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...
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 km², 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 km². This site holds a mixture of humid semi-evergreen forest, woody savanna, grassland savanna, and gallery forest of the Sudano-Zambesian 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.
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):

\[ AGB = 0.0559 (\rho D^2 H) \]  
\[ H = e^{1.321 + 0.482 \ln D + 0.027 \rho} \]  
where AGB = above-ground biomass (tons), ρ = wood specific density (g/cm³) 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

\[ C = \frac{\text{total biomass}}{2} \]  

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

\[ BA = p_i \times (1/2D)^2 = p_i \times (D/2)^2 \]  

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

\[ SW = -\sum p_i \ln p_i \]  

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 (m²) | 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.
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 \( \geq 1 \) cm. We recorded 4987 stems of trees and lianas, with dbh \( \geq 1 \) 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 \( \geq 10 \) 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 \( \geq 1 \) cm (27 stems with dbh \( \geq 10 \) cm) representing 15 species, 15 genera, and 11 families. The mean number of trees ha\(^{-1}\) with dbh \( \geq 10 \) cm was 270/674 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 \( \geq 1 \) cm had a mean of 2.8 stems ha\(^{-1}\), with a range of 1–6 stems ha\(^{-1}\). In all, shrubs (dbh \( \geq 10 \) cm) represent a mean SW index of 1.8, ranging from 0-3.4, lianas (dbh \( \geq 1 \) cm) 0.26 ranging 0.6–1.8, and trees (dbh \( \geq 10 \) 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).

#### 3.2. Basal area

The 17 ha plots gave a total basal area (dbh \( \geq 10 \) 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

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**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             | KFN  | Kpep     | 6.79533      | 10.10048      | 481.0         |
| 2    | PSF             | KFN  | Kpep     | 6.79533      | 10.10048      | 481.0         |
| 3    | PSF             | KFN  | Kpep     | 6.79533      | 10.10048      | 481.0         |
| 4    | G/WS_MV_PSF     | KFN  | Kpep     | 6.79339      | 10.09769      | 429.0         |
| 5    | PSF/G/WS        | KFN  | Kpep     | 6.79359      | 10.09773      | 433.0         |
| 6    | G/WS_GF_SF      | KFN  | Kpep     | 6.79267      | 10.10803      | 439.0         |
| 7    | G/WS_GF_SF      | KFN  | Kpep     | 6.79267      | 10.10803      | 439.0         |
| 8    | G/WS_MV_GF      | KFN  | Kpep     | 6.79502      | 10.11571      | 396.0         |
| 9    | G/WS            | KFN  | Kpep     | 6.79484      | 10.11546      | 407.0         |
| 10   | G/WS_PSF        | KFN  | Kpep     | 6.79516      | 10.11585      | 410.0         |
| 11   | SF_GF,G/WS      | KFN  | Kpep     | 6.79534      | 10.11585      | 422.0         |
| 12   | G/WS_GF         | KFN  | Tunka-Esu| 6.73506      | 10.11741      | 898.0         |
| 13   | G/WS_GF         | KFN  | Tunka-Esu| 6.73506      | 10.11741      | 898.0         |
| 14   | G/WS            | KFN  | Tunka-Esu| 6.73506      | 10.11741      | 898.0         |
| 15   | G/WS_GF         | KFN  | Tunka-Esu| 6.73394      | 10.11772      | 846.0         |
| 16   | G/WS_MV         | KFN  | Tunka-Esu| 6.73394      | 10.11772      | 846.0         |
| 17   | G/WS_PSF        | KFN  | 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.

