Ojelel *et al. BMC Ecology and Evolution* (2025) 25:12
https://doi.org/10.1186/s12862-024-02323-1

BMC Ecology and Evolution

RESEARCH

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Comparative analysis of floristic richness and diversity in six central forest reserves of north eastern Uganda

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Abstract

As the extinction risk of plants increases globally, there is need to prioritize areas with high floristic richness and diversity to inform the design of evidence-based conservation interventions. As such, this study aimed to comparatively analyse floristic diversity in six central forest reserves (CFR) of north eastern Uganda. This was guided by two objectives namely; (i) to determine the floristic richness and diversity in the CFRs and (ii) to evaluate the similarity and complementarity of floristic composition. Data was collected from nested quadrats (20 × 20 m for trees, 10 × 10 m for shrubs and 5 × 5 m for herbaceous climbers, forbs and grasses) placed at intervals of 100 m along a transect of 1000 – 1500 m. Species richness, diversity and evenness were determined for each CFR. Binary similarity coefficients were computed because only presence/absence data of plant species was recorded. A sum of 417 plant species in 76 families were recorded representing 8.7% of known vascular plants reported in Uganda. The CFRs have significantly variable Shannon–Wiener diversity indices ranging from 4.2 in Kano CFR to 4.47 in Bululu hill CFR ($t = 85.291$, $df = 4$, $p = 0.00$). The CFRs cluster into two groups namely Onyurut and Ogera hills and Akur, Kano, Bululu hills and Mount Moroto. The lowest similarity index was between Ogera hills and Moumt Moroto CFRs (0.37 or 37%) while the highest was between Akur and Kano CFRs (0.63 or 63%). The CFRs complement one another by supporting plant species not recorded elsewhere with three CFRs (Bululu hills, Mount Moroto and Onyurut) accounting for 81.53% of the plant taxa. The CFRs in NE Uganda have richness and floristic diversity with up to 8.7% of the known plants in Uganda present. The conservation status of these species is Vulnerable (4), Near Threatened (4), Least Concern (137), Data Deficient (1) and Not Evaluated (271). The two similarity clusters depict variation in altitudinal, proximity and climatic conditions. Five CFRs are required to conserve 95% of the species recorded. Therefore, the CFRs investigated play a complementary role in conserving the floristic diversity in north eastern Uganda.

Keywords Floristic, Richness, Diversity, Similarity, Complementarity, Central forest reserves, North eastern Uganda

Introduction

Biodiversity is crucial for ecosystem functioning and human well-being [50] as nearly 1.5 billion people globally directly depend on tropical forests for food, timber, medicines, and other important ecosystem functions and services [25]. The recognition of this importance is manifested in the international commitments such as the Convention on Biodiversity (CBD), associated Aichi Biodiversity Targets to halt its decline [8] and the Kumming-Montreal global biodiversity framework [19]. Notably, there is growing interest among scientists, policy makers, land managers, and the general public to understand the patterns and causes of biodiversity loss across space and time [51]. The origin of this interest is twofold; first the desire to conserve

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biodiversity and secondly; the potential for biodiversity changes to have an impact on the benefits that people derive from nature [28].

Globally, 2 in 5 (or 39%) of the world's vascular plant species are threatened with extinction [35]. Thus, understanding the patterns of distribution [43], and identification of areas with a high value for biodiversity protection is paramount [16]. The warm mixed forest, savannahs, shrub, tropical forest, and tropical woodlands are projected to lose the most species [50] mainly due to anthropogenic activities which endanger the ecosystems [27]. These activities include habitat loss, introduction of alien species, direct exploitation, climate change and pollution [17, 42].

Floristic composition and its distribution remains scarcely known in the species-rich tropical Africa [43]. The lack of suitable data for prioritising conservation actions often hampers conservation efforts. Information on the rarest and most threatened plants and habitats, is often diffuse and difficult to access or is outdated [11]. Floristic diversity within communities (alpha diversity) and between communities or the degree of community differentiation (beta diversity) [55] can guide resource managers to prioritize conservation strategies since sites with exceptional or poor diversity [40] are known. Additionally, it can aid in the evaluation of the relative importance of environmental and spatial drivers in shaping species assemblages [49].

Uganda is exceptionally rich in biodiversity with surveys reporting occurrence of over 18,783 species of flora and fauna [34]. There are approximately 4,800 species of higher plants in Uganda, of which 70 are endemic and mainly concentrated in tropical forests in the western region. Further, Uganda has a high number of species relative to its size due to the varied habitats, altitude and location at the confluence of six of White's Phytochoria [20, 54]. However, the rate of biodiversity loss was calculated in 2004 to be around 10–11% per decade or 1% per annum [39]. The main drivers of this loss are habitat loss, agricultural encroachment and expansion, climate change effects, over-harvesting of resources, diseases, pollution, introduction of alien species, demographic factors, poverty and national policies [34].

In recognition of the role of biodiversity in development, the Government of Uganda has made significant progress in putting in place policies, laws and institutional frameworks on the conservation of biodiversity. The key national policy framework is the National Environment Policy (1994) from which sectoral policies such as wildlife policy (1999), Forestry policy (2001) among others are anchored. The National Environment Act Cap 153 provides the overall management, coordination and monitoring of environment management and conservation. There are also sectoral legislations such as the Forestry and Tree Planting Act (2003), Wildlife Act (2000). Uganda is also a signatory to international conventions, protocols and agreements such as Convention on Biological Diversity (CBD) [7], Convention on International Trade in Endangered Species of Fauna and Flora (CITES) (1973); African Convention on Conservation of Conservation of Nature and Natural Resources (1968) and regional frameworks such as the East African Community Protocol on Environment and Natural Resources Management.

North eastern Uganda located in the western range of the Somali-Masai Regional Centre of Endemism [14, 54] has not been adequately surveyed due to a prolonged history of insecurity caused mainly by cattle rustlers [20]. As such, the available floristic information in most sites comprises of plant lists for trees and shrubs which were recorded by the Forest Department in 1990's as indicator taxa for selected large CFRs [12]. In small size CFRs (such as Ogera hills, Bululu and Onyurut investigated in this study), there is no record of botanical surveys carried out. Additionally, the study focused on CFRs which are classified by the National Forestry Authority (2005) to be of environmental and biodiversity conservation within this region. The general objective of the study was to contribute to evidence-based conservation of plant diversity in north eastern Uganda with three specific objectives were; (1) to determine the botanical richness and diversity in the six central forest reserves of north eastern Uganda, (ii) to analyse the similarity and complementarity of these CFRs in floristic conservation and (iii) to ascertain the conservation status of plant species within these CFRs. The information generated on species diversity is a pre-requisite for gauging ecosystems health, resilience to disturbance, spatio-temporal monitoring of changes in biodiversity, and prioritization of sites in resource allocation.

Materials and methods

Study area

The study was conducted in six CFRs located in north eastern Uganda (Fig. 1) in the western range of the Somali-Masai Regional Centre of Endemism [14, 54]. Uganda has 506 CFRs totaling to 1,262,090 ha of the land cover. These are managed by the central government through the National Forestry Authority (NFA). The region region has been poorly surveyed due to

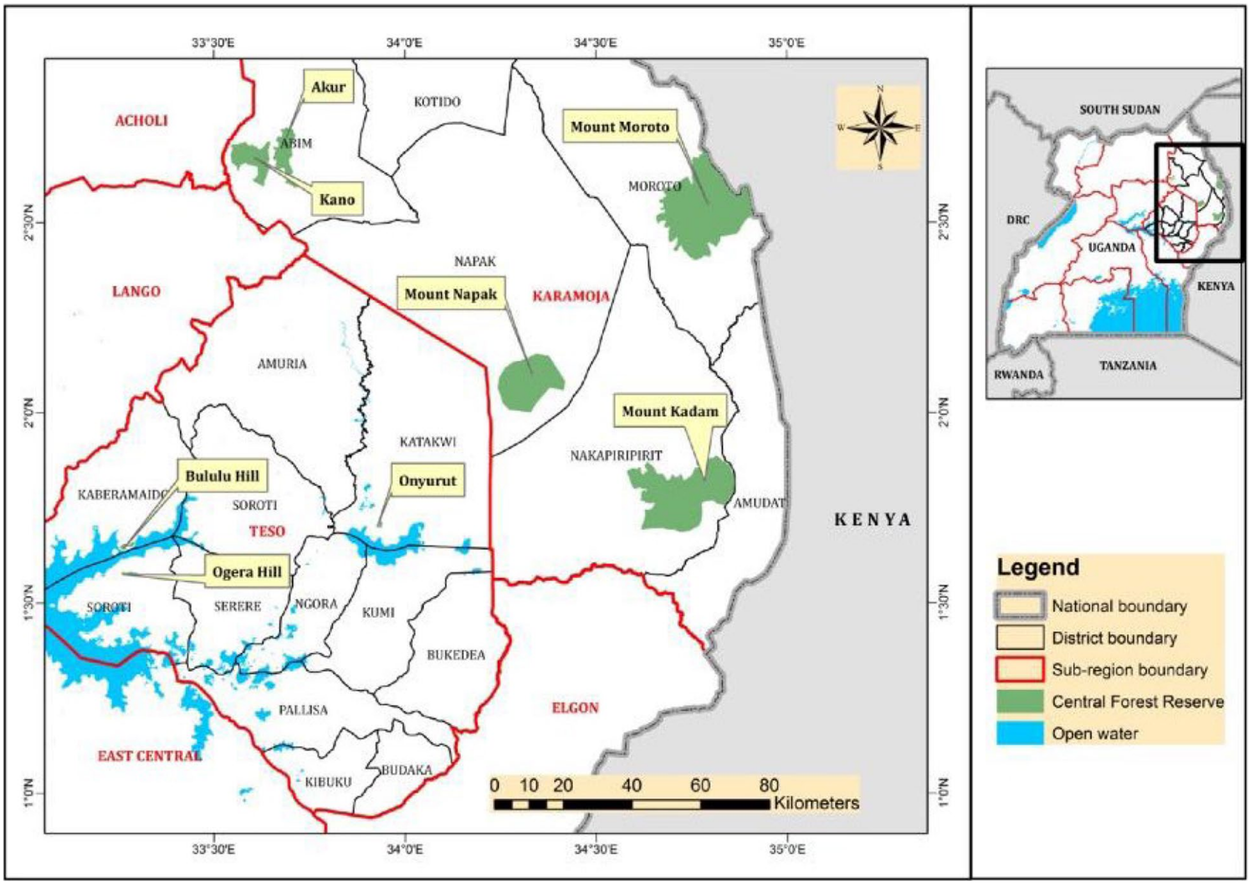

Fig. 1 Location of forest reserves in north eastern Uganda

prolonged insecurity caused by the armed cattle rustlers [20]. Indeed, two CFRs namely Mount Napak and Mount Kadam were omitted during floristic surveys due to reports of insecurity. With the exception of Onyurut, all the CFRs studied are located on either hills or mountains and with variable sizes.

Onyurut CFR covers 158 ha and is located in Katakwi district within 1°47′19"N 33°57′12"E to 1°46′46"N 33°56′21"E Its vegetation is predominantly dominated by *Combretum adenogonium*, *C. molle*, *Acacia brevispica* and *Zanthoxylum leprieurii* with patches of grassland dominated by *Brachiarria decumbens*, *Hyparrhenia filipenduda* and *Hyparrhenia dissoluta* species. The geology of the area is comprised of Precambrian age basement complex rock of granites, mignalites, gneiss, schists and quartzites with mainly of ferralitic soils (sandy sediments and sandy loam). The climate is characterized by two seasons: a wet season during March – October and a dry season during November – February. The mean annual rainfall varies from 1000 mm – 1500 mm [46]). The CFR is used by adjacent communities for small scale subsistence farming and settlement, brick making, charcoal production, and cattle grazing. It's a catchment for L. Bisina. It also acts as a windbreak for Toroma trading center and Katakwi Township on the eastern part. It supplies forest products to the communities around L. Bisina and also provides habitat for wildlife (FSC 2018).

Mount Moroto CFR is located in Moroto district within 2^{0}24' to 2^{0}42' North and 34^{0}39' to 34^{0}56' East [12]. It covers 48,300 ha which is predominantly a dormant volcano with an altitudinal range of 960–3084 m. The reserve is perched on the top of the escarpment of the Eastern Rift, directly behind and to the east of the town of Moroto, and its eastern boundaries are also those of the Ugandan border with Kenya. Much of the site is dominated by Afromontane undifferentiated forest, a drier montane forest type characterised by valuable timber trees *Podocarpus milanjianus*, *Afrocarpus* (Podocarpus) *gracilior*, and *Juniperus procera* ([12, 24]). The area experiences a semi-arid type of climate with sporadic uni-modal rainfall patterns occurring between May and August and an intensely hot, dry season occurring from November to March [2]. Rainfall in the area ranges from 350 to 1000 mm per annum and is available in time and space [31]. Significant areas of the reserve, particularly at lower altitudes in the north and south, have been transformed by farming of crops.

Kano CFR (8,293 ha) is located in Labwor hills in Abim district within 2°40′55"N 33°38′48"E to 2°41′12"N 33°37′14"E. Its vegetation is broadly classified as dry *Combretum-Oxytenanthera-Hyparrhenia* savanna woodland [12]. It is a key site for biodiversity conservation, hill reserve, and protects River Amal which serves the communities of Kano and Abim parishes [33]. It is composed of remnant hills (inselbergs) formed by weathering and erosion of the surface, leaving behind hard resistant granitic rocks which stand prominently high above the earth's surface. The soils are mainly ferralitic, vertiso and ferruginous tropical soils, with lesser types including lithosols [45]. This CFR receives a wet and dry woodland savannah climate characterized by an intensively hot dry season lasting from December to February with strong winds and a rainy season from March to November, with a dry spell in June and/or July. Rainfall is about 1350 mm per annum, fairly evenly distributed, except in the eastern belt which has lower rainfall. The daily temperatures range from 20 °C to 35 °C and relative humidity can reach 60% during the rainy season [45]. The reserve is faced with various human activities such as collection of Non Timber Forest Products (NTFPs) like *Oxytenanthera abyssinica* (bamboo), wild edible fruits and vegetables; stone quarrying, charcoal production and firewood collection, bush burning, human settlement and cultivation, illegal timber harvesting, and collection of construction materials.

Akur CFR is also located within the Labwor hills of Abim district within 2°41′11"N 33°42′13"E to 2°41′08"N 33°40′15"E and covers 6,434 ha. The soils and climatic conditions in this CFR are similar to those of Kano CFR on the account of their close proximity of less than 2km. It is a critical site for biodiversity conservation, hill reserve and River Ojulu originates from it [33]. In Akur CFR, the hills are not sufficiently high (1200 m above sea level) to cause much differentiation of the vegetation on account of increasing altitude [33]. Its vegetation is broadly classified as dry *Combretum-Oxytenanthera-Hyparrhenia* savanna woodland [12]. The most important factor limiting the vegetation is most probably soil depth and its associated character of soil moisture [33]. The thickest tree growth is found on the deep alluvial soils along the lines of the valleys near the hills; further from the hills, the riparian forest thins out into grass 'vlei' with scattered trees. Higher up on the hills, there is usually less soil and the strips of riverine forest are correspondingly narrow, but larger trees occur in the open savanna than on the lower slopes.

Ogera hills CFR is located in Serere district within 1°34′01"N 33°16′50"E to 1°36′19"N 33°16′45"E an altitudinal range of 1036–1160 m [32]. It covers 427 ha and the vegetation is mainly comprised of high grass and low tree bushes. The trees are mainly combretaceous and are sometimes stunted in form with species such as *Combretum molle, C. collinum, C. adenogonium* and the grass *Loudetia arundinceum* mostly on hill slopes. In some parts, tree growth is dense with a tangle of creepers and bushes while some areas with illegal activities like charcoal burning have low tree cover. It is underlain by rocks of the basement complex Precambrian age that include granites, mignalites, gneiss, schists and quartzites. The soils fall mainly under four major units; Serere catena; Metu complex series. These are mainly of the ferralitic type (sandy sediments and sandy loams), and bottomlands contain widespread deposits of alluvium, pierced by isolated inselbergs. The climate is modified by the large swamp area surrounding Lake Kyoga. Rainfall normally ranges from 1000 to 1500 mm coming in two seasons namely March–July and September – November [47]. The CFR protects steep & rocky hