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Plant diversity and conservation concerns in a semi-deciduous rainforest in Cameroon: implications for sustainable forest management

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Abstract Plant diversity conservation has become one of the most critical objectives of forest management in an ecologically sustainable way. However, biodiversity conservation and sustainable management issues are sometimes neglected in Cameroon's communal forests because their botanical importance, and high-priority species for conservation are poorly known. In the present study, done in the Doume Communal Forest (DCF) situated in eastern Cameroon, we explore its potential in terms of plant diversity as well as conservation value. Forest inventories done in thirty 1-ha plots were analysed using diversity indices, species and family importance values index as well as IUCN conservation status. A total of 22,064 stems with a diameter ≥ 1 cm were recorded within thirty 1-ha sampling plots, belonging to 307 species, 194 genera and 72 families. The DCF is particularly rich in members of the Malvaceae, Annonaceae, Meliaceae and Apocynaceae. The list of the plant species known from the DCF reaches 330 species, with 290 identified at the species level. It was found out that 49 species can be considered high-priority species for conservation and that these species include species that are rare and threatened in Cameroon, and even one species endemic to the country. This study highlights the botanical importance of communal forests in Cameroon and recommends that botanical assessments of these forests are performed to contribute to the sustainable management and conservation of their biodiversity.

Keywords biodiversity conservation · ecological values · endemism · rare species · threatened species · high-priority species for conservation · Doume Communal Forest

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Introduction

Tropical forests are essential for human survival and well-being. They are at the centre of debates on climate change and sustainable forest management (SFM) because of their dual roles in climate change mitigation and biodiversity conservation (Bodegom et al. 2009; Bele et al. 2015; Poorter et al. 2016; Arasa-Gisbert et al. 2018). They also provide a wide range of other ecosystem services that contribute to people's quality of life (IPBES 2019). It is now globally recognized that forests must be managed sustainably (United Nations 1992; Kohm and Franklin 1997). Many forests are still subject to deforestation and degradation, which has a significant negative impact on terrestrial biodiversity and, thus, on ecosystem services closely linked to biodiversity.

Because it is irreversible, extinction is the major problem of the ongoing biodiversity crisis. Even though the conservation of biodiversity and reduction of its loss has been reasserted by the Aichi targets for 2020 by the Parties to the United Nations Convention on Biological Diversity (CBD) after failing to meet the 2010 target (Butchart et al. 2010; CBD 2011), its loss does not seem to be slowing down. Anthropogenic disturbances have resulted in a loss of species diversity, with the current rate of extinctions being at least 1,000 times higher than natural extinction rates (De Vos et al. 2015). Therefore, the most obvious among them may be the lost opportunity for future resource use. Onana (2011) already noted that some species lose their habitat and sometimes become extinct without being even known to science. With the loss of species, we lose the ultimate source and the basis of the ecosystems' structure and function that support humans and all life on Earth (Mittermeier et al. 2011). Therefore, maintaining the biodiversity of forest ecosystems is essential to the supply of ecosystem services and not less important to support their health and resilience (Butchart et al. 2010; Pereira et al. 2013).

In many respects, conservation and sustainable management are local and people generally care more about the biodiversity in the place in which they live. Based on this observation and since the summit of the earth in 1992, Cameroon has made many efforts towards the path of conservation and SFM. These efforts has been evident through (i) the signing and ratification of the CBD treaty in 1994 and later the climate change treaty such as REDD +; (ii) the implementation of international treaties signed at the national level by restructuring its institutional framework and adopting a forest law supplemented through an implementing decree. Elsewhere, with the forest code, the Republic of Cameroon aims to promote sustainable management and conservation purpose of its forests while encouraging all users' participation in the process of decentralized management of the forest. Thus, the Republic of Cameroon decided to retrocede to the requested municipalities to manage and exploit forest areas for the benefit of their entire population. Such forests are called Communal Forests (CFs).

In Cameroon, the concept of communal forestry has evolved, and in 2018, sixty-four communal forests were representing an area of 1,812,150 ha or 8% of the country's total forest area (MINFOF 2018). Communal forests represent forest management centred on commercial wood resources with an obligation to deal with the aspirations, interests and uses of local populations. Thus, the communal forest is a recent framework for effective participatory forest management where sustained tree harvesting must be combined at a local scale to enhance riparians' well-being (Poissonnet and Lescuyer 2005). Like with forest management units (FMUs), the manager of each CF should elaborate a management plan that is the keystone of sustainable forest management. It is generally revisable every fifteen years, depending on the legislation, whose decisions ratified by the company, and the administration in charge of the forests will constitute the fundamental elements of implementing these two key stakeholders' forest policies. The management plan should be the result of a thorough study of the forest's potential and the risks that may weigh on the forest and its functions, and this study must have been guided by the development possibilities of the forest (ATIBT 2007).

However, most of the studies carried out in CFs and FMUs of tropical forests concluded that conservation issues and some SFM aspects are neglected to benefit woody resources assessment (Anonymous 2015; Tchouto et al. 2006). In most of these studies, floristic diversity is limited to tree species with a minimum diameter of exploitability for CFs and FMUs and even protected areas' management plans. Therefore, this approach is not sufficient for plant diversity assessment because most components of the diversity of the ecosystems, such as shrubs, small trees, lianas, herbaceous plants and epiphytic flora as well as their conservation status, are not taken into account (Tchouto 2004). Most African countries like Cameroon have decided to establish large forest areas in protected areas as their biodiversity conservation strategy (Mengue-Medou 2002; Muhumuza and Balkwill 2013). Terrestrial biodiversity is too widely dispersed to allow its measurement to be focused solely within strictly protected areas. Managed landscapes will continue to play vital roles as buffer zones and corridors supporting protected areas and more generally as habitat for wild species, some of which are likely never adequately represented within the protected area network (Dudley et al. 2005). Measurement across the whole mosaic of land-cover types is therefore essential, including in the area of sustainable use, particularly forests inside and outside protected areas.