**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)                        |

**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.
Brachystegia (31.4 m²), Maranthes (26.3 m²), Uapaca (17.7 m²), Daniellia (17.1 m²), Pseudospondias (11.3 m²), and Terminalia (10.3 m²) (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 m² ha⁻¹ whereas lianas gave 3.6 m² ha⁻¹. Semi-deciduous forest had the largest basal area of 27.7 m² ha⁻¹, followed by secondary forest (12.9 m² ha⁻¹), gallery forest (7.7 m² ha⁻¹), grassland/woody savanna (1.6 m² ha⁻¹), and mixed vegetation (0.8 m² 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 66.6% (201 stems), woody and grassland savanna 66.2% (2029 stems), mixed vegetation 21.2% (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 ubangienense (75 stems), and Brachystegia eurycoma (70 stems). In this vegetation type, 37 species were rare, with one individual each, such as Belischnedia gabonensis, Bridelia atroviridis, Daniellia oliveri, Englerophytum stelechanthum, and Shirakiosis 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 zyga (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 womulu, 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 aereoh, 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 Amonia senegalensis, Belischnedia anacardioideae, 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), Pilostigma thonningii (111 stems), Cussonia arbores (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             | Diospyros monbuttensis                      |
| Ebenaceae               |                                             |
| Acanthaceae             | Asystasia decipiens Heine                   |
| Amarantaceae            | Amaranthus sp.                              |
| Anacardiaceae           | Lankea kerstingii Engl. & K.Krause          |
| Annonaceae              | Annona chlororrhiza Engl. & Diels.          |
| Annonaceae              | Uvaria sp.                                  |
| Annonaceae              | Xylopia sp.                                 |
| Apocynaceae             | Bauhina axillaris (Benth.) Hua              |
| Apocynaceae             | Landisia sp.                                |
| Asclepiadaceae          | Mansonia sp.                                |
| Asparagaceae            | Asparagus flagellarii (Kunth) Baker         |
| Asparagaceae            | Chlorophyllum macropyllyll (A.Rich.) Aschers.|
| Asteraceae              | Chromolaena odorata (L.) R.M.King & H.Robinson (nat.) |
| Asteraceae              | Vernonia kotchyi Sch. Bip.                  |
| Bignoniaceae            | Crescentia cujate Billb. & Beurl. (ex.)    |
| Chrysobalanaceae        | Dactylylavia barteri (Hook.f.ex. Oliv.) G.T.Prance & F.White |
| Chrysobalanaceae        | Magniptriala cuneatifolia Hauman            |
| Clusiaceae              | Garcinia cf barteri Oliv.                   |
| Colchicaceae            | Gloriosa simplex L.                         |
| Combretaceae            | Agelea pseudobulbique G.Schellenb.          |
| Combellinaceae          | Paltota ambiata (P.Beauv.) C.B.Clark        |
| Commoraceae             | Commoriosa griffioniana Baill.              |
| Commoraceae             | Jaun dees rubescens (Baker) G.Schellenb.    |
| Costaceae               | Costus spectabilis (Pendl.) K.Schum.        |
| Dicapetalaceae          | Dicapetalum sp.                             |
| Dilleniaceae            | Tetracera masuana De Wild. & T.Durand       |
| Dilleniaceae            | Tetracera sp.                               |
| Dioscoreaceae           | Dioscorea alata L.                          |
| Ebenaceae               | Diospyros monbuttenis Gürke                |
| Euphorbiaceae           | Shtraktia elliptica (Hochst.) Esser         |
| Fabaceae                | Albizia adiantifolia (Shum.) W.F.Wright     |
| Fabaceae                | Anthonotha macrophylla P.Beauv.             |
| Fabaceae                | Canfalia macroalyce Benth.                  |
| Fabaceae                | Dalbergia sp.                               |
| Fabaceae                | Dalbergiella welwitschii Baker              |
| Fabaceae                | Desmodium hirnum Guill. & Perr.            |
| Fabaceae                | Desmodium velutinum (Wild.) DC.             |
| Fabaceae                | Dülautum zonkri Harms                       |
| Fabaceae                | Didonionodontion micronum (Harms) Baker     |
| Fabaceae                | Pseudardbra hookeri Wright & Am.            |
| Fabaceae                | Sebania sp.                                 |
| Fabaceae                | Tamarindus indica Linn.                     |
| Fabaceae                | Tephrosia barbigera Welw.ex Bak.            |
| Gentianaceae            | Anthocleista liebrechtsiana De Wild         |
| Hypericaceae            | Porioperum glaucum                         |
| Hypericaceae            | Porioperum sp.                              |
| Hypericaceae            | Porioperum sp.3                             |
| Lamiaceae               | Lippia africana Moldenke                    |
| Lamiaceae               | Vitex myrmecophila Millbr.                  |
| Lamiaceae               | Vitex thyrsifolia Baker                     |
| Leeaceae                | Leea guineensis G.Don                      |
| Loganiaceae             | Strychnos spinosa Lam.                      |
| Loganiaceae             | Strychnos trifolioides Hutch. & M.B.Moss    |
| Malvaeceae              | Cola millenii K. Schum.                     |
| Malvaeceae              | Microcos mollis Juss.                       |
| Malvaeceae              | Sida corymbosa R.E.Fr.                      |
| Malvaeceae              | Sterculia setigera Delile                   |
| Marantaceae             | Megaphrynium macrostachyum (Benth.) Milne-Redd. |

Table 5 (continued)

| Family                  | Species                                      |
|-------------------------|----------------------------------------------|
| Melastomataceae         | Dísosotis brazzeae Cogn.                    |
| Moraceae                | Ficus crassipes Millbr. & Burret             |
| Musaceae                | Ensete lividangonanum (J.Kirk) Cheesman     |
| Myristicaceae           | Coelocarya botryoides Verm.                 |
| Myrtaceae               | Eugenia obanensis Baker.f.                 |
| Ochnaceae               | Campyloperum calamatum (Gilg.) Farron       |
| Ochnaceae               | Campyloperum excavatum (Van Tiegh.) Farron  |
| Ochnaceae               | Campyloperum flavum (Schunk. & Thonn.) Farron |
| Ochnaceae               | Rhadophyllum affine (Hook.f.) Van Tiegh.    |
| Olacaceae               | Strombosis grandifolia Hook.f.              |
| Orchidaceae             | Anisotricha rothschildiana O'Brien          |
| Orchidaceae             | Anisotrichynchos serratia Summerh.          |
| Orchidaceae             | Bulbophyllum colubrinum (Rchb.f.) Rchb.f.   |
| Orchidaceae             | Bulbophyllum vulcanicum Kraenzl.            |
| Orchidaceae             | Eulophyllum eglossa (Rchb.f.) Rolfe         |
| Orchidaceae             | Habenaria longirostris Summerhayes          |
| Orchidaceae             | Habenaria malacophylla Rchb.f.              |
| Orchidaceae             | Liparis calif. Finet                        |
| Orchidaceae             | Liparis gueneensis Lindl.                   |
| Orchidaceae             | Nervillia sp.                               |
| Orchidaceae             | Polyalthya odorata Lindl.                   |
| Orchidaceae             | Vanilla imperialis Kraenzl.                 |
| Passifloraceae          | Adenia cisumpeoleades (Planch.ex Hook.) Harms |
| Passifloraceae          | Adenia sp.1                                 |
| Petiveriaeae            | Hilleria latifolia H.Walter                 |
| Phyllanthaceae          | Bridelia microantha (Hochst.) Baill.         |
| Phyllanthaceae          | Macaranga assas Amoogou                    |
| Phyllanthaceae          | Phyllanthus muellianus (Kunze) Exell        |
| Pittosporaceae          | Pittosporum viridiflorum Sims subsp. Dalzieli (Hutch.) Cuf. |
| Proteaceae              | Protea madiensis Oliv.                      |
| Rhizophoraceae          | Cassiopoa zenkeri (Engl.) Alston            |
| Rosaceae                | Pruna africana (Hook.f.) Kalkman            |
| Rubiaceae               | Euclinsia longiflora Salisb.                |
| Rubiaceae               | Gardenia lutea Fresen.                      |
| Rubiaceae               | Gardenia vogeli Hook.f.ex Planch            |
| Rubiaceae               | Ixora anemodemos K.Schum                    |
| Rubiaceae               | Ixora bauchaniensis Hut. & Dalziel          |
| Rubiaceae               | Leptacina sp.                               |
| Rubiaceae               | Polyphaurina arbuscula K.Schum.             |
| Rubiaceae               | Psychoria cf ebensis K.Schum.               |
| Rubiaceae               | Psychoria peduncularis (Salish.) Steyerm.   |
| Rubiaceae               | Psychoria vogeliana Benth.                  |
| Rubiaceae               | Psychoria sp.                               |
| Rubiaceae               | Psyrax kraussiana (Hiern) Bridson           |
| Rubiaceae               | Rothmannia ebamutensis Sonkö                 |
| Rusaceae                | Dracaena sveniana Brong.ex E.Morren         |
| Rusaceae                | Dracaena sarcolosa Lindl.                   |
| Rutaceae                | Clausena anisata (Wild.) Hook.f.ex Benth.   |
| Sapindaceae             | Paulinia pinnata L.                         |
| Sapotaceae              | Porteria pierre (A.Chev.) Baehni            |
| Simulaceae              | Simalax kraussiana Meiss.                   |
| Thymelaeaceae           | Dicerandra eliptica Planch.                 |
| Violaceae               | Rinorea denate (P.Beauv.) O.Kuntze          |
| Zingiberaceae           | Aframomum daniellii (Hook.f.) K.Schum.      |
| Zingiberaceae           | Renedia sp.                                 |

sénégalensis, 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.
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), corresponding to 457.5 t/ha of carbon (Table 6). *Brachystegia eurycoma* had the highest AGB of any species (439.3 t/ha), equivalent to 219.6 t/ha of carbon (Table 7). Mean AGB by vegetation type was 203.8 t/ha in mixed vegetation forest, 72.0 t/ha in grassland/woody savanna, 141.0 t/ha in gallery forest, 167.7 t/ha in secondary forest, and 321.5 t/ha 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 Banerghatta 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, 141.0 t/ha in gallery forest, 167.7 t/ha in secondary forest, and 321.5 t/ha 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,
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. Krause     | -  | 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  | Pseudopanax microcarpa (A.Rich.) Engl.  | 1  | -    | 4  | 85  | 7  | 97    |
| Annonaceae     | Annona senegalensis Pers.               | -  | -    | -  | 95  | -  | 95    |
| Annonaceae     | Cleistopholis patens (Benth.) Engl. & Diels. | -  | -    | -  | 3   | -  | 3     |
| Annonaceae     | Cleistopholis staudtii Engl. & Diels.   | -  | -    | -  | 2   | -  | 2     |
| Apocynaceae    | Alstonia boonei De Wild                 | -  | -    | -  | 1   | -  | 1     |
| Apocynaceae    | Funtumia elastica (Preuss) Stapf        | -  | -    | -  | 20  | 1  | 21    |
| Apocynaceae    | Holarrhena floribunda (G.Don) Dur & Schinz | 1  | 6    | -  | 2   | -  | 9     |
| Apocynaceae    | Raoulafia coffea Sonnd.                 | -  | -    | -  | 6   | -  | 6     |
| Apocynaceae    | Raoulafia vomitoria Afzel.              | -  | -    | -  | 1   | -  | 1     |
| Apocynaceae    | Raoulafia sp.                           | -  | -    | -  | 6   | -  | 6     |
| Apocynaceae    | Voacanga africana Stapf                 | -  | -    | -  | 1   | -  | 1     |
| Araliaceae     | Cussonia arborea Hochst.ex.A.Rich.      | 2  | 105  | 2  | -   | -  | 110   |
| Araliaceae     | Polycaulis fuber (Herrm) Harms          | 1  | 9    | -  | 7   | 1  | 18    |
| Areceaceae     | Eulais guineensis Jacq.                | -  | -    | -  | 1   | 43 | 49    |
| Bignoniaceae   | Markhamia tomentosa (Benth.) K.Schum.  | -  | -    | 2  | -   | 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 buxospermum P.Beauv.             | 1  | 12   | -  | 11  | 9  | 33    |
| Burseraceae    | Canarium schweinfurthi Engl.           | 1  | 1    | 12 | -   | 15  |
| Ceropaciaceae  | Musanga cecropioides R.Br.ex.Tedlie     | -  | -    | -  | 2   | -  | 2     |
| Cerejeiroaeae  | Myrtianthus arbores P.Beauv.            | -  | -    | -  | 1   | -  | 1     |
| Chrysobalanaceae | Magnipiptula butyri De Wild.             | -  | 1    | -  | -   | 1  | 1     |
| Chrysobalanaceae | Magnipiptula butyri subsp. balingmeaensis De Wild. | -  | -    | 2  | -   | 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     | Garzia cf manii Oliv.                   | -  | -    | -  | 1   | -  | 1     |
| Clusiaceae     | Garzia epunacta Stapf                   | -  | -    | -  | 10  | 4  | 14    |
| Clusiaceae     | Mammea africana Sabine                   | -  | -    | -  | 3   | -  | 3     |
| Clusiaceae     | Symphonia globifera 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      | Diospyrus sp.                           | -  | -    | -  | 1   | -  | 1     |
| Euphorbiaceae  | Alchornea cordifolia (Schum. & Thonn.) Müll.Arg. | 1  | 3    | -  | -   | -  | 4     |
| Euphorbiaceae  | Macaranga spinosa Müll.Arg.             | -  | -    | -  | 2   | -  | 2     |
| Euphorbiaceae  | Neoboutonia velleina Prain              | -  | 6    | -  | -   | -  | 6     |
| Euphorbiaceae  | Ricinodendron heudelotii (Baill.) Pierre ex Baill. | -  | 4    | 17 | 18  | 18 | 43    |
| Euphorbiaceae  | Shirakiopsis elliptica (Hochst.) Esser  | -  | -    | -  | 1   | -  | 1     |
| Fabaceae       | Afzelia africana Sm.                    | 1  | 1    | -  | 5   | -  | 7     |
| Fabaceae       | Afzelia bipinnataeis 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       | Anglocalyx pynaertii De Wild.           | -  | -    | -  | 2   | -  | 2     |
| Fabaceae       | Anthonotha macrophylla P.Beauv.         | -  | -    | -  | 13  | 4  | 17    |
| Fabaceae       | Baphia buettneri Harms subsp. hylophala (Harms) Soladoye | -  | -    | -  | 12  | 5  | 17    |
| Fabaceae       | Baphia sp.                              | -  | -    | -  | 2   | -  | 2     |
| Fabaceae       | Brachystegia eurycoma Harms             | -  | 1    | -  | 70  | 6  | 77    |
(continued on next page)
| Family             | Species                                      | GF | G/WS | MV | PSF | SF | Total |
|--------------------|----------------------------------------------|----|------|----|-----|----|-------|
| Fabaceae           | Cassia arereh Delile                          | 1  | -    | 4  | -   | -  | 5     |
| Fabaceae           | Danielia oliveri (Rolfe) Hutch. & Dalziel     | 20 | 147  | 1  | 1   | 1  | 170   |
| Fabaceae           | Dialium cf pachyphylum 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     |
| Fabaceae           | Erythrophleum suaveolens (Guill. & Perr.) Bresan | 3  | 14   | 4  | 28  | 1  | 50    |
| Fabaceae           | Parkia africana R.Br.                         | 1  | 13   | -  | 1   | 8  | 23    |
| Fabaceae           | Parkia cf pachyphylum Harms                  | -  | -    | -  | 3   | -  | 3     |
| Fabaceae           | Parkia filicoides Welv. ex Oliv.              | -  | -    | -  | 3   | -  | 3     |
| Fabaceae           | Penthaclethra macrophylla Benth.              | -  | -    | -  | 3   | -  | 3     |
| Fabaceae           | Pericopsis laxiflora (Benth.) Van Mensuwen    | 3  | 39   | -  | -   | -  | 42    |
| Fabaceae           | Pilansigia thoungingi (Schum.) Milne-Redh.   | 4  | 111  | 4  | -   | -  | 119   |
| Fabaceae           | Pterocarpus erinaceus Poir                    | 1  | 1    | -  | -   | -  | 2     |
| Fabaceae           | Pterocarpus osun Craib                        | -  | -    | 7  | -   | -  | 7     |
| Fabaceae           | Pterocarpus suaveolens (Schum.)               | -  | -    | 12 | -   | 12  |
| Fabaceae           | Pterocarpus thonningii (Schum.)               | 4  | 111  | 4  | -   | -  | 119   |
| Gentianaceae       | Anthocleista djalonensis A.Chev.              | -  | 1    | -  | 4   | -  | 15    |
| Hymenocardiaeees   | Hymenocardia acida Tul.                       | 11 | 237  | 1  | -   | -  | 249   |
| Hyperaceae         | Harungana madagascariensis Poir.             | 7  | 29   | -  | -   | 7  | 43    |
| Hypericaceae       | Psorospermum febrifugum Spach.               | 2  | 29   | -  | -   | -  | 31    |
| Icacinaceae        | Raphiostylis sp                             | -  | -    | 1  | -   | -  | 1     |
| Irvingiaceae       | Irvingia grandifolia (Engl.) Engl.           | -  | -    | -  | 1   | -  | 1     |
| Irvingiaceae       | Irvingia wumbulu Vermoesen                  | -  | -    | 6  | 1   | 7  | 14    |
| Irvingiaceae       | Klainedoxa gabonensis Pierre                 | -  | -    | -  | 1   | 1   |
| 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          | Belchromia angolensis (Engl. & Krause) Robyns & Wilckeck | -  | -    | 1  | 2   | -  | 3     |
| Lauraceae          | Belchromia gabonensis (meissn.) Benth. & Hook.f. | -  | -    | 1  | -   | 1  |
| Lecythidaceae      | Napoleonaea imperialis P.Beauv.              | -  | -    | 1  | 8   | 5  | 14    |
| Loganiaceae        | Stychnus sp.2                               | -  | -    | -  | 1   | -  | 1     |
| Loganiaceae        | Stychnus sp.3                               | -  | 2    | -  | -   | -  | 2     |
| Malvaceae          | Cola caricafolia K.Schum                     | 1  | -    | 5  | 68  | 4  | 78    |
| Malvaceae          | Cola cordifolia (Cav.) R.Br.                 | 1  | -    | 4  | -   | 5  |
| Malvaceae          | Cola sp                                     | -  | -    | -  | 1   | 2  |
| Malvaceae          | Cola sp.2                                  | 1  | -    | -  | -   | -  |
| Malvaceae          | Microcos flavescens Juss                    | -  | 4    | -  | -   | -  |
| Malvaceae          | Sterculia tragacantha Lindl.                | 4  | 3    | 13 | 10  | 30 |
| Meliaceae          | Entandrophragma angolense (Welv.) C.DC.      | -  | -    | 2  | 27  | -  | 29    |
| Meliaceae          | Entandrophragma candolleti Harms            | -  | -    | 30 | -   | 30  |
| Meliaceae          | Trichilia rubescens Oliv.                   | -  | -    | -  | 1   | 1   |
| Meliaceae          | Trichilia sp.                               | -  | 2    | -  | -   | -  |
| Moraceae           | Antiaris toxicaria Lesch.                   | -  | -    | -  | 3   | 4   |
| Moraceae           | Ficus abutilifolia (Miq.) Miq.              | -  | -    | -  | 3   | -  |
| Moraceae           | Ficus adolfi-friderici Mildbr.              | -  | -    | -  | -   | 1  |
| Moraceae           | Ficus babil Warb.                           | -  | -    | -  | 1   | 2   |
| Moraceae           | Ficus cf sur Forsk.                          | -  | 3    | -  | 1   | -  |
| Moraceae           | Ficus exasperata Vahl                       | -  | 4    | -  | 3   | 1  |
| Moraceae           | Ficus glamous Delile                        | 3  | 18   | -  | 1   | 8   |
| Moraceae           | Ficus mucus Welv.ex Picalho                 | -  | -    | -  | 3   |
| Moraceae           | Ficus natalensis Hochst.                    | -  | -    | 1  | -   | -  |
| Moraceae           | Ficus sur Forsk.                            | -  | -    | 3  | -   |
| Moraceae           | Ficus vallis-choudae Delile                 | 7  | 9    | 6  | 22  |
| Moraceae           | Ficus vogeliana (Miq.) Miq.                | -  | -    | -  | 1   |
| Moraceae           | Ficus sp.2                                 | -  | 1    | -  | -   |
| Moraceae           | Ficus sp.3                                 | -  | 29   | -  | 1   | 30  |

(continued on next page)
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

| 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.) Esenl | 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 afoleli R.Br. ex Oliv.     | -  | 11   | -  | 1   | -  | 12    |
| Ochnaceae   | Ochna sp.                       |-  | -    | -  | 1   | -  | 1     |
| Olacaceae   | Oler subcortisides Oliv.         |-  | -    | -  | 7   | 2  | 9     |
| Pandanaceae | Pandanus candelabrum P.Beauv.    | -  | -    | -  | -   | -  | 6     |
| Passifloraceae| Adenia sp.                      |-  | -    | -  | 1   | -  | 1     |
| Passifloraceae| Barteria fistulosa Mast.        |-  | -    | 2  | -   | -  | 2     |
| Phyllanthaceae | Antidesma chervallieri        | -  | 1    | -  | 1   | -  | 2     |
| Phyllanthaceae | Bridelia atroviridis Müll.Arg. | -  | -    | 2  | -   | -  | 1     |
| Phyllanthaceae | Bridelia ferruginea Benth.     | -  | 4    | -  | -   | -  | 4     |
| Phyllanthaceae | Bridelia grandi Pierre ex Hutch. | -  | 1    | -  | 3   | -  | 4     |
| Phyllanthaceae | Bridelia iscroneura Müll.Arg. | 1  | 66   | 1  | -   | -  | 68    |
| Phyllanthaceae | Bridelia sp.                    | 1  | 3    | -  | -   | -  | 4     |
| Phyllanthaceae | Macaranga monandra Müll.Arg.    | -  | -    | -  | -   | -  | 4     |
| Phyllanthaceae | Margaritaria discoides (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 Aubr. & Léandri | -  | 1    | -  | 53  | 2  | 56    |
| Phyllanthaceae | Uapaca togoensis F. Pax         | 96 | 86   | 20 | 11  | -  | 213   |
| Rhamnaceae  | Maesopsis emnii Engl.           | 3  | 1    | -  | 34  | -  | 38    |
| Rhizophoraceae | Cassipourea zenkeri (Engl.) Alston. | -  | -    | 4  | -   | -  | 4     |
| Rubiaceae   | Allophyllus bullatus Radlk.     | 2  | 17   | -  | 22  | -  | 22    |
| Rubiaceae   | Bietenia stipulosa (DC) Leroy   | -  | -    | 2  | 36  | 38  |
| Rubiaceae   | Exora exausia K. Schum.         | -  | -    | 31 | -   | -  | 31    |
| Rubiaceae   | Exora sp.2                      | -  | -    | -  | 2   | -  | 2     |
| Rubiaceae   | Macrophyra longistyia (DC.) Hiern | 2  | -    | 18 | -   | 20  |
| Rubiaceae   | Morelia senegalenis A. Rich.ex DC. | 2  | 1    | 8  | 2   | 13  |
| Rubiaceae   | Nauclea latifolia SM.           | 3  | 225  | 8  | -   | -  | 236   |
| Rubiaceae   | Pavetta acnonica Bremek.        | -  | -    | 3  | -   | 3    |
| Rubiaceae   | Pavetta calothyrsa Bremek.      | -  | -    | 1  | -   | 1    |
| Rubiaceae   | Rothmannia sp.1                 | -  | -    | 2  | -   | 2    |
| Salicaceae  | Homalium africanum (Hook.) Benth. | -  | -    | 2  | -   | 2    |
| Sapindaceae | Alephryllus bailulus Radlk.     | 2  | 17   | 3  | -   | -  | 22    |
| Sapotaceae  | Chrysophyllum unguineum (De Wild.) Govaerts | 2  | -    | 3  | 75  | -  | 80    |
| Sapotaceae  | Englerophyllum stelchanthum Krause | -  | -    | 1  | -   | -  | 1     |
| Sapotaceae  | Pouteria alnifolia (Baker) Roberty | -  | -    | 1  | -   | -  | 1     |
| Sapotaceae  | Synaspalum stipulatum (Raddl.) Engl. | -  | -    | 4  | -   | -  | 4     |
| Simaroubaceae | Quassia angustifolia Cheek & Jongkind | -  | -    | 4  | -   | -  | 4     |
| Simaroubaceae | Quassia sylystris Cheek & Jongkind | -  | 1    | -  | 1   | -  | 2     |
| Ulmaceae    | Celtis philippinensis 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.
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 [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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