in April–October each year, with August and September being the wettest months. No detailed climatic data are available for this area; however, it is not expected to deviate much from the nearby Mbembe Forest, <100 km away, which has the following climatic conditions: rainfall 1824–1958 mm, and annual mean temperature 21–24 °C. It's unfortunate that the KFNP area does not have a climate station. The nearest small rain gauge station is at Ako which is > 50 km away, and a weather station in Bamenda which is further away from the field site. KFNP soils are ferruginous, brown to gray in color [17], and with an acidity of around pH 5.6. Plots were established in the central part of the park, at elevations of 429–898 m.

2.2. Field sampling

Representative plots occurring in clusters of pre-classified vegetation formations (dry semi-deciduous, grassland savanna, gallery forest, swamp and secondary forest), as described in Letouzey 1985 [16] were sampled. Plots were selected using a simple random approach in each cluster. Four and a half hectares were sampled in a dry semi-deciduous forest: 10.1 ha in grassland/woody savanna, 1 ha in secondary forest, 0.8 ha in gallery forest, and 0.4 ha in mixed vegetation (Table 1). However, 0.2 ha of fallow land with no trees were recorded in plot 11 (Table 1). During the study period, the savanna areas of the reserve were under intensive cattle grazing, and the semi-deciduous forest was subjected to subsistence crop farming.

We used line transects of 500 × 20 m as plots, established across the various vegetation types (Figure 3). We established 17 plots in total (Table 2), on which all trees and lianas ≥10 cm trunk diameter at breast height (1.3 m, dbh) were sampled. Trees, shrubs, and lianas with trunk dbh <10 cm were measured with calipers, whereas trees and lianas ≥10 cm were measured with a diameter tape. Lianas were measured above the last rooting points, at 1.3 m above the ground [18, 19, 20]. Tree height was determined as the average of visual estimates by 3 field staff. All individuals were measured, and identified to morphospecies; voucher specimens were collected for each morphospecies. Dominant species were defined as species with highest abundance of stems; rare

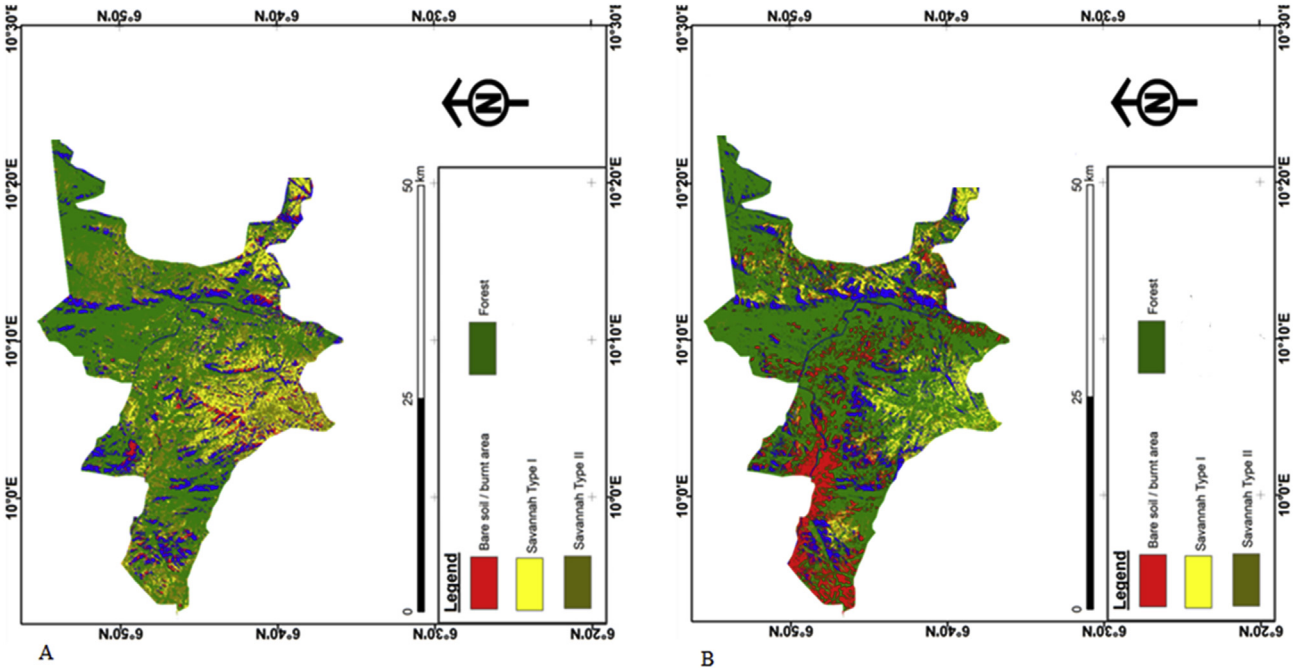

Figure 1. A. 60 m Landsat MSS (Multispectral Scanner) of 1979, B. 30 m Landsat 8 of 2015 for Kimbi Fungom National Park, Cameroon.

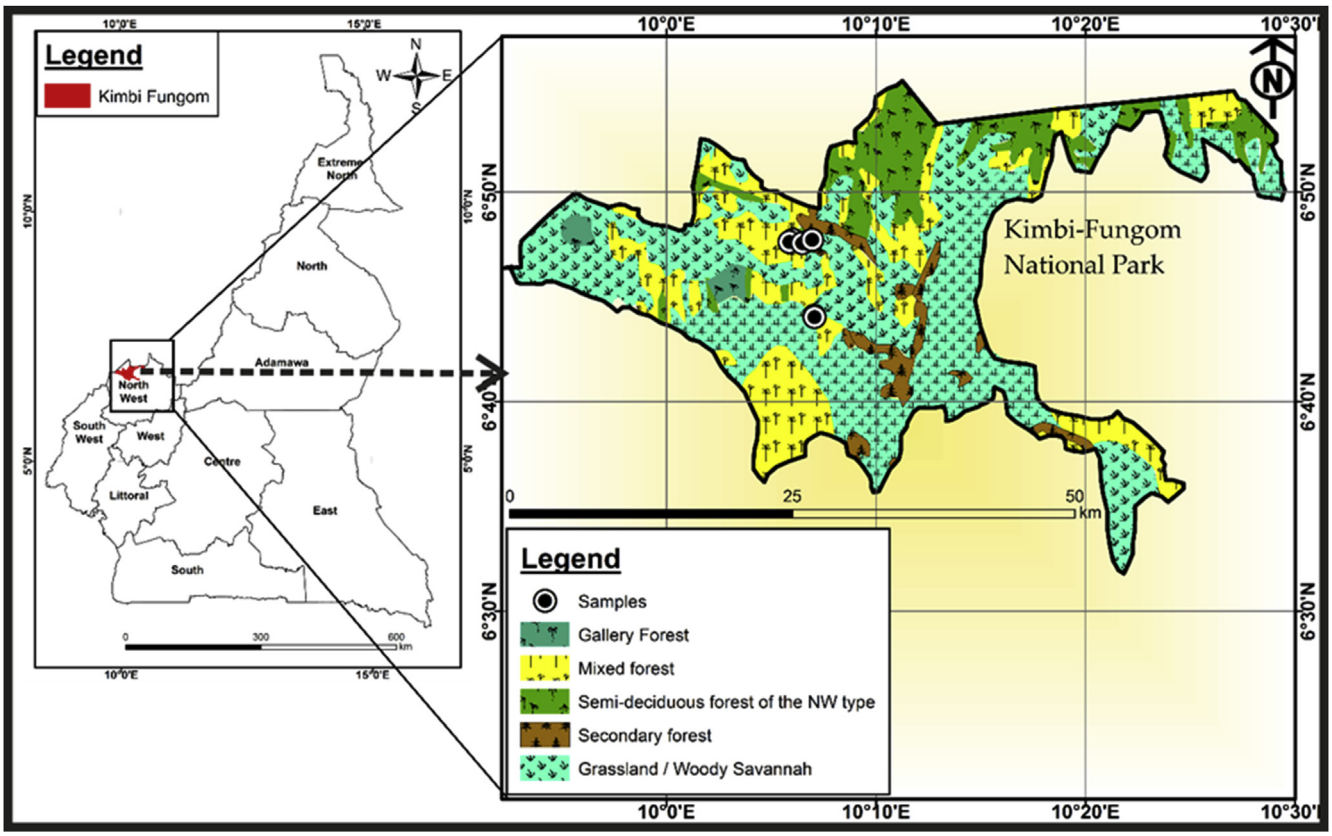

Figure 2. Map of vegetation types and sample locations across Kimbi-Fungom National Park, Cameroon.

species were those with <5 stems for each vegetation type. Habitat type (swamp SW, flat dry forest FD, slope SL, plateau PL) was recorded for each plot. Finally, outside of plots sampled, observational data were accumulated as we traversed the area, to enhance the general species list for the area.

2.3. Data analysis

TWINSPAN multivariate analysis was used to classify vegetation types using the PC-ORD package [21]. Species diversity estimates and correspondence analysis were achieved using PAST, version 2.17 [22]. Data for each vegetation type were separated into different life forms: trees ≥10 cm, shrubs ≤10 cm, and lianas ≥1 cm [23, 24, 25]. Forest structure was classified into three strata (life forms): <10 m, 10–30 m (10–29 m), and ≥30 m height.

Above-ground biomass (AGB) was estimated for all trees with dbh ≥10 cm, using the allometric equation of [26] (equation 1). Tree height was estimated following [27] (equation 2):

$$AGB = 0.0559\left(p\,D^2H\right) \quad (1)$$

$$H = e^{1.321+0.482\ \ln\ D+0.027\ln p} \quad (2)$$

where AGB = above-ground biomass (tons), ρ = wood specific density (g/cm^3) at 0% humidity [28], D (dbh) = diameter at breast height (1.30 m), e indicates the exponential function, and H = height (m).

Carbon was estimated for trees ≥10 cm as

$$C = \text{total biomass}/2 \quad (3)$$

Forest structure and composition were described using parameters, including basal area, relative density, relative dominance, relative frequency, and the importance value index [29].

We calculated basal area (BA), the area occupied by plant (species) at breast height, as

$$BA = p_i{}^*(1/2D)^2 = p_i{}^*(D)^2/4 \quad (4)$$

The Shannon-Weiner index (SW) is a useful index of diversity in 1-ha plots [29] and is calculated via the following formula:

$$SW = -\sum pilnpi \quad (5)$$

Table 1. Mean above-ground biomass, carbon, basal area, and species richness, across five vegetation types in Kimbi-Fungom National Park, Cameroon.

Vegetation Types	Area (ha)	Biomass (t/ha)	Carbon (t/ha)	Basal Area (m^2)	Number of Species	Abundance
Semi-deciduous forest	4.5	1453.2 (321.5)	726.6 (160.8)	27.7	126.0	1584.0
Grassland/woody savanna	10.1	728.8 (72.0)	364.4 (36)	1.6	75.0	2817.0
Secondary forest	1.0	161 (167.7)	80.5 (83.9)	12.9	54.0	280.0
Gallery forest	0.8	112.8 (141)	56.4 (70.5)	7.7	53.0	307.0
Mixed vegetation	0.4	81.5 (203.8)	40.7 (101.9)	0.8	36.0	135.0
Total	16.8	2537.3 (149.2)	1268.6 (75.5)	50.7	344.0	5123.0

First values are totals, Values in parenthesis = Corresponding mean values.

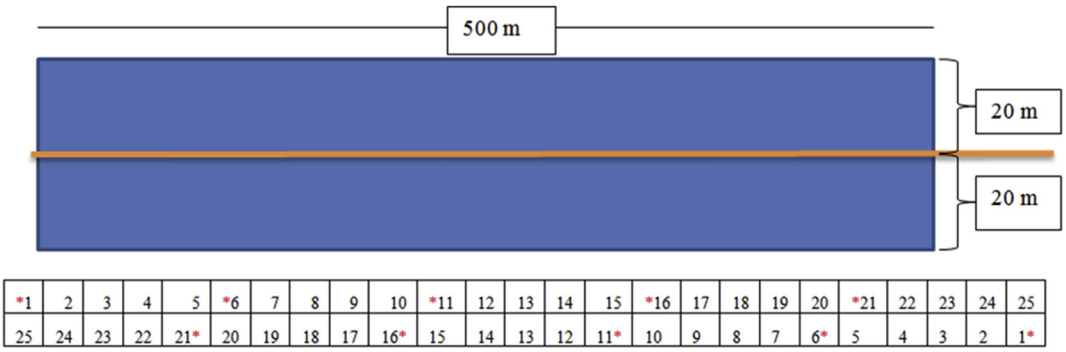

Figure 3. Field sampling design, showing two equal transect plots, with each plot covering an area of 1ha (500 m × 20 m). The red asterisks at 1, 6, 11, 16, and 21 represent locations of nested plots of 10 m × 10 m with more detailed sampling.

Table 2. Sampling plot locations in the Kimbi-Fungom National Park, Cameroon.

Plot	Vegetation type	Site	Location	Latitude (N)	Longitude (E)	Elevation (m)
1	PSF	KFNP	Kpep	6.79533	10.10048	481.0
2	PSF	KFNP	Kpep	6.79533	10.10048	481.0
3	PSF	KFNP	Kpep	6.79528	10.10029	474.0
4	G/WS_MV_PSF	KFNP	Kpep	6.79339	10.09769	429.0
5	PSF_G/WS	KFNP	Kpep	6.79359	10.09773	433.0
6	G/WS_GF_SF	KFNP	Kpep	6.79267	10.10803	439.0
7	G/WS_GF_SF	KFNP	Kpep	6.79267	10.10803	439.0
8	G/WS_MV_GF	KFNP	Kpep	6.79502	10.11571	396.0
9	G/WS	KFNP	Kpep	6.79484	10.11546	407.0
10	G/WS_PSF	KFNP	Kpep	6.79516	10.11585	410.0
11	SF_GF_G/WS	KFNP	Kpep	6.79534	10.11585	422.0
12	G/WS_GF	KFNP	Tunka-Esu	6.73506	10.11741	898.0
13	G/WS_GF	KFNP	Tunka-Esu	6.73506	10.11741	898.0
14	G/WS	KFNP	Tunka-Esu	6.73506	10.11741	898.0
15	G/WS_GF	KFNP	Tunka-Esu	6.73394	10.11772	846.0
16	G/WS_MV	KFNP	Tunka-Esu	6.73394	10.11772	846.0
17	G/WS_PSF	KFNP	Tunka-Esu	6.73394	10.11772	846.0

GF = Gallery Forest, G/WS = Grassland/Woody Savanna, MV = Mixed Vegetation, PSF = Primary Semi-deciduous Forest, SF = Secondary Forest.

where p_i is the proportion of individual of a species (number of individual of a species/total number of all species) and ln is the natural logarithm. The natural logarithm of the number of species or ln(S), is the maximum value of SW [29].

3. Results

3.1. Species composition and diversity

In total, 5551 stems of trees, shrubs, and lianas (multiple stems inclusive) were recorded in the 17 1-ha plots, with dbh ≥1 cm. We recorded 4987 stems of trees and lianas, with dbh ≥1 cm, belonging to 201 morphospecies, with an average density of 293 stems ha^{-1}; 564 trees and lianas had multiple stems. We recorded 4607 trees with dbh ≥10 cm, representing 178 species, 110 genera, and 42 families; an additional 350 trees with dbh <10 cm represented 84 species, 72 genera, and 33 families. We also recorded 30 stems of lianas ≥1 cm (27 stems with dbh ≥10 cm) representing 15 species, 15 genera, and 11 families (Table 3). In all, 147 species (76.9%) were identified to the species level; 118 genera (83.6%) were identified. The mean number of trees ha^{-1} with dbh ≥10 cm was 270 ± 74 trees ha^{-1} (range 157–404 trees ha^{-1}). Shrubs with dbh <10 cm had an average of 135 ha^{-1}, with a range of 5–495 ha^{-1}. Lianas with dbh ≥1 cm had a mean of 2.8 stems ha^{-1}, with a range of 1–6 stems ha^{-1}. In all, shrubs (dbh ≤10 cm) represent a mean SW index of 1.8, ranging from 0-3.4, lianas (dbh ≥1 cm) 0.26 ranging 0.6–1.8, and trees (dbh ≥10 cm) 3.14 ranging 2.6–3.5. These results reflect highest diversity in trees, followed by shrubs, in the study site (Table 3).

Species richness and diversity varied among plots and life forms, with a mean of 43 ± 13 species ha^{-1}, ranging 27–65 species ha^{-1}. The Shannon-Weiner diversity index was invariably ≥2.5, with an average of 3.1, ranging 2.7–3.5 (Table 4). In all, 144 species were collected outside sample plots as observational effort (Table 5).

Table 3. Vegetation cover types and corresponding numbers of species, stems, mean Shannon-Weiner diversity index, and range of values of Shannon-Weiner index in Kimbi-Fungom National Park, Cameroon.

Vegetation cover	Number of species	Number of stems	Mean Shannon-Weiner diversity index
shrubs	84	350	1.8 (0–3.4)
lianas	10	30	0.26 (0.26–1.8)
trees	178	4607	3.12 (2.6–3.5)

3.2. Basal area

The 17 ha plots gave a total basal area (dbh ≥10 cm) of 257.4 m^2, with a mean per plot of 15.1 m^2 ha^{-1} (range 6.8–32.4 m^2 ha^{-1}). The dominant family was Fabaceae (87.0 m^2, 33.2%; Table 6) followed by Chrysobalanaceae (27.3 m^2), Phyllanthaceae (21.6 m^2), Anacardiaceae (19.0 m^2), and Combretaceae (11.0 m^2). Dominant genera were

Table 4. Summary of density, number of species, above-ground biomass, carbon, and basal area in 17 ha plot across five vegetation types in Kimbi-Fungom National Park, Cameroon.

Plot	Vegetation type	Elevation (m)	Stem density	Tree density	Number of species	AGB (t/ha)	Carbon (t/ha)	BA (m^2/ha)
1	PSF	481.0	407.0	404.0	65.0	346.8	173.4	30.2
2	PSF	481.0	389.0	389.0	63.0	360.3	180.2	30.6
3	PSF	474.0	381.0	375.0	58.0	361.9	181.0	32.4
4	G/WS_MV_PSF	429.0	353.0	335.0	58.0	199.7	99.9	18.5
5	PSF_G/WS	433.0	237.0	213.0	43.0	137.2	68.6	14.6
6	G/WS_GF_SF	439.0	313.0	292.0	57.0	149.6	74.8	14.8
7	G/WS_GF_SF	439.0	356.0	311.0	50.0	86.2	43.1	11.9
8	G/WS_MV_GF	396.0	251.0	190.0	29.0	48.3	24.2	6.8
9	G/WS	407.0	314.0	250.0	32.0	68.9	34.5	9.6
10	G/WS_PSF	410.0	241.0	183.0	32.0	60.8	30.4	7.5
11	SF_GF_G/WS	422.0	202.0	157.0	27.0	89.4	44.7	8.6
12	G/WS_GF	898.0	289.0	244.0	36.0	80.6	40.3	10.6
13	G/WS_GF	898.0	297.0	292.0	34.0	86.0	43.0	10.9
14	G/WS	898.0	298.0	249.0	30.0	93.9	47.0	11.7
15	G/WS_GF	846.0	280.0	250.0	33.0	88.0	44.0	11.1
16	G/WS_MV	846.0	221.0	194.0	34.0	78.8	39.4	10.1
17	G/WS_PSF	846.0	296.0	259.0	52.0	200.4	100.2	17.4
	Total		5125.0	4587.0	733.0	2537.2	1268.9	257.4
	Mean		301.5	269.8	43.1	149.2	74.6	15.1
	Standard deviation		60.4	74.1	13.3	104.8	52.4	8.2

GF = Gallery Forest, G/WS = Grassland/Woody Savanna, MV = Mixed Vegetation, PSF = Primary Semi-deciduous Forest, SF = Secondary Forest.

Brachystegia (31.4 m^2), *Maranthes* (26.3 m^2), *Uapaca* (17.7 m^2), *Daniellia* (17.1 m^2), *Pseudospondias* (11.3 m^2), and *Terminalia* (10.3 m^2) (Table 6). Dominant species were *Brachystegia eurycoma*, *Maranthes glabra*, *Daniellia oliveri*, *Uapaca togoensis*, *Pseudospondias microcarpa*, and *Terminalia glaucescens* (Table 7). The total basal area for trees <10 cm dbh was 1.7 m^2 ha^{-1} whereas lianas gave 3.6 m^2 ha^{-1}. Semi-deciduous forest had the largest basal area of 27.7 m^2 ha^{-1}, followed by secondary forest (12.9 m^2 ha^{-1}), gallery forest (7.7 m^2 ha^{-1}), grassland/woody savanna (1.6 m^2 ha^{-1}), and mixed vegetation (0.8 m^2 ha^{-1}) (Table 1).

3.3. Forest structure

Average tree height in the five vegetation types ranged from 2–45 m. The 17 ha plots held 4607 trees of 178 species, 110 genera, and 42 families in morphospecies for trees ≥10 cm dbh. Trees <10 m tall formed the bulk of abundance, representing 66.6% (3068 tree stems). Trees 10–29 m tall represented 29.0% (1336 tree stems), and trees of height ≥30 m represented 4.1% (190 stems) of the total stems. Based on the different vegetation types, for trees <10 m tall, gallery forest represented 6.6% (201 stems), woody and grassland savanna 66.2% (2029 stems), mixed vegetation 2.1% (63 stems), semi-deciduous forest 19.8% (606 stems), and secondary forest 5.5% (169 stems), of total numbers of stems.

3.4. Classification and vegetation patterns

Multivariate analyses using TWINSPAN revealed five vegetation types, a dry semi-deciduous forest (here termed primary forest), and four dry forest types (here identified as secondary forest, gallery forest, mixed vegetation, and grassland/woody savanna) in Cameroon (Figure 4), with 4607 stems in 178 morphospecies, 110 genera, and 42 families. Twenty-one and twelve individuals were not identified to genus and family, respectively. Main and secondary forest matrices were based on abundances of tree species ≥10 cm that were all identified to species, measured for dbh, and with data on elevation (Figure 4).

In all, seven plots held elements of semi-deciduous forest, representing 4.5 ha of 17 ha sampled, with a total of 1559 stems in 130 species, 89 genera, and 39 families. Dominant species were *Maranthes glabra*, (227 stems), *Sorindeia grandifolia* (95 stems), *Spondianthus preussii* (93 stems), *Pseudospondias microcarpa* (85 stems), *Chrysophyllum ubanguiense* (75 stems), and *Brachystegia eurycoma* (70 stems). In this vegetation type, 37 species were rare, with one individual each, such as *Beilschmiedia gabonensis*, *Bridelia atroviridis*, *Daniellia oliveri*, *Englerophytum stelechanthum*, and *Shirakiopsis elliptica*.

Secondary forest (three plots), with 0.96 ha of the 17 ha sampled, had 259 stems pertaining to 55 species, 44 genera, and 26 families. One morphospecies was identified only to genus and one only to family. Dominant species were *Hallea stipulosa* (36 stems), *Ricinodendron heudelotii* (18 stems), *Albizia zygia* (17 stems), *Trema orientalis* (12 stems), and *Anthocleista djalonensis* and *Sterculia tragacantha* with 10 stems each. Eighteen species were rare in this vegetation type, with one individual each, such as *Alstonia boonei*, *Daniellia oliveri*, *Erythrophleum suaveolens*, *Irvingia wombulu*, and *Quassia sylvestris*.

Gallery forest, found in eight plots representing 0.8 ha of the 17 ha sampled, had a total of 276 stems belonging to 53 species, 44 genera, and 24 families. Dominant species were *Uapaca togoensis* (96 stems), *Daniellia oliveri* (20 stems), *Vitex doniana* (13 stems), and *Hymenocardia acida* (11 stems); 19 rare species included *Afzelia africana*, *Albizia adianthifolia*, *Cassia arereh*, *Cola cordifolia,* and *Pterocarpus erinaceus*.

Mixed vegetation (four plots), representing 0.4 ha, had 129 stems belonging to 37 species, 31 genera, and 21 families, with two morphospecies not identified to genus or family. Dominant species were *Uapaca togoensis* (20 stems), *Maranthes glabra* (15 stems), *Vitex doniana* (9 stems), and *Nauclea latifolia* (8 stems); 16 rare species included *Annona senegalensis*, *Beilschmiedia anacardioides*, *Brachystegia eurycoma*, *Elaeis guineensis*, and *Vitex rivularis*.

Grassland/woody savanna (14 plots), representing 10.1 ha of the 17 ha sampled, had a total of 2383 stems belonging to 77 species, 55 genera, and 29 families (three morphospecies were not identified to genus, 28 morphospecies were not identified to family). Dominant species in this vegetation type were *Hymenocardia acida* (237 stems), *Terminalia glaucescens* (231), *Crossopteryx febrifuga, Nauclea latifolia* (225 stems), *Lophira lanceolata* (186 stems), *Daniellia oliveri* (147 stems), *Entada abyssinica* (116 stems), *Piliostigma thonningii* (111 stems), *Cussonia arborea* (105 stems), and *Uapaca togoensis* (86 stems). Rare species totaled 21, including *Albizia adianthifolia*, *Antidesma chevalieri, Erythrina senegalensis Maesopsis eminii*, *Magnistipula butayei*, *Milicia excelsa*, *Morelia*

Table 5. Plant species recorded in observational efforts (i.e., outside of sampling plots) in Kimbi-Fungom National Park, Cameroon.

Family	Species
Acanthaceae	*Acanthus montanus* (Nees) T.Anderson
Acanthaceae	*Asystasia decipiens* Heine
Amaranthaceae	*Amaranthus* sp.
Anacardiaceae	*Lannea kerstingii* Engl. & K.Krauce
Annonaceae	*Artabotrys aurantiacus* Engl. & Diels.
Annonaceae	*Uvaria* sp.
Annonaceae	*Xylopia* sp.
Apocynaceae	*Baissea axillaris* (Benth.) Hua
Apocynaceae	*Landolphia* sp.
Asclepiadaceae	*Marsdenia* sp.
Asparagaceae	*Asparagus flagellaris* (Kunth) Baker
Asparagaceae	*Chlorophytum macrophyllum* (A.Rich.) Aschers.
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Robinson (nat.)
Asteraceae	*Vernonia kotschyana* Sch. Bip.
Bignoniaceae	*Crescentia cujute* Billb. & Beurl. (exo.)
Chrysobalanaceae	*Dactyladenia barteri* (Hook.f.ex Oliv.) G.T.Prance & F.White
Chrysobalanaceae	*Magnistipula cuneatifolia* Hauman
Clusiaceae	*Garcinia* cf *barteri* Oliv.
Colchicaceae	*Gloriosa simplex* L.
Combretaceae	*Agelaea pseudobliqua* G.Schellenb.
Commeliniaceae	*Palisota ambigua* (P.Beauv.) C.B.Clarke
Connaraceae	*Connarus griffonianus* Baill.
Connaraceae	*Jaundea pubescens* (Baker) G.Schellenb.
Costaceae	*Costus spectabilis* (Fenzl) K.Schum.
Dichapetalaceae	*Dichapetalum* sp.
Dilleniaceae	*Tetracera masuiana* De Wild. & T.Durand
Dilleniaceae	*Tetracera* sp.
Dioscoreaceae	*Dioscorea alata* L.
Ebenaceae	*Diospyros monbuttensis* Gürke
Euphorbiaceae	*Shirakiopsis elliptica* (Hochst.) Esser
Fabaceae	*Albizia adianthifolia* (Shum.) W.F.Wright
Fabaceae	*Anthonotha macrophylla* P.Beauv.
Fabaceae	*Crotalaria macrocalyx* Benth.
Fabaceae	*Dalbergia* sp.
Fabaceae	*Dalbergiella welwitschii* Baker
Fabaceae	*Desmodium hirtum* Guill. & Perr.
Fabaceae	*Desmodium velutinum* (Wild.) DC.
Fabaceae	*Dialium zenkeri* Harms
Fabaceae	*Oddoniodendron micranthum* (Harms) Baker
Fabaceae	*Pseudarthria hookeri* Wright & Arn.
Fabaceae	*Sesbania* sp.
Fabaceae	*Tamarindus indica* Linn.
Fabaceae	*Tephrosia barbigera* Welw.ex Bak.
Gentianaceae	*Anthocleista liebrechtsiana* De Wild
Hypericaceae	*Psorospermum glaucum*
Hypericaceae	*Psorospermum* sp.
Hypericaceae	*Psorospermum* sp.3
Lamiaceae	*Lippia africana* Moldenke
Lamiaceae	*Vitex myrmecophila* Mildbr.
Lamiaceae	*Vitex thyrsifolia* Baker
Leeaceae	*Leea guineensis* G.Don
Loganiaceae	*Strychnos spinosa* Lam.
Loganiaceae	*Strychnos tricalysioides* Hutch. & M.B.Moss
Malvaceae	*Cola millenii* K. Schum.
Malvaceae	*Microcos mollis* Juss.
Malvaceae	*Sida corymbosa* R.E.Fr.
Malvaceae	*Sterculia setigera* Delile
Marantaceae	*Megaphrynium macrostachyum* (Benth.) Milne-Redh.
Melastomataceae	*Dissotis brazzae* Cogn.
Moraceae	*Ficus craterostoma* Mildbr. & Burret
Musaceae	*Ensete livingstonianum* (J.Kirk) Cheesman
Myristicaceae	*Coelocaryon botryoides* Verm.
Myrtaceae	*Eugenia obanensis* Baker.f.
Ochnaceae	*Campylospermum calanthum* (Gilg.) Farron
Ochnaceae	*Campylospermum excavatum* (Van Tiegh.) Farron
Ochnaceae	*Campylospermum flavum* (Schum. & Thonn.) Farron
Ochnaceae	*Rhabdophyllum affine* (Hook.f.) Van Tiegh.
Olacaceae	*Strombosia grandifolia* Hook.f.
Orchidaceae	*Ancistrochilus rothschildianus* O'Brien
Orchidaceae	*Ancistrorhynchus serratus* Summerh
Orchidaceae	*Bulbophyllum colubrinum* (Rchb.f.) Rchb.f.
Orchidaceae	*Bulbophyllum vulcanicum* Kraenzl.
Orchidaceae	*Eulophia euglossa* (Rchb.f.) Rolfe
Orchidaceae	*Habenaria longirostris* Summerhayes
Orchidaceae	*Habenaria malacophylla* Rchb.f.
Orchidaceae	*Liparis caillei* Finet
Orchidaceae	*Liparis guineensis* Lindl.
Orchidaceae	*Nervilia* sp.
Orchidaceae	*Polystachya odorata* Lindl.
Orchidaceae	*Vanilla imperialis* Kraenzl.
Passifloraceae	*Adenia cissampeloides* (Planch.ex Hook.) Harms
Passifloraceae	*Adenia* sp.1
Petiveriaceae	*Hilleria latifolia* H.Walter
Phyllanthaceae	*Bridelia micrantha* (Hochst.) Baill.
Phyllanthaceae	*Macaranga assas* Amougou
Phyllanthaceae	*Phyllanthus muellerianus* (Kuntze) Exell
Pittosporaceae	*Pittosporum viridiflorum* Sims subsp. Dalzielii (Hutch.) Cuf.
Proteaceae	*Protea madiensis* Oliv.
Rhizophoraceae	*Cassipourea zenkeri* (Engl.) Alston
Rosaceae	*Prunus africana* (Hook.f.) Kalkman
Rubiaceae	*Euclinia longiflora* Salisb.
Rubiaceae	*Gardenia lutea* Fresen.
Rubiaceae	*Gardenia vogelii* Hook.f.ex Planch
Rubiaceae	*Ixora anemodesma* K.Schum
Rubiaceae	*Ixora bauchiensis* Hutch. & Dalziel
Rubiaceae	*Leptactina* sp.
Rubiaceae	*Polysphaeria arbuscula* K.Schum.
Rubiaceae	*Psychotria* cf *ebensis* K.Schum.
Rubiaceae	*Psychotria peduncularis* (Salisb.) Steyerm.
Rubiaceae	*Psychotria vogeliana* Benth.
Rubiaceae	*Psychotria* sp.
Rubiaceae	*Psydrax kraussioides* (Hiern) Bridson
Rubiaceae	*Rothmannia ebamutensis* Sonké
Ruscaceae	*Dracaena aubryana* Brongn.ex E.Morren
Ruscaceae	*Dracaena surculosa* Lindl.
Rutaceae	*Clausena anisata* (Wild.) Hook.f.ex Benth.
Sapindaceae	*Paullinia pinnata* L.
Sapotaceae	*Porteria pierrei* (A.Chev.) Baehni
Smilacaceae	*Smilax kraussiana* Meisn.
Thymelaeaceae	*Dicranolepis disticha* Planch.
Violaceae	*Rinorea dentata* (P.Beauv.) O.Kuntze
Zingiberaceae	*Aframomum daniellii* (Hook.f.) K.Schum.
Zingiberaceae	*Renealmia* sp.

senegalensis, Pterocarpus erinaceus, and *Uapaca paludosa* (Table 1). Five quadrats were devoid of trees, shrubs, and lianas, representing 0.2 ha. As such, a total of 16.8 ha was sampled for woody vegetation at an elevation of 396–481 m.

Table 6. Eleven plant families with the highest above-ground biomass, and carbon stock in 17 1-ha plots in Kimbi-Fungom National Park, Cameroon.

Family	Biomass (t/ha)	Carbon (t/ha)	BA (m^2/ha)	Abundance	Relative abundance (%)
Fabaceae	914.9	457.5	83.3	887	17.3
Chrysobalanaceae	436.5	218.3	27.2	282	5.5
Phyllanthaceae	184.0	92.0	19.7	503	9.8
Anacardiaceae	159.8	79.9	18.6	331	6.5
Rubiaceae	138.8	69.4	7.7	783	15.3
Combretaceae	111.0	55.5	10.3	294	5.7
Ochnaceae	92.0	46.0	8.9	229	4.5
Arecaceae	56.0	28.0	5.5	49	1.0
Moraceae	49.3	24.7	7.3	198	3.9
Myristicaceae	46.0	23.0	5.7	40	0.8
Euphorbiaceae	45.7	22.8	9.0	159	3.1
Total	2234	1117.1	203.0	3755	73.3

Table 7. Ten species with highest above-ground biomass, and carbon stock in 17 1-ha plots in Kimbi-Fungom National Park, Cameroon.

Species	Biomass (t/ha)	Carbon (t/ha)	Basal Area (m^2/ha)	Abundance	Relative abundance (%)
Brachystegia eurycoma Harms	439.3	219.6	31.4	77.0	1.5
Maranthes glabra (Oliv.) G.T. Prance	426.2	213.1	26.2	263.0	5.1
Daniellia oliveri (Rolfe) Hutch. & Dalziel	145.4	72.7	16.9	174.0	3.4
Erythrophleum suaveolens (Guill. & Perr.) Brenan	132.6	66.3	7.5	51.0	1.0
Pseudospondias microcarpa (A.Rich.) Engl.	113.0	56.5	11.2	99.0	1.9
Terminalia glaucescens Planch.ex Benth.	102.9	51.5	9.5	271.0	5.3
Uapaca togoensis Pax	100.5	50.3	10.8	256.0	5.0
Lophira lanceolata Tiegh. Ex Keay	89.5	44.8	8.6	213.0	4.2
Pycnanthus angolensis (Welw.) Exell	46.0	23.0	5.7	40.0	0.8
Ricinodendron heudelotii (Baill.) Pierre ex Baill.	23.4	11.7	6.1	45.0	0.9

3.5. Above-ground biomass and carbon

Our 17 ha of sample plots yielded a total above-ground biomass of 2537.3 t, and carbon content of 1268.6 t (Table 4). Among the 11 families with highest AGB, Fabaceae had the highest AGB (914.9 t ha^{-1}), corresponding to 457.5 t ha^{-1} of carbon (Table 6). *Brachystegia eurycoma* had the highest AGB of any species (439.3 t ha^{-1}), equivalent to 219.6 t ha^{-1} of carbon (Table 7). Mean AGB by vegetation type was 203.8 t ha^{-1} in mixed vegetation forest, 72.0 t ha^{-1} in grassland/woody savanna, 141.0 t ha^{-1} in gallery forest, 167.7 t ha^{-1} in secondary forest, and 321.5 t ha^{-1} in semi-deciduous forest (Table 1).

An overall species list and abundance in the 17 1-ha permanent plots is represented in Table 8. The correspondence analysis showed that the first two axes accounted for 82% (axis 1 = 65% and axis 2 = 17%) of total variation in this study. Axes 1 and 2 explained over 71% of the variance. The correspondence analysis revealed two distinct associations among the variables; low number of species, low above-ground biomass, and grassland/woody savannah were associated, whereas high number of species, high above-ground biomass and semi-deciduous forest were associated (Figure 5).

4. Discussion

Tree diversity, density, and trunk diameter are important indicators in assessing forest above ground biomass and other ecological processes in tropical forests; these indicators vary across regions, vegetation types, and habitats. Average tree density in the dry forest of KFNP was generally lower compared to tropical dry forests in other regions: for example, mean tree densities of 994 stems ha^{-1} (dbh >10 cm) and 3486 stems ha^{-1} (dbh >1 cm) were documented in the tropical dry forest of Bannerghatta National Park of the Eastern Ghats in southern India and Hawaiian lowland dry forest, respectively [30, 31]. A study in nearby Mbembe Forest Reserve, in different vegetation types, gave an average of 741 stems ha^{-1} in woody savanna, 236 stems ha^{-1} in grassland savanna, and 4963 stems ha^{-1} in semi-deciduous forest at dbh ≥1 cm [10]. Trees with dbh ≥10 cm in Mbembe Forest had an average of 311 stems ha^{-1} in woody savanna, 124 stems ha^{-1} in grassland savanna, and 408 stems ha^{-1} in semi-deciduous forest [10]. The low tree density in KFNP and indeed in the greater Bamenda Highlands could be attributed to unsustainable practices such as gathering of fuel wood, timber exploitation, pastoral nomadism, and subsistence agriculture. Nevertheless, globally,

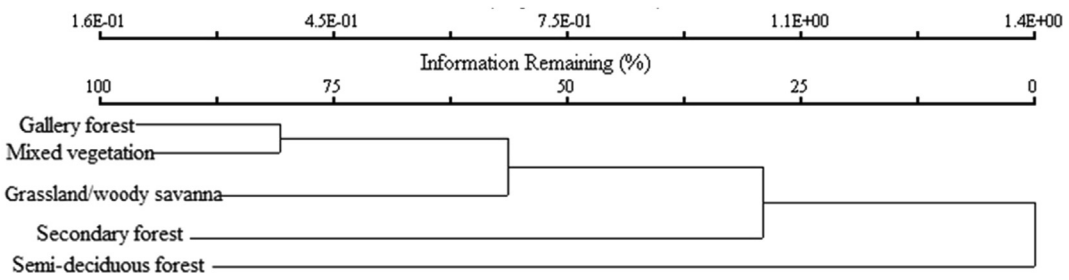

Figure 4. TWINSPAN dendrogram of 120 species of vascular plants with dbh ≥10 cm in 17 1-ha plots each in Kimbi-Fungom National Park, Cameroon.

Table 8. Species list and abundance (number of individual stems) in 17 ha of sampling plots, Kimbi-Fungom National Park, Cameroon.

Family	Species	GF	G/WS	MV	PSF	SF	Total
Anacardiaceae	*Lannea microcarpa* Engl. & K. Krauce	-	2	-	8	1	11
Anacardiaceae	*Lannea schimperi* (Hochst.ex. A. Rich.) Engl.	3	50	2	-	-	55
Anacardiaceae	*Lannea* sp.1	-	1	-	1	-	2
Anacardiaceae	*Lannea* sp.2	10	27	4	13	6	60
Anacardiaceae	*Pseudospondias microcarpa* (A.Rich.) Engl.	1	-	4	85	7	97
Anacardiaceae	*Sorindeia grandifolia* Engl.	-	-	-	95	-	95
Annonaceae	*Annona senegalensis* Pers.	2	56	1	-	-	59
Annonaceae	*Cleistopholis patens* (Benth.) Engl. & Diels.	-	-	-	3	-	3
Annonaceae	*Cleistopholis staudtii* Engl. & Diels.	-	-	-	2	-	2
Annonaceae	*Cleistopholis* sp.	-	-	-	2	1	3
Annonaceae	*Monodora tenuifolia* Benth.	-	-	-	1	1	2
Annonaceae	*Monodora* sp.2	-	-	-	2	-	2
Apocynaceae	*Alstonia boonei* De Wild	-	-	-	1	1	2
Apocynaceae	*Funtumia elastica* (Preuss) Stapf	-	-	-	20	1	21
Apocynaceae	*Holarrhena floribunda* (G.Don) Dur & Schinz	1	6	-	2	-	9
Apocynaceae	*Rauvolfia caffra* Sond.	-	-	-	6	-	6
Apocynaceae	*Rauvolfia vomitoria* Afzel.	-	-	-	1	-	1
Apocynaceae	*Rauvolfia* sp.	-	-	-	6	-	6
Apocynaceae	*Voacanga africana* Stapf	-	-	-	1	-	1
Araliaceae	*Cussonia arborea* Hochst.ex.A.Rich.	3	105	2	-	-	110
Araliaceae	*Polycias fulva* (Hiern) Harms	1	9	-	7	1	18
Arecaceae	*Elaeis guineensis* Jacq.	-	-	1	43	5	49
Bignoniaceae	*Markhamia tomemtosa* (Benth.) K.Schum.	-	-	-	2	-	2
Bignoniaceae	*Newbouldia laevis* (P.Beauv.) Seeman ex Bureau	-	-	-	35	-	35
Bignoniaceae	*Spathodea campanulata* P.Beauv.	-	6	-	-	7	13
Bignoniaceae	*Stereospermum kunthianum* Cham.	-	5	-	-	-	5
Bombacaceae	*Bombax buenopozense* P.Beauv.	1	12	-	11	9	33
Burseraceae	*Canarium schweinfurthii* Engl.	1	1	1	12	-	15
Burseraceae	*Dacryodes* sp.	-	-	-	1	-	1
Cecropiaceae	*Musanga cecropioides* R.Br.ex Tedlie	-	-	-	2	-	2
Cecropiaceae	*Myrianthus arboreus* P.Beauv.	-	-	-	1	-	1
Chrysobalanaceae	*Magnistipula butayei* De Wild.	-	1	-	-	-	1
Chrysobalanaceae	*Magnistipula butayei* subsp. *balingembeaensis* De Wild.	-	-	-	2	-	2
Chrysobalanaceae	*Maranthes glabra* (Oliv.) G.T.Prance	1	5	15	237	2	260
Chrysobalanaceae	*Parinari curatellifolia* Planch.ex Benth.	-	14	-	-	-	14
Chrysobalanaceae	*Parinari* sp.1	-	-	-	1	-	1
Clusiaceae	*Garcinia* cf *mannii* Oliv.	-	-	-	1	-	1
Clusiaceae	*Garcinia epunctata* Stapf	-	-	-	10	4	14
Clusiaceae	*Mammea africana* Sabine	-	-	-	3	-	3
Clusiaceae	*Symphonia globulifera* L.f.	-	-	-	1	-	1
Combretaceae	*Combretum* sp.	2	12	4	3	-	21
Combretaceae	*Terminalia glaucescens* Planch. ex Benth.	6	231	1	2	2	242
Ebenaceae	*Diospyros* sp.	-	-	-	1	-	1
Euphorbiaceae	*Alchornea cordifolia* (Schum. & Thonn.) Müll.Arg.	1	3	-	-	-	4
Euphorbiaceae	*Macaranga spinosa* Müll.Arg.	-	-	-	-	2	2
Euphorbiaceae	*Neoboutonia velutina* Prain	-	6	-	-	-	6
Euphorbiaceae	*Ricinodendron heudelotii* (Baill.) Pierre ex Baill.	4	4	-	17	18	43
Euphorbiaceae	*Shirakiopsis elliptica* (Hochst.) Esser	-	-	-	1	-	1
Fabaceae	*Afzelia africana* Sm.	1	1	-	5	-	7
Fabaceae	*Afzelia bipindensis* Harms	2	-	-	4	-	6
Fabaceae	*Albizia adianthifolia* (Schum.) W.F.Wright	1	1	-	5	6	13
Fabaceae	*Albizia zygia* (DC.) J.F.Macbr.	-	2	-	-	-	2
Fabaceae	*Albizia* sp.	5	5	-	11	17	38
Fabaceae	*Angylocalyx pynaertii* De Wild.	-	-	-	2	-	2
Fabaceae	*Anthonotha macrophylla* P.Beauv.	-	-	-	13	4	17
Fabaceae	*Baphia buettneri* Harms subsp. *hylophila* (Harms) Soladoye	-	-	-	12	5	17
Fabaceae	*Baphia* sp.	-	-	-	2	-	2
Fabaceae	*Brachystegia eurycoma* Harms	-	-	1	70	6	77

(*continued on next page*)

Table 8 (*continued*)

Family	Species	GF	G/WS	MV	PSF	SF	Total
Fabaceae	*Cassia arereh* Delile	1	4	-	-	-	5
Fabaceae	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel	20	147	1	1	1	170
Fabaceae	*Dialium* cf *pachyphyllum* Harms	-	-	3	10	-	13
Fabaceae	*Dialium* sp.	-	-	-	2	-	2
Fabaceae	*Entada abyssinica* Steud. ex A.Rich.	3	116	-	1	-	120
Fabaceae	*Erythrina senegalensis* A.DC.	-	1	-	-	-	1
Fabaceae	*Erythrophleum ivorense* A.Chev.	-	-	-	12	-	12
Fabaceae	*Erythrophleum suaveolens* (Guill. & Perr.) Brenan	3	14	4	28	1	50
Fabaceae	*Parkia africana* R.Br.	1	13	-	1	8	23
Fabaceae	*Parkia filicoidea* Welw. ex Oliv.	-	-	-	3	-	3
Fabaceae	*Penthaclethra macrophylla* Benth.	-	-	-	3	-	3
Fabaceae	*Pericopsis laxiflora* (Benth.) Van Meeuwen	3	39	-	-	-	42
Fabaceae	*Piliostigma thonningii* (Schum.) Milne-Redh.	4	111	4	-	-	119
Fabaceae	*Pterocarpus erinaceus* Poir	1	1	-	-	-	2
Fabaceae	*Pterocarpus osun* Craib	-	-	-	7	-	7
Fabaceae	*Pterocarpus soyauxii* Taub.	-	-	1	14	-	15
Gentianaceae	*Anthocleista djalonensis* A.Chev.	-	1	-	4	10	15
Hymenocardiaceae	*Hymenocardia acida* Tul.	11	237	1	-	-	249
Hyperaceae	*Harungana madagascariensis* Poir.	7	29	-	-	7	43
Hypericaceae	*Psorospermum febrifugum* Spach.	2	29	-	-	-	31
Hypericaceae	*Psorospermum* sp.4	-	-	-	1	-	1
Icacinaceae	*Rhaphiostylis* sp.	-	-	-	1	-	1
Irvingiaceae	*Irvingia grandifolia* (Engl.) Engl.	-	-	-	1	-	1
Irvingiaceae	*Irvingia wombulu* Vermoesen	-	-	-	6	1	7
Irvingiaceae	*Klainedoxa gabonensis* Pierre	-	-	-	1	1	2
Irvingiaceae	*Klainedoxa* sp.	-	-	-	1	-	1
Lamiaceae	*Vitex* cf *simplicifolia* Oliv.	2	-	-	-	-	2
Lamiaceae	*Vitex doniana* Sweet	13	55	9	6	1	84
Lamiaceae	*Vitex grandifolia* Gürke	-	-	-	3	-	3
Lamiaceae	*Vitex rivularis* Gürke	-	-	1	1	-	2
Lauraceae	*Beilschmiedia anacardioides* (Engl. & Krause) Robyns & Wilczeck	-	-	1	2	-	3
Lauraceae	*Beilschmiedia gaboonensis* (meissn.) Benth. & Hook.f.	-	-	-	1	-	1
Lecythidaceae	*Napoleonaea imperialis* P.Beauv.	-	-	1	8	5	14
Loganiaceae	*Strychnos* sp.2	-	-	-	1	-	1
Loganiaceae	*Strychnos* sp.3	-	2	-	-	-	2
Malvaceae	*Cola caricaefolia* K.Schum	1	-	5	68	4	78
Malvaceae	*Cola cordifolia* (Cav.) R.Br.	1	-	-	4	-	5
Malvaceae	*Cola* sp.	-	-	-	1	1	2
Malvaceae	*Cola* sp.2	1	-	-	-	-	1
Malvaceae	*Microcos flavescens* Juss	-	4	-	-	-	4
Malvaceae	*Sterculia tragacantha* Lindl.	4	3	-	13	10	30
Meliaceae	*Entandrophragma angolense* (Welw.) C.DC.	-	-	2	27	-	29
Meliaceae	*Entandrophragma candollei* Harms	-	-	-	30	-	30
Meliaceae	*Trichilia rubescens* Oliv.	-	-	-	-	1	1
Meliaceae	*Trichilia* sp.	-	2	-	-	-	2
Moraceae	*Antiaris toxicaria* Lesch.	-	-	-	3	4	7
Moraceae	*Ficus abutilifolia* (Miq.) Miq.	-	-	-	3	-	3
Moraceae	*Ficus adolfi-friderici* Mildbr.	-	-	-	-	1	1
Moraceae	*Ficus bubu* Warb.	-	-	-	1	1	2
Moraceae	*Ficus* cf *sur* Forssk.	-	3	-	1	-	4
Moraceae	*Ficus exasperata* Vahl	-	4	-	3	1	8
Moraceae	*Ficus glumosa* Delile	3	18	-	1	8	30
Moraceae	*Ficus mucuso* Welw.ex Ficalho	-	-	-	3	-	3
Moraceae	*Ficus natalensis* Hochst.	-	-	1	-	-	1
Moraceae	*Ficus sur* Forssk.	-	-	-	3	-	3
Moraceae	*Ficus vallis-choudae* Delile	-	9	7	-	6	22
Moraceae	*Ficus vogeliana* (Miq.) Miq.	-	1	-	-	-	1
Moraceae	*Ficus* sp.2	-	1	-	-	-	1
Moraceae	*Ficus* sp.3	-	29	1	-	-	30

(*continued on next page*)

Table 8 (*continued*)

Family	Species	GF	G/WS	MV	PSF	SF	Total
Moraceae	*Ficus* sp.5	1	4	-	-	-	5
Moraceae	*Ficus* sp.8	-	15	-	-	-	15
Moraceae	*Ficus* sp.10	2	6	-	-	3	11
Moraceae	*Milicia excelsa* (Welw.) C.C.berg	-	1	-	5	-	6
Moraceae	*Trilepisium madagascariense* DC.	-	-	-	6	-	6
Myristicaceae	*Pycnanthus angolensis* (Welw.) Exell	6	1	1	30	2	40
Myrtaceae	*Syzygium guineense* (Wild.) DC	8	60	-	1	-	69
Ochnaceae	*Lophira lanceolata* Tiegh. Ex Keay	8	186	4	-	-	198
Ochnaceae	*Ochna afzelii* R.Br. ex Oliv.	-	11	-	1	-	12
Ochnaceae	*Ochna* sp.	-	-	-	1	-	1
Olacaceae	*Olax subscorpioidea* Oliv.	-	-	-	7	2	9
Pandanaceae	*Pandanus candelabrum* P.Beauv.	-	-	-	-	6	6
Passifloraceae	*Adenia* sp.	-	-	-	1	-	1
Passifloraceae	*Barteria fistulosa* Mast.	-	-	-	2	-	2
Phyllanthaceae	*Antidesma chevalieri*	-	1	-	1	-	2
Phyllanthaceae	*Bridelia atroviridis* Müll.Arg.	-	-	-	1	-	1
Phyllanthaceae	*Bridelia ferruginea* Benth.	-	4	-	-	-	4
Phyllanthaceae	*Bridelia grandis* Pierre ex Hutch.	-	1	-	3	-	4
Phyllanthaceae	*Bridelia scleroneura* Müll.Arg.	1	66	1	-	-	68
Phyllanthaceae	*Bridelia* sp.	1	3	-	-	-	4
Phyllanthaceae	*Macaranga monandra* Müll.Arg.	-	-	-	-	4	4
Phyllanthaceae	*Margaritaria discoidea* (Baill.) Webster	3	20	3	20	6	52
Phyllanthaceae	*Spondianthus preussii* Engl.	-	-	7	93	2	102
Phyllanthaceae	*Uapaca guineensis* var. *guineensis* Müll.Arg.	-	-	-	21	-	21
Phyllanthaceae	*Uapaca paludosa* Aubrév. & Léandri	-	1	-	53	2	56
Phyllanthaceae	*Uapaca togoensis* Pax	96	86	20	11	-	213
Rhamnaceae	*Maesopsis eminii* Engl.	3	1	-	34	-	38
Rhizophoraceae	*Cassipourea zenkeri* (Engl.) Alston.	-	-	-	4	-	4
Rubiaceae	*Aidia genipiflora* (DC.) Dandy	-	-	-	2	-	2
Rubiaceae	*Aidia* sp.	-	-	-	1	-	1
Rubiaceae	*Craterispermum laurinum* (Poir) Benth.	-	-	-	37	-	37
Rubiaceae	*Crossopteryx febrifuga* (Afzel. ex G.Don) Benth.	8	225	1	-	-	234
Rubiaceae	*Cuviera* sp.	-	1	-	-	-	1
Rubiaceae	*Hallea stipulosa* (DC) Leroy	-	-	-	2	36	38
Rubiaceae	*Ixora euosmia* K. Schum.	-	-	-	31	-	31
Rubiaceae	*Ixora* sp.2	-	-	-	-	2	2
Rubiaceae	*Macrosphyra longistyla* (DC.) Hiern	2	-	-	18	-	20
Rubiaceae	*Morelia senegalensis* A. Rich.ex DC.	2	1	-	8	2	13
Rubiaceae	*Nauclea latifolia* SM.	3	225	8	-	-	236
Rubiaceae	*Pavetta baconiella* Bremek.	-	-	-	3	-	3
Rubiaceae	*Pavetta calothyrsa* Bremek.	-	-	-	1	-	1
Rubiaceae	*Rothmannia* sp.1	-	-	-	2	-	2
Salicaceae	*Homalium africanum* (Hook.f.) Benth.	-	-	-	2	-	2
Sapindaceae	*Allophyllus bullatus* Radlk.	2	17	-	3	-	22
Sapotaceae	*Chrysophyllum ubanguiense* (De Wild.) Govaerts	2	-	3	75	-	80
Sapotaceae	*Englerophytum stelechanthum* Krause	-	-	-	1	-	1
Sapotaceae	*Pouteria alnifolia* (Baker) Roberty	-	-	-	1	-	1
Sapotaceae	*Synsepalum stipulatum* (Radlk.) Engl.	-	-	-	4	-	4
Simaroubaceae	*Quassia sanguinea* Cheek & Jongkind	-	-	-	4	-	4
Simaroubaceae	*Quassia sylvestris* Cheek & Jongkind	-	1	-	-	1	2
Ulmaceae	*Celtis philippensis* Blanco	-	-	-	7	-	7
Ulmaceae	*Trema orientalis* (L.) Blume	1	1	-	7	12	21
	Grand Total	276	2384	129	1559	259	4607

GF = Gallery forest, G/WS = Grassland/Woody savanna, MV = Mixed vegetation, PSF = Primary Semi-deciduous Forest, SF = Secondary Forest.

tropical dry forests are highly threatened: recent reports are that tropical dry forests in Latin America and the Caribbean have been reduced to <10% of their original extent [32]. Our results highlight the poor current state of the dry forest of KFNP and the need for appropriate interventions.

Mean tree species richness (for trees with dbh ≥10 cm) of 43.1 ± 13.3 species ha^{-1} (27–65 species ha^{-1}) in KFNP was comparable to that in the dry forest of Africa (Cameroon and Congo; 23, 33) and the Western Ghats, India, which ranged from 30-57 species ha^{-1} [34-35]. Studies of

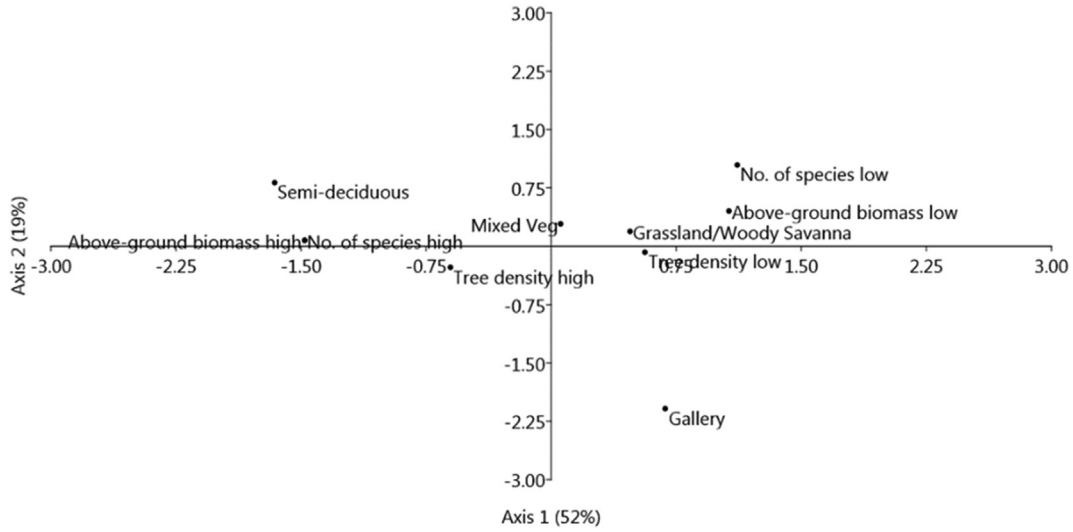

Figure 5. Correspondence analysis showing association among variables, such as number of species, vegetation and biomass.

19 mature tropical forest sites in the Neotropics, Southeast Asia, Australia, and Africa revealed a minimum value for species richness for trees with dbh ≥10 cm of 56 species [33]. However, the mean tree species richness of 43.1 species ha^{-1} in KFNP (Table 4) is low in comparison to the rainforests of the Rumpi Hills (lowland forest 117.5 species ha^{-1}, submontane forest 75 species ha^{-1}) and Korup National Park lowland rain forest (88.5 species ha^{-1}) [23-25,36-37]. Thus, KFNP, with a mean of 43.1 species ha^{-1} and Mbembe Forest (29.8 species ha^{-1}) can be considered as relatively species-poor.

In this study, the most abundant families were Fabaceae, Rubiaceae, and Phyllanthaceae (Table 6), and the most abundant species were *Terminalia glaucescens*, *Maranthes glabra*, and *Uapaca togoensis* (Table 7). Ten species in our study yielded 1618.8 t of AGB amounting to 63.8% of the total (2537.3 t) with an overall abundance of 1489 tree stems (Table 7). The number of species and basal area were higher in the dry semi-deciduous forest than in the other vegetation types (Table 1), which is expected, since semi-deciduous forest is closer to lowland or mid-elevation rainforest with large trees than the open grassland and woody savanna that are prone to fire annually. It is evident from the maps (Figure 1) presented in the introduction that the forest has been degraded substantially over a 36-year period, from 1979-2015.

This study is one of few in Cameroon and the broader Congo Basin region that have calculated diversity, above-ground biomass, and carbon in a dry forest [10, 11, 38, 39]. In the 17 ha sampled, we calculated a mean AGB of 149.2 t ha^{-1} and carbon of 74.6 tC ha^{-1}. These values are far lower compared to values of AGB (≥429 t ha^{-1}) and carbon stock (≥249 tC ha^{-1}) documented for other Central African forests [37]. Although the present study revealed that KFNP is poor in mean AGB and carbon, exceptions were observed for some specific plots; for example, plots 1–3 had high mean AGB of 356.3 t ha^{-1} and mean carbon of 178.2 tC ha^{-1}, and were only slightly lower than values from studies elsewhere in the region [40, 41] (Table 4). In Congo Brazzaville (Iboukikro and Ngambali Forest), a study of 6 1-ha plots in a gallery forest revealed a higher mean of 170.7 tC ha^{-1} [39] than the gallery forest in KFNP (70.5 tC ha^{-1}).

The semi-deciduous forest showed a strong association of high AGB with number of species, and mixed vegetation had the lowest AGB in KFNP (Table 1, Figure 5). While the low carbon content in the grassland/woody savanna, gallery, and mixed forest may be attributed to the scanty vegetation and/or anthropogenic activities, other factors such as rainfall, duration of wet season, and topography can also influence net primary productivity of tropical dry forest [2]. Our results in some ways reaffirm the assertion that higher species richness could be associated with higher carbon storage in some forests [42]. The study further highlights the need for restorative interventions, such as reforestation, especially in the grassland/woody savanna vegetation.

5. Conclusions

The forest of the Kimbi-Fungom National Park is generally poor in plant diversity, biomass and carbon, especially in the secondary, mixed vegetation, gallery and grassland/woody savanna vegetation types. This work underlines an urgent need to implement efficient management practices to restore the forest.

Data of this study is part of a general database of species from 70 1-ha permanent plots established by the Tropical Plant Exploration Group on the continental Cameroon Mountains and hosted by the Global Biodiversity Information Facility [43].

Declarations

Author contribution statement

Moses Nsanyi Sainge: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Felix Nchu: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Andrew Peterson Townsend: Conceived and designed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

Data associated with this study has been deposited at The Global Biodiversity Information Facility (GBIF).

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References

[1] UNEP/CBD, Global Strategy for Plant Conservation for a World Flora Online by 2020, United Nations Environmental Program/Convention for Biological Diversity, 2012.
[2] P.G. Murphy, A.E. Lugo, Ecology of tropical dry forest, Annu. Rev. Ecol. Systemat. 17 (1986) 67–88.
[3] D.H. Janzen, Tropical dry forests: the most endangered major ecosystem, in: E.O. Wilson (Ed.), Biodiversity, National Academic Press, Washington, DC, 1988, pp. 130–137.
[4] United Nations Framework Convention on Climate Change (UNFCCC), Adoption of the Paris agreement 21, Conference of the Parties, Paris, 2015, p. 31.
[5] F. White, Vegetation Map of Africa, *United Nations Educational Scientific and Cultural Organization*, Paris, 1983, p. 356.
[6] L. Poorter, F. Bongers, R.H.M.J. Lemmens, West african forest, in: L. Poorter, F. Bongers, F.Y.N. Kouamé, W.D. Hawthorne (Eds.), Biodiversity of West African Forest. An Ecological Atlas of Woody Plant Species, CAB International, *Cambridge*, USA, 2003, p. 528.
[7] J.C. Olivry, Fleuves et riviéres du Cameroun. Collection Monographies Hydrologiques d'ORSTOM 9, Mesres-Orstom, Paris, 1986, p. 717.
[8] J.M. Onana, The vascular plants of Cameroon. A taxonomic check list with IUCN assessments. *Flore du Cameroun 39*, IRAD-National Herbarium of Cameroon, Yaoundé, 2011, p. 195.
[9] J.M. Onana, The World Flora online 2020 project: will Cameroon come up to the expectation, Rodriguesia 66 (2015) 961–972.
[10] M.N. Sainge, M.N. Lyonga, M.B. Libalah, R.A. Achah, J.N. Fon, D. Kenfack, J.H.E. Moudingo, Biodiversity Assessment and Conservation Status of Plants in the Mbembe Forest Reserve, Donga-Mantung Division, North West Region, Cameroon, II, Tropical Plant Exploration Group (TroPEG) Cameroon, 2014, p. 131, 978-9956-621-64-4.
[11] N.M. Sainge, Patterns of Distribution and Endemism of Plants in the Cameroon Mountains: A Case Study of Protected Areas in Cameroon: Rumpi Hills Forest Reserve (RHFR) and the Kimbi Fungom National Park (KFNP), Tropical Plant Exploration Group (TroPEG) Cameroon, 2016, p. 171.
[12] J.-M. Onana, M. Cheek, Red Data Book of the Flowering Plants of Cameroon, *Royal Botanic Gardens*, Kew, 2011, p. 578.
[13] M. Cheek, J.M. Onana, B.J. Pollard, The Plants of Mount Oku and the Ijim Ridge, Cameroon, Royal Botanic Garden, Kew, 2000, p. 211.
[14] Y. Harvey, B.J. Pollard, I. Darbyshire, J.M. Onana, M. Cheek, The Plants of Bali Ngemba Forest Reserve: A Conservation Checklist, Royal Botanic Gardens, Kew, 2004, p. 154.
[15] M. Cheek, Y. Harvey, J.M. Onana, The Plants of Dom, Bamenda Highlands, Cameroon: A Conservation Checklist, Royal Botanic Gardens, Kew, 2010, p. 162.
[16] R. Letouzey, Carte phytogéographique du Cameroun, 1–5, Institut de la Carte Internationale de la Végétation, Toulouse-France, 1985, p. 240.
[17] B.P.K. Yerima, E.V. Ranst, Major Soil Classification Systems Used in the Tropics: Soils of Cameroon: Distribution, Genesis, Characteristics, Management and Utilization, 2005, p. 295. Oxford, Trafford.
[18] C.E.N. Ewango, The Liana Assemblage of a Congolian Rainforest: Diversity, Structure and Dynamics. Thesis, Wageningen University, Wageningen, Netherland, 2010, p. 161.
[19] C.E.N. Ewango, F. Bongers, J.-R. Makana, L. Poorter, M.S.M. Sosef, Structure and Composition of the liana assemblage of a mixed rain forest in the Congo Basin, Plant Ecol. Evol. 148 (2015) 29–42.
[20] D. Thomas, R.J. Burnham, G. Chuyong, D. Kenfack, N.M. Sainge, Liana abundance and diversity in Cameroon's Korup national park, in: Stefan A. Schnitzer, Frans Bongers, Robyn J. Burnham, Francis E. Putz (Eds.), Patterns of Liana Demography and Distribution: from Local to Global, JohnWiley & Sons, 2015. Ecology of lianas.
[21] B. McCune, M.J.P.C.- Mefford, ORD Multivariate Analysis of Ecological Data, MjM Software design, Oregon, USA, 2006, p. 28. Version 5.10.
[22] Ø. Hammer, D.A.T. Harper, P.D. Ryan, PAST: paleontological Statistics Software package for education and data analysis, Palaeontol. Electron. 4 (1) (2001) 9.
[23] D.W. Thomas, D. Kenfack, G.B. Chuyong, M.N. Sainge, E. Losos, R.S. Condit, N.C. Songwe, Tree Species of Southwestern Cameroon: Tree Distribution Maps, Diameter Tables, and Species Documentation of the 50-hectare Korup Forest Dynamics Plot, Center for Tropical Forest Science of the Smithsonian Tropical Research Institute, Washington D.C, 2003, p. 247.
[24] B.G. Chuyong, R. Condit, D. Kenfack, C.E. Losos, N.M. Sainge, N.C. Songwe, D.W. Thomas, Korup forest dynamics plot, Cameroon, in: C.E. Losos, E.G. Leigh Jr. (Eds.), Tropical Forest Diversity and Dynamism, University of Chicago Press, Chicago, 2004, pp. 506–516.
[25] D. Kenfack, D.W. Thomas, G.B. Chuyong, R. Condit, Rarity and abundance in a diverse african forest, Biodivers. Conserv. 16 (2007) 2045–2074.
[26] J. Chave, M. Réjou-méchain, A. Búrquez, E. Chidumayo, M.S. Colgan, W.B.C. Delitti, A. Duque, T. Eid, P.M. Fearnside, R.C. Goodman, M. Henry, A. Martinez-yrizar, W.A. Mugasha, H.C. Muller-Landau, M. Mencuccini, B.W. Nelson, A. Ngomanda, E.M. Nogueira, E. Ortiz Malavassi, R. Pélissier, P. Ploton, C.M. Ryan, J.G. Saldarriaga, G. Vieilledent, Improved allometric models to estimate the aboveground biomass of tropical trees, Global Change Biol. 20 (2015) 3177–3190.
[27] N.A. Djomo, N. Picard, A. Fayolle, M. Henry, A. Ngomanda, P. Ploton, J. McLellan, J. Saborowski, I. Adamou, P. Lejeune, Tree allometry for estimation of carbon stocks in African tropical forests, Forestry: Int. J. For. Res. For. 1–10 (2016).
[28] S. Carsan, C. Orwa, C. Harwood, R. Kindt, A. Stroebel, H. Neufeldt, R. Jamnadass, African Wood Density Database, World Agroforestry Centre, Nairobi. Kenya, 2012. http://worldagroforestry.org/sea/Products/AFDbases?WD/Index.htm.
[29] F. Dallmeier, Long-Term Monitoring of Biological Diversity of Tropical Forest Areas: Methods for the Establishment and Inventory of Permanent Plots, United Nation Educational Scientific and Cultural Organization, Paris, 1992, p. 72.
[30] R. Ostertag, F. Inman-Narahari, S. Cordell, C.P. Giardina, L. Sack, Forest structure in low-diversity tropical forests: a study of Hawaiian wet and dry forests, PloS One 9 (2014) 1–18.
[31] P.S. Gopalakrishna, M.L. Kaonga, R.K. Somashekar, H.S. Suresh, R. Suresh, Tree diversity in the tropical dry forest of Bannerghatta national park in eastern Ghats, southern India, Eur. J. Ecol. 1 (2015) 12–27.
[32] K.R. Banda, A. Delgado-Salinas, K.G. Dexter, R. Linares-Palomino, A. Oliveira-Filho, D. Prado, et al., Plant diversity patterns in neotropical dry forests and their conservation implications, Science 353 (2016) 1383–1387.
[33] D.M. Newbery, J.S. Gartlan, A structural analysis of rain forest in Korup and Douala-Edea, Cameroon, Proc. R. Soc. Edinb. 104B (1996) 177–224.
[34] N. Parthasarathy, R. Karthikeyan, Plant biodiversity and conservation of two tropical dry evergreen on the Coromandel Coast, South India, Biodivers. Conserv. 6 (1997) 1063–1083.
[35] O.L. Philips, A.H. Gentry, Increasing turnover through time in tropical forests, Science 263 (1994) 954–958.
[36] C.F. Gonmadje, C. Doumenge, D. Mckey, B. Sonké, Tree diversity and conservation value of Ngovayang's lowland forest, Cameroon, Biodivers. Conserv. 20 (2011) 2627–2648.
[37] S.L. Lewis, B. Sonké, T. Sunderland, S.K. Begne, G. Lopez-Gonzalez, G.M.F. Van der Heijden, O.L. Philips, K. Affum-Baffoe, T.R. Baker, L. Banin, J.-F. Bastin, H. Beeckman, P. Boeckx, J. Bogaert, C. De Cannière, E. Chezeaux, C.J. Clark, M. Collins, G. Djagbletey, M.N.K. Djuikouo, V. Droissart, J.-L. Doucet, C.E.N. Ewango, S. Fauset, T.R. Feldpausch, E.G. Foli, J.-F. Gillet, A.C. Hamilton, D.J. Harris, T.B. Hart, T. de Haulleville, A. Hladik, K. Hufkens, D. Huygens, P. Jeanmart, K.J. Jeffery, E. Kearsley, M.E. Leal, J. Lloyd, J.C. Lovett, J.-R. Makana, Y. Malhi, A.R. Marshall, L. Ojo, K.S.-H. Peh, G. Pickavance, J.R. Poulsen, J.M. Reitsma, D. Sheil, M. Simo, K. Steppe, H.E. Taedoumg, J. Talbot, J.R.D. Taplin, D. Taylor, S.C. Thomas, B. Toirambe, H. Verbeeck, J. Vleminckx, L.J.T. White, S. Willcock, H. Woell, L. Zemagho, Above ground biomass and structure of 260 African tropical forests, Phil. Trans. R. Soc. Biol. 368 (2013) 1–14.
[38] M.N. Sainge, M.N. Lyonga, M.B. Libalah, R.A. Achah, J.N. Fon, D. Kenfack, Biodiversity Assessment and Conservation Status of Plants in the Mbembe Forest Reserve, Donga-Mantung Division, North West Region, Cameroon, Report to Rufford Small Grant Foundation, Tropical Plant Exploration Group (TroPEG) Cameroon, 2012, p. 120.
[39] R. Ekoungoulou, X.D. Liu, J.J. Loumeto, S.A. Ifo, Y.E. Bocko, F.E. Koula, S.K. Niu, Tree allometry in tropical forest of Congo for carbon stocks estimation in above-ground biomass, Open J. For. 4 (2014) 481–491.
[40] I.D. Thompson, B. Mackey, S. McNulty, A. Mosseler, Forest Resilience, Biodiversity, and Climate Change. A Synthesis of the Biodiversity/resilience/stability Relationship in forest Ecosystems, Secretariat of the Convention on Biological Diversity, Montreal, 2009, p. 67. Technical Series no. 43.
[41] B.B.N. Strassburg, A. Kelly, A. Balmford, R.G. Davies, H.K. Gibbs, A. Lovett, L. Miles, C.D.L. Orme, J. Price, R.K. Turner, A.S.L. Rodrigues, Global congruence of carbon storage and biodiversity in terrestrial ecosystems, Conserv. Lett. 3 (2010) 98–105.
[42] X. Liu, et al., Tree species richness increases ecosystem carbon storage in subtropical forests, 20181240, Proc. R. Soc. B 285 (2018).
[43] N.M. Sainge, N.M. Lyonga, F. Nchu, P. Townsend, Plant diversity and distribution on the continental Cameroon Mountains, Glob. Biodivers. Inf. Facil. (2018).