The present study focuses on the Doume Communal Forest (DCF) situated in Cameroon's eastern region and belonging to the Guineo-Congolese domain (Letouzey 1985). This forest is important for national development and the livelihoods of about 22,763 locals (Anonymous 2015). It provides various ecosystem services, supports riparian people's livelihoods and harbours many endangered animal and plant species populations. In addition to supporting biodiversity, these forests also store and absorb substantial but seldom measured quantities of carbon (Zekeng et al. 2020). These forests are also subject to intense pressure because of rapid population growth, logging and hunting activities, which exert a diverse ecological impact on the forest ecosystems. Zekeng et al. (2019) have shown that the degradation and conversion of the forests in Cameroon to other land use types such as agroforestry systems is moving at a worrying speed. Therefore, with the increasing destruction of natural ecosystems, identifying species with high conservation priorities and their habitat areas is an essential requirement for many environmental applications, including land use planning and landscape monitoring. This study aimed to assess the plant diversity and its conservation value in the DCF to demonstrate that communal forests deserve more attention in terms of biodiversity conservation and SFM.

Material and methods

Study site

The study was conducted in the moist, semi-deciduous communal forest managed by the municipality of Doume (4°31′0″ S, 13°47′5″ W). The Doume municipality is situated in the Upper Nyong division of Cameroon's eastern region, 58 km from Abong-Mbang and 57 km from Bertoua. Spread over an area of 2,500 km^2, the municipality of Doume is bordered by Ndiang, Abong Mbang, Doumaintang and Angossas in the north, south, east and southwest, respectively. Two blocks of the forest constitute the Doume Communal Forest (DCF) of 45,359 ha (Fig. 1).

Topographically, the region is covered by a succession of low hills with generally gentle slopes interspersed with small streams, or swampy depressions, sometimes vast (several hundred metres), but without a distinct watercourse. The elevation varies from 540 to 676 m above sea level, with some particularly marked summits, culminating at less than 700 m (Anonymous 2015). The climate is tropical, with a wet and a dry season. The mean annual temperature is 25°C and annual rainfall varies between 1,300 and 1,800 mm. The soils are ferralitic with high sand content, high water retention capacity and high humus content resulting from the decomposition of plants and organic matter (Zekeng 2020; Zekeng et al. 2020).

Sampling design, botanical inventory and measurements

Representative and homogeneous vegetation types were selected based on physical features (e.g. topography and altitude) and analyses of land use and land cover change of the study area (Zekeng et al. 2019). Thirty 1-ha (100 × 100 m) plots were established within the two blocks of the DCF, avoiding rivers and swampy vegetation types. Each 1-ha (100 × 100 m) plot was subdivided into 25 subplots of 20 m × 20 m. Five sub-quadrats of 5 m × 5 m were also installed at the four corners and the centre.

Within each plot, complete inventories of all vascular plants with a diameter at breast height (DBH) ≥ 10 cm, hereafter large trees, were realized. All the vascular plants with DBH between 5.0 and 9.9 cm, hereafter medium trees, were identified, and their DBH recorded from thirteen plots of 20 m × 20 m of the 1-ha plot. Stems of 1.0–4.9cm diameter, hereafter small stems, were recorded within the five 5 m × 5-m sub-quadrats. If applicable, trees were measured 50 cm above the top of buttresses, or 2 cm above the deformities (Condit 1998).

During the fieldwork, direct identification was performed at the time of tree mensuration by observing the leaves, flowers, habit, slash and other diagnostic characters. A unique code was attributed to unidentified

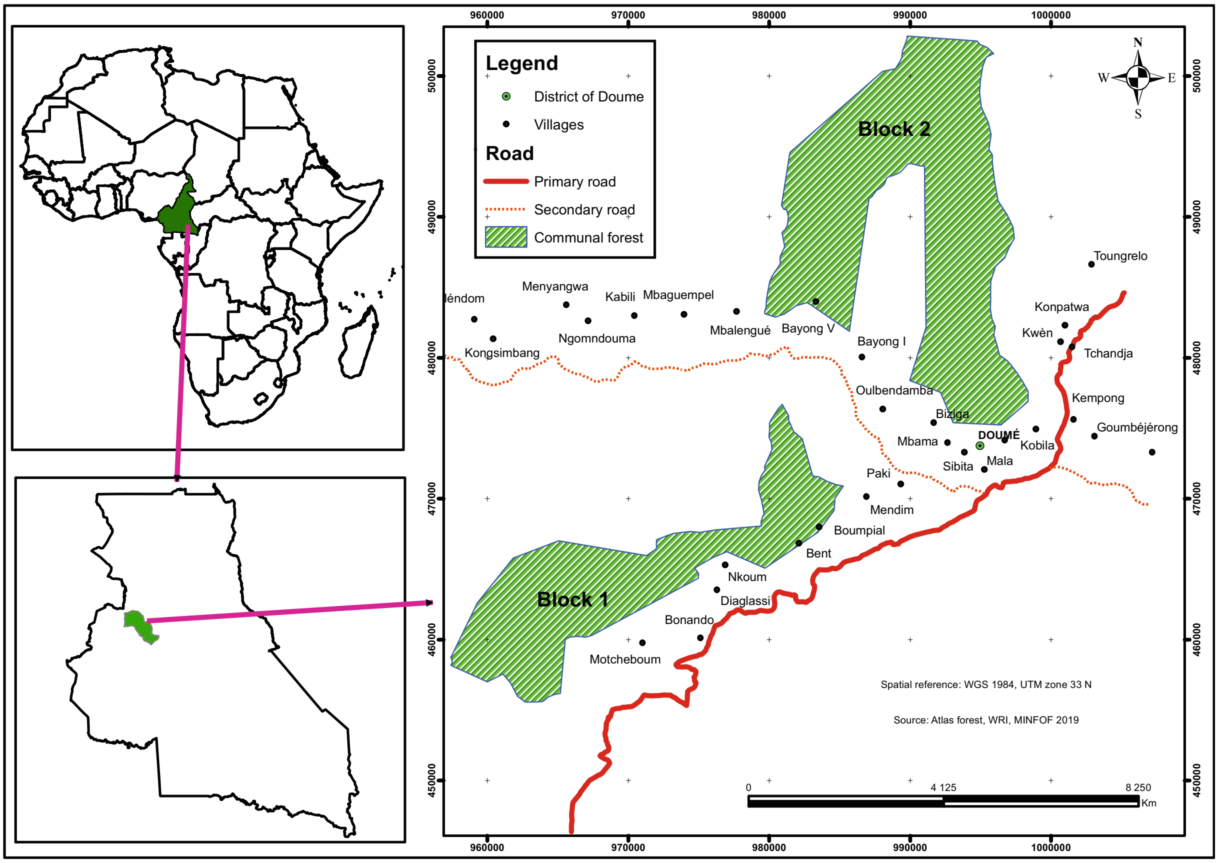

Fig. 1 Map and localization of the Doume Communal Forest, showing the two blocks (FC DOUME block 1 and 2) of it.

species for re-use during the inventory if encountered later within the plot or locality. Also, herbarium specimens were collected for further checking and identification at the National Herbarium of Cameroon. A datasheet of each specimen was filled out describing its vegetative characters. The names of each species identified during the fieldwork were homogenized for synonymies and orthographic problems using several plant databases such as the Plant List database (Hassler 2018). The Angiosperm Phylogeny Group IV (APG; Byng et al. 2016) was used for families' botanical nomenclature. For the Leguminosae subfamilies, the new subfamily classification based on a taxonomically comprehensive phylogeny was used (LPWG 2017).

Data analysis

In ecology, diversity implies a measure of both species number and evenness. To describe the diversity patterns across the Doume Communal Forest plots, alpha diversity indices were used, since they represent the number of species in a chosen community (Kent and Coker 1992) or a set of samples (Magurran 2004). Diversity indices consider the number of species and whether species are more or less equally abundant or if, on the contrary, one or more species dominate. Diversity was assessed using species richness, expressed as the Shannon-Weaver (Shannon and Weaver 1949), Simpson (Simpson 1949) and α-Fisher (Fisher et al. 1943) indices, which are the most widely used and thus facilitate comparisons with other studies.

Species richness refers to the number of species present, without any particular regard for the exact area or number of individuals examined. Nevertheless, it is useful to distinguish between numerical species richness, the number of species present in a collection containing a specified number of individuals (Hurlbert 1971). To determine whether sample size in this study was sufficient, sample-based rarefaction curves were plotted.

The Shannon-Weaver index (Shannon and Weaver 1949) assumes that individuals are randomly sampled or distributed from an indefinitely large population and that all species are represented in the sample. The Shannon-Weaver index is computed from the following equation:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i,$$

where p_i is the proportion of individuals belonging to the ith species found in a sample.

The Simpson index (Simpson 1949) is a measure of the number of species present and also takes into account the relative abundance of each species. It represents the probability that two randomly selected individuals in the area belong to the same species. It measures how individuals were distributed among species of a population and it is given by:

$$\gamma = \sum_i P_i^2,$$

where Pi is the proportion of individuals belonging to the ith species found in a sample. Due to its reciprocal character, it starts with the value of 1 and raises up to the total number of species.

Trees diversity was also estimated using a common diversity index, the α-Fisher index (Fisher et al. 1943), which assumes that samples are a reasonable fit to a log-series. It is independent of sample size and it describes how the individuals are divided among the species. The α-Fisher index provides good discrimination between sites, it is not very sensitive to density fluctuations and it is normally distributed:

$$a = \frac{N(1-x)}{x}, \text{with } x \text{ estimated} \quad \text{from } \frac{S}{N} = \frac{(1-x)}{x[-\ln(1-x)]},$$

where N represents the total number of individuals and S the total number of species (Magurran 1988).

The species importance value index (IVI; Curtis and McIntosh 1951) and the family importance value index (FIV; Cottam and Curtis 1956) were used to describe the ecological importance of species and families within the thirty 1-ha plots. The IVI was used to determine the leading dominant taxa in the vegetation sample and computed using the following formulae:

$$\text{Relative density} = (\text{number of species individuals or family individuals}/\text{total number of individuals}) \times 100.$$

$$\text{Relative frequency} = (\text{frequency of a species}/\text{sum of all frequencies}) \times 100.$$

$$\text{Relative dominance} = (\text{basal area of the species or family}/\text{total basal area}) \times 100$$

$$\text{Family relative diversity} = (\text{number of species in a family}/\text{total number of species}) \times 100$$

$$\text{IVI} = \text{relative density} + \text{relative dominance} + \text{relative frequency},$$

$$\text{FIV} = \text{Relative dominance} + \text{Relative density} + \text{Relative diversity}$$

High-priority species for conservation are defined as species with high conservation value, such as Cameroon's endemic species, rare species or endangered species (Tchouto et al. 2006; Onana and Cheek 2011; Onana 2013). For the establishment of this priority species list, several steps were followed. Firstly, using a management plant of the Doume Communal Forest and the thirty 1-ha plots field inventory, a plant checklist was generated. Secondly, to determine the threatened status of the species on this checklist, and to identify endemic species, floras and monographs were consulted (Onana 2011; Onana and Cheek 2011), as were the IUCN (2020) red data list, the African Plant Database (2020) database and the Plant List database (Hassler 2018).

The notion of rarity is understood differently according to the authors that worked on it, often according to the objectives sought (Tchouto et al. 2006; Gonmadje et al. 2012; Onana 2013). In this work, which aims to draw attention to policies on the management of communal forests, it was decided to use the notion of a rarity as defined in Cameroon's forestry law. Indeed, the forest law of 1994 and its application decree considered all species with less than one tree per 100 ha rare. The major African phytochoria (White 1979; White 1983) were used to determine the plant check-list's distribution patterns. Therefore, each species was assigned to one of the following categories: (1) Widespread (Ws) including pan-African and paleotropical, (2) Guineo-Congolian (Gc), (3) Upper and Lower Guinea (Gu), (4) Lower Guinea (Lg), (5) Cameroon (Cam) and (6) Oriental Semi-deciduous Cameroon (OS-Cam). Based on the species information above, a list of high-priority species for conservation was produced, with preference given to taxa that are endemic to Cameroon.

Results

Species richness in the Doume Communal Forest

A total of 22,100 stems with a diameter of ≥ 1 cm were recorded within the thirty 1-ha sampling plots, where 22,064 stems belonging to 307 species were identified and classified into 194 genera and 72 families. More than 89% of morphospecies were identified at the species level, 6% at the generic level, 2% at the family level, and 3% remained unidentified. The total number of stems registered and identified is distributed as follows: 15,168 large trees (DBH ≥ 10 cm) belonging to 271 species, 4,567 medium trees (5 ≤ DBH < 10 cm) belonging to 242 species, and 2,010 small stems (1 ≤ DBH < 5 cm) belonging to 167 species. Many species were recorded to occur in more than one diameter class.

The rarefaction curve, showing the tree species richness in the thirty 1-ha sample plots rises only slowly towards the end, suggesting that the forest trees species composition can be considered satisfactorily sampled (Fig. 2). This study found that for the whole tree community, the number of species per plot varied from 109 to 131 species. Variation of between 93 and 116 species was found among the thirty 1-ha plot for the large tree diameter class. The areas sampled in each of the thirty 1-ha plots showed a variation of 43 to 61 species for medium trees and 19 to 29 species for small stems in the DCF plots.

Diversity indices in the Doume Communal Forest

The Shannon-Weaver index for the whole tree community (4.05 ± 0.15) as well as for large trees (3.99 ± 0.19) did not vary too much, in contrast to medium trees (3.53 ± 0.27) and small stems (2.79 ± 0.26). The same trends were found for the Simpson and the Fisher-α index. However, for small stems, it was found that the values of the Simpson index were low (0.91 ± 0.04), with greater variation (CV ≥ 3.96) among the plots than the other trees classes (CV ≤ 3.41). For the α-Fisher index, it was found that small stems had low values (17.55 ± 5.65) and more marked variation (CV ≥ 32.17) among plots than the other tree size classes (Table 1).

Floristic composition of Doume Communal Forest plots

The FIV average values of the most important families within the whole thirty 1-ha plots are presented in Table 2. The families Malvaceae (FIV = 28.16), Annonaceae (FIV = 24.95), Meliaceae (FIV = 16.97) and Apocynaceae (FIV = 16.92) are the four most important families with the highest FIV, considering the whole tree community of the 30 1-ha sample plots of DCF. Moreover, these four families also appear as the families with the highest FIV in the large and small trees classes (Table 2).

For the whole tree community, the most diverse families with more than fifteen species were of the Malvaceae (24 species), Rubiaceae (20 species), Euphorbiaceae (19 species), Annonaceae (18 species), Leguminosae-Detarioideae (17 species) and Sapotaceae (17 species). However, these most diverse families are not the same when considering trees by the three diameter classes. Because their emergent or large canopy trees account for much

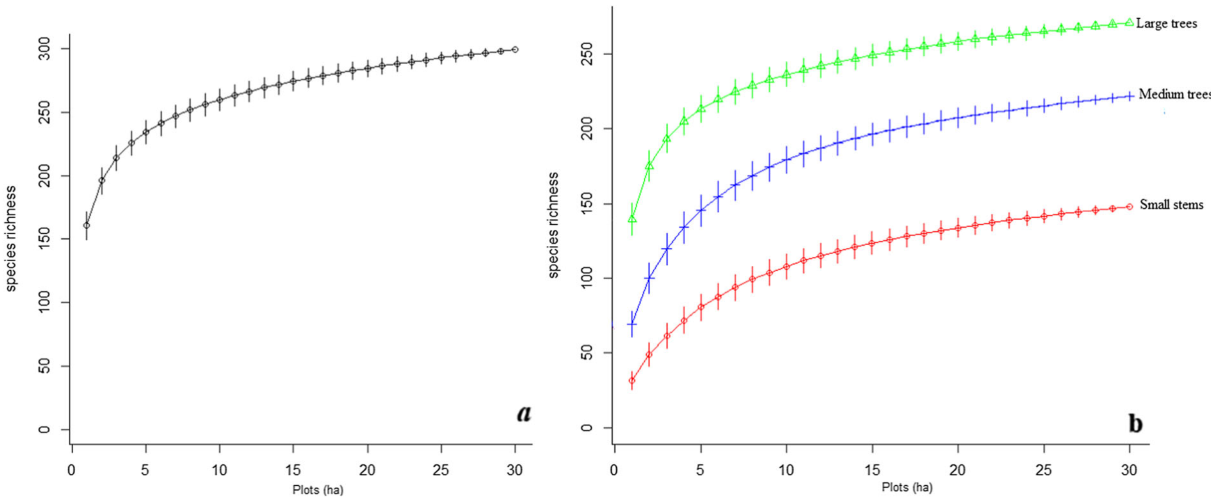

Fig. 2 Rarefaction curve showing species richness of the a – whole tree community and b – tree size classes for the thirty 1- ha plots of the Doume Communal Forest.

of the basal area recorded in the plots, species of the Malvaceae, Cannabaceae, Urticaceae and Leguminosae-Caesalpinioideae were the most dominant, contributing primarily to the floristic composition of the canopy, thereby justifying their high FIV at the level of large tree. The Annonaceae, Meliaceae, Apocynaceae and Phyllanthaceae owed their high FIV values to their density, contributing mostly to the medium trees classes with numerous individuals but exhibiting a rather low basal area; high FIV values were produced by medium trees and small stems. Other families, such as Leguminosae-Detarioideae, have approximately the same proportions of FIV for large trees (FIV = 11.38) and small stems level (FIV = 12.81; Table 2).

In general, among the species with the highest IVI values for the whole tree community, some species appear also at the top in one of the three diameter classes' levels, a few species appear in any two of the diameter classes, and some species even appear in all three diameter classes, for example *Eriocoelum macrocarpum* and *Trichilia dregeana* (Table 3). The four species with the highest IVI in the whole tree community, which is also true for the tree census at the level of large trees, were *E. macrocarpum*, *Musanga cecropioides*, *Trichilia dregeana* and *Pycnanthus angolensis*, belonging to the Sapindaceae, Urticaceae,

Table 1 Average values and coefficient of variation for species richness and diversity for the whole tree community and tree size classes among the thirty 1-ha plots

Estimate parameters	Whole tree community	Large trees	Medium trees	Small stems
Average ± Standard error				
Richness	121.03 ± 11.98	104.83 ± 11.96	51.63 ± 9.08	24.37 ± 4.81
Shannon-Weaver	4.05 ± 0.15	3.99 ± 0.19	3.43 ± 0.27	2.79 ± 0.26
Simpson	0.97 ± 0.01	0.97 ± 0.01	0.94 ± 0.03	0.91 ± 0.04
Fisher-α	42.24 ± 5.30	40.38 ± 6.24	30.97 ± 9.10	17.55 ± 5.65
Coefficient of variation				
Richness	9.89	11.41	17.58	19.74
Shannon-Weaver	3.67	4.89	7.77	9.44
Simpson	0.84	1.27	3.41	3.96
Fisher-α	12.54	15.44	29.39	32.17

Table 2 Average family importance value index of the most important families (in bold) for the whole tree community and the tree size classes (by decreasing the whole tree community) within the 30 1-ha of the Doume Communal Forest plots

Families	Average family importance value index			
	Whole tree community	Large trees	Medium trees	Small stems
Malvaceae	**28.16**	**29.14**	9.74	**22.22**
Annonaceae	**24.95**	**26.40**	**33.37**	**15.03**
Meliaceae	**16.97**	**16.23**	**21.15**	**26.23**
Apocynaceae	**16.92**	**16.18**	**20.22**	**34.27**
Euphorbiaceae	**15.96**	**16.18**	**12.20**	**14.15**
Cannabaceae	**14.72**	**16.18**	**9.94**	7.71
Leguminosae-Detarioideae	**11.65**	**11.38**	8.43	**12.81**
Phyllanthaceae	**11.64**	**12.94**	6.14	2.76
Leguminosae-Caesalpinioideae	**11.31**	**12.32**	3.30	3.83
Urticaceae	**11.15**	**11.92**	5.52	6.26
Myristicaceae	10.26	10.69	**11.23**	9.48
Irvingiaceae	8.99	9.31	**14.83**	8.07
Sapindaceae	8.44	8.24	**12.39**	**12.29**
Moraceae	8.40	7.54	**10.36**	9.88
Rubiaceae	7.58	6.13	5.52	**16.07**
Salicaceae	6.96	6.19	**10.42**	**22.92**
Pandaceae	1.84	0.59	0.88	**15.97**

Meliaceae and Myristicaceae families, respectively. *Musanga cecropioides*, *Sterculia rhinopetala*, *Terminalia superba* and *P. angolensis* were the most dominant species contributing to the canopy's floristic composition, where large trees result in high IVI values. Whilst the species *T. dregeana*, *E. macrocarpum*, *Homalium* sp. (Salicaceae), *Tabernaemontana crassa* (Apocynaceae) and *Microdesmis puberula* owed their high IVI values to their abundance, contributing mostly to the medium class, high IVI values being provided by medium trees or small stems (Table 3). Across all the thirty 1-ha sample plots, 16% of the species were represented by only one or two individuals (51 species out of all the 307 species).

Conservation value and endemism

A plant checklist of 330 species including 23 species of vascular plants (only trees) found in the forest management plan and the 307 plant species encountered in the thirty 1-ha plots was made. Of these species, 291 species have been identified at the specific level.

Among the 291 species whose range was known, a small proportion consisted of widespread species found in various African phytochoria (16 %). Most species in the list are Guineo-Congolian wide (69%) or restricted to the Upper and Lower Guinea (6%). However, 25 species (9%) are only known from the Lower Guinean domain. Of these species, only *Penianthus camerounensis* (Menispermaceae) is endemic to Cameroon (Table 4).

A list of 49 plant species considered species with high-priority for conservation, including rare species, threatened species and Cameroon endemics, with information on their habit and chorology is provided. This list included 38 species threatened at the global level. Moreover, it was found that heigh species threatened at the global level are not threatened at the national level. It was also found that two species threatened at the national level were not at the global level (Table 4).

Discussion

Diversity of the semi-deciduous Doume Communal Forest

A better floristic characterization of forest communities is based on the interpretation of diversity indices (Sonké

Table 3 Average importance value index of the most important species (in bold) for the whole tree community and the tree size classes within the thirty 1-ha plots of the Doume Communal Forest

Species	Average importance value index			
	Whole tree community	Large trees	Medium trees	Small stems
Eriocoelum macrocarpum	**8.39**	**8.15**	**12.72**	**11.57**
Musanga cecropioides	**8.33**	**9.00**	2.43	1.67
Trichilia dregeana	**6.95**	**6.35**	**14.91**	**18.92**
Pycnanthus angolensis	**6.60**	**6.90**	**7.12**	6.19
Sterculia rhinopetala	**6.59**	**7.22**	4.11	2.43
Terminalia superba	**6.31**	**6.96**	0.78	–
Tabernaemontana crassa	**5.78**	5.25	**9.96**	**19.87**
Anonidium mannii	**5.61**	**6.45**	**4.85**	**–**
Celtis adolfi-friderici	**5.12**	**5.82**	3.02	1.24
Uapaca guineensis	**4.95**	**5.54**	2.92	1.44
Funtumia elastica	4.63	**5.30**	4.20	0.40
Desbordesia glaucescens	4.58	4.80	**4.97**	3.93
Homalium sp.	4.41	3.44	**10.18**	**19.00**
Polyalthia suaveolens	4.11	4.15	**5.93**	**6.90**
Annickia chlorantha	3.37	3.56	**5.30**	1.58
Microdesmis puberula	1.84	0.59	1.63	**15.24**
Rinorea sp.	1.70	1.09	3.12	**7.33**
Streblus usambarensis	1.63	0.47	**7.78**	5.87
Tabernaemontana pachysiphon	1.39	0.15	2.63	**12.16**
Thomandersia hensii	0.94	0.35	1.91	**6.89**
Octolobus spectabilis	0.83	0.31	1.47	**7.40**

2004; Mbolo et al. 2016), so a forest is considered rich if it is characterized by a Shannon diversity index greater than or equal to 3.5 (Kent and Coker 1992). Therefore, the DCF plots, which at the levels of the whole tree community and the large and medium tree groups had high values of Shannon diversity ($H' > 3.5$) and Fisher-α can, accordingly, be considered very diverse. The semi-deciduous DCF harbours a rich and diverse trees flora. However, the Shannon-Weaver index of small stems groups showed that it is not rich and diverse and the rarefaction species accumulation curve confirmed this. Indeed, this curve shows that the rate of species increases with sampling effort had reached an asymptote, indicating that the diversity of the DCF small stem group had been satisfactorily captured and that even if the sample area increases, the diversity will not increase. However, the Simpson index justifies the representativeness of the flora by some species in terms of their abundance (Sonké 2004). McElhinny et al. (2005) showed that diversity indices such as Shannon's, Simpson's and Pielou's are only elements of measurement and biodiversity characterization.

This study showed that among the thirty 1-ha plots of the DCF, species richness varied from 109 to 133 species·ha^{-1} and that this species richness decreased with tree size groups. The species richness of large trees found in this study (104 ± 12 species·ha^{-1}) was similar to the values of 119 ± 9 and 96 ± 10 species ha^{-1} found in Cameroon Atlantic forest of Okoroba and Yingui, respectively (Fobane 2017), and the value of 110 species·ha^{-1} was found in the lowland evergreen forest of Ngovayang (Gonmadje 2012). However, the number of 271 species found in the thirty 1-ha plots of the semi-deciduous forest of east Cameroon was greater than the value of 207 species found in terra firme evergreen forest in the Dja Biosphere Reserve in Cameroon (Djuikouo et al. 2010) and the value of 205 species found in the same sites (Tabue et al. 2016). Moreover,

Table 4 List of high-priority species for conservation found in the Doume Communal Forest

Family	Species	Chorology	Habit	IUCN local status (Onana 2011)	IUCN global status (IUCN 2020)
Anacardiaceae	*Antrocaryon micraster* A. Chev. & Guillaumin*		tr	LC	VU
Burseraceae	*Dacryodes igaganga* Aubrév. & Pellegr.	Lg	tr. sh	VU	VU
Chrysobalanaceae	*Maranthes gabunensis* (Engl.) Prance*	Gc	tr	LC	LC
Clusiaceae	*Garcinia kola* Heckel	Gc	tr. sh	VU	VU
	Garcinia mannii	Gc	tr.sh	VU	VU
Combretaceae	*Terminalia ivorensis* A. Chev.*	Gu	tr	LC	VU
Cordiaceae	*Cordia platythyrsa* Baker	Gc	tr. sh	LC	VU
Ebenaceae	*Diospyros crassiflora* Hiern	Gc	tr. sh	NT	VU
Leguminosae-Detarioideae	*Afzelia africana* Pers.	Ws	tr	VU	VU
	Afzelia bipindensis Harms	Gc	tr.sh	VU	VU
	Afzelia pachyloba Harms	Gc	tr	VU	VU
	Bikinia letestui (Pellegr.) Wieringa*	Lg	tr	LC	
	Brachystegia cynometroides Harms*	Lg	tr	LC	LC
	Brachystegia mildbraedii Harms*	Lg	tr	LC	LC
	Daniella ogea (Harms) Rolfe ex Holland*	Gu	tr	LC	LC
	Didelotia unifoliolata J.Léonard	Lg	tr	LC	NT
	Gossweilerodendron balsamiferum (Vermoesen) Harms	Gc	tr. sh		EN
	Gossweilerodendron joveri Aubrév.	Gc	tr		VU
	Tetraberlinia bifoliolata (Harms) Hauman*	Gc	tr	LC	LC
Leguminosae - Papilionoideae	*Pericopsis elata* (Harms) Meeuwen*	Gc	tr	LC	EN
	Pterocarpus mildbraedii Harms	Ws	tr. sh	LC	VU
Leguminosae-Caesalpinioideae	*Albizia ferruginea* (Guill. and Perr.) Benth.	Gc	tr	LC	VU
Malvaceae	*Bombax brevicuspe* Sprague	Gc	tr	LC	VU
	Mansonia altissima A. Chevalier	Gu	tr. sh	VU	LC
	Nesogordonia papaverifera (A. Cheval.) Capuron	Gc	tr.sh	VU	VU
	Pterygota bequaertii De Wild.	Gc	tr	LC	VU
	Pterygota macrocarpa K. Schum.	Gc	tr. sh	LC	VU
Meliaceae	*Entandrophragma angolense* (Welw.) C. DC.	Ws	tr. sh	VU	VU
	Entandrophragma candollei Harms	Gc	tr. sh	LC	VU
	Entandrophragma cylindricum (Sprague) Sprague	Gc	tr. sh	VU	VU
	Entandrophragma utile (Dawe & Sprague) Sprague	Gc	tr. sh	VU	VU
	Khaya anthotheca (Welw.) C.DC.	Gc	tr		VU
	Khaya grandifoliola C. DC.	Ws	tr. sh		VU
	Khaya ivorensis A. Chev.	Gc	tr	VU	VU
	Leplaea cedrata (A.Chev.) E.J.M.Koenen & J.J.de Wilde	Gc	tr. sh	VU	VU
	Leplaea thompsonii (Sprague & Hutch.) E.J.M.Koenen & J.J.de Wilde	Gc	tr. sh	LC	VU
	Turraeanthus africanus (Welw. ex C. DC.) Pellegr.	Gc	tr. sh	LC	VU

Table 4 (continued)

Family	Species	Chorology	Habit	IUCN local status (Onana 2011)	IUCN global status (IUCN 2020)
Menispermaceae	*Penianthus camerounensis* A.J.F.M. Dekker**	Cam	sh	LC	
Ochnaceae	*Lophira alata* Banks ex Gaertn. fil.*	Gc	tr	VU	VU
Ochnaceae	*Ochna calodendron* Gilg & Mildbr.	Gc	tr.sh	VU	LC
Putranjivaceae	*Drypetes preussii* (Pax) Hutch.	Lg	tr. sh	VU	VU
Rhizophoraceae	*Anopyxis klaineana* (Pierre) Engl.	*Gc*	tr. sh	NT	VU
Rubiaceae	*Mitragyna ledermannii* (K.Krause) Ridsdale	Gc	tr		VU
	Nauclea diderrichii (De Wild. & T.Durand) Merrill	Gc	tr. sh	VU	VU
Salicaceae	*Dovyalis cameroonensis* Cheek & Ngolan	Gc	tr. sh		CR
Sapotaceae	*Autranella congolensis* (De Wild.) A.Chev.	Gc	tr	LC	CR
	Baillonella toxisperma Pierre	Lg	tr.sh	VU	VU
	Chrysophyllum lacourtianum De Wild.*	Gc	tr	LC	
	Tieghemella africana Pierre	Gc	tr	EN	EN

Chorology: Lg – Lower Guinea; Gc – Guineo-Congolian; Gu – Upper and Lower Guinea; IUCN status: categories of the threat as EN – Endangered; VU – Vulnerable; LC – Least Concern and NT – Near Threatened; Habit: tr – trees and sh – shrubs; *rare species with less than 0.02 trees per ha and therefore excluded from logging in the DCF, **endemic species

this result is also higher than the value of 127 species obtained in a semi-deciduous forest of east Cameroon (Chimi et al. 2018). Previous studies in this area showed that disturbance that has occurred a long time ago increased species richness (Zekeng et al. 2020), and soil conditions and topography also drove this species richness (Zekeng 2020). Therefore, ecological factors (i.e. rainfall, topography, disturbance and soil conditions, etc.) might explain the difference in species richness of the DCF plots compared to the studies mentioned above.

Elsewhere, it was found that the thirty 1-ha plots of the semi-deciduous forest host 242 medium tree species, with an average of 52 ± 9 species·ha^{-1}, and that is greater than the value of 24 species found in a semi-deciduous forest of east Cameroon (Chimi et al. 2018). Besides, the 167 small stems species with the average of 24 ± 5 species·ha^{-1} found in the DCF was also greater than the value of thirty species obtained in 3.4 ha of a semi-deciduous forest (Chimi et al. 2018).

Floristic composition

The different tree diameter classes each had a different assemblage of ecologically dominant species. The most important species found in the three strata included *Eriocoelum macrocarpum*, *Musanga cecropioides*, *Trichilia dregeana*, *Pycnanthus angolensis*, *Sterculia rhinopetala*, *Terminalia superba*, *Tabernaemontana crassa*, etc. According to the importance value index, among the most species, there was a high abundance of pioneer species that could indicate a more advanced level of forest degradation in the inventory plot. Effectively, the DCF was subject to normal and legal exploitation under the licensing regime between 1971 and 1980. Also reported has been the illegal exploitation in the form of wild sawing between 2009 and 2014 (Anonymous 2015). Therefore, some plots have experienced logging of varying intensity, mirroring the status of a large fraction of forests in the Congo basin (Megevand et al. 2013). Long-term disturbance, varying between 0.00 and 8.31%, which has occurred in this area, may also explain the abundance of pioneer species found in the plots inventoried (Zekeng 2020; Zekeng et al. 2020). The variation of species along the different strata may be explained by the environment's quality (Zekeng 2020). Indeed, previous studies in this area have shown that different indicator species were observed in the different strata, which was consequent to the soil composition and the topography of each habitat (Zekeng 2020).

Throughout the sample area, the Malvaceae and Cannabaceae were among the ten families with the highest FIV (Table 2). These two APG IV classification families included the Sterculiaceae and Ulmaceae's conventional systematic, respectively, the presence of which is characteristic of semi-deciduous forests (Letouzey 1985). The leading dominant families described in the Doume Communal forest are similar to those characteristic of the West African semi-deciduous forest belt (White 1983; Vooren and Sayers 1992; Bakayoko et al. 2001), which includes members of the Malvaceae, Cannabaceae, Fabaceae, Moraceae, Ebenaceae, Rubiaceae, Putranjivaceae and Euphorbiaceae.

Implications for biodiversity conservation and sustainable forest management

The present study found that species with high priority for conservation in the DCF terra-firme forest account for about 16% of all the species. This result shows that communal forests require rigorous attention to the application of standards and rules for sustainable management as well as for biodiversity conservation. Even if similar comparisons cannot be made with other studies carried out in protected areas (e.g. Kenfack et al. 2007; Gonmadje 2012; Fobane 2017), it emerges from this study that production forest areas should also receive at least minimum attention from the point of view of both biodiversity conservation and sustainable management. Besides, it should be noted that herbaceous plants have not been evaluated, so an increase in sampling in the Doume Communal Forest could result in some additional high=priority species for conservation. Larger study areas usually contain greater numbers of endemic and threatened species than smaller areas (Brooks et al. 2002). Therefore, if adjacent forests were included in the present study, the number of such species may increase. This study provided the conservation status of the species at a national scale (Onana and Cheek 2011) as well as the global scale (IUCN 2020). This study reveals that some species were threatened at the global level, while at the local level they were not threatened and *vice versa*.

Endemic species are at a great risk of extinction because of their confinement in specific habitats and their low density (Myers et al. 2000; Brooks et al. 2002). Therefore, they are essential for conservation. Previous studies done in this area highlight deforestation, degradation and conversion trajectories (Zekeng et al. 2019). Therefore, given the need to preserve these fragile and endangered species, it becomes essential to characterize and protect the habitat that shelters them to avoid a total and irreversible erosion of this unique biodiversity. This study also highlights the necessity to determine the habitat and real threats facing these species considered high-priority species for conservation. This observation is not unique to the DCF as it can also be observed in other communal forests whose results have not yet been published. It should be noted that the notion of sustainable management and biodiversity conservation constitutes a major challenge of communal forestry, just like that of community forestry. Total destruction of some forest plots in Bimbia Bonadikombo community forest was noted (Ferenc et al. 2018).

Elsewhere, this study found out that some high-priority species for conservation were recorded in the understorey. Considering that this forest is being logged, it is urgent to ensure that it is managed sustainably. Indeed, the loss of biodiversity in production forests is most often linked to non-compliance with the operator's management plan (Ferenc et al. 2018). Sometimes it is related to non-compliance with low-impact logging standards, which is occasionally unintentional because of lack of knowledge. Therefore, the capacity of the communal forestry unit's members to master reduced-impact logging standards should be strengthened to ensure its correct implementation in the field by each logger.

Zekeng et al. (2019) point out that agroforestry systems, including agricultural plantations, are the forest's main drivers to non-forest land conversion. They also note the urgency to stop this in this communal forest to avoid the loss or disappearance of the high-priority species for conservation identified in the Doume Communal Forest. The intrusion of local people into the DCF to convert forest land into agricultural land can be justified because most local people say they do not feel the impact of forest exploitation on their well-being. Therefore, the mayor's office should ensure that the council's actions contribute to these populations' well-being. Moreover, it is urgent to confine and connect the farmers to the agricultural land they already occupy. It will be essential to build the farmers' capacities to utilize sustainable agricultural techniques and the manufacturing of biofertilizers, which would also increase agricultural yields.

It has also been reported that species richness increased aboveground carbon in the Doume Communal Forest (Zekeng 2020). This is important because it has been shown that these species could constitute a potential carbon sink. For this reason, management techniques that enhance carbon storage would be fundamental for improving the forest's capacity to store carbon (Zekeng et al. 2020). These measures could contribute to the effectiveness of sustainable forest management. To reduce the riparian population's pressures on the DFC, we suggest that its managers introduce incentives, such as REDD+ or subsidies, to promote local food production.

Conclusion

The importance of the Doume Communal Forest for the conservation of tree diversity within Cameroon has long been overlooked. The present study has determined the floristic diversity of understorey and overstorey strata of this communal forest belonging to Cameroon's semi-deciduous forest. The research has shown that the Doume Communal Forest is rich and diverse. It documents that most species inventoried in this forest have Guineo-Congolian-wide distributions and that it is also home to endemic, rare and threatened species. This study begins to fill in a significant gap in the floristic knowledge about Cameroon's communal forests. Its results give a first idea of the Communal Forest's diversity and endemism. Further studies characterizing plant diversity and biogeography of endemic and rare species in the entire Doume Communal Forest and other communal forests are required to confirm these first conclusions and gain the data needed to support informed decisions on conservation and more sustainable management of the communal forests of Cameroon.

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Authors' contributions J.C.Z., R.S., W.N.M and M.M.M.A designed the research; J.C.Z. and P.A.E. collected the data; J.C.Z. analysed the data; J.C.Z., J.L.F. and M.N.H. wrote the first draft; and all the author's comments and discussed the results.

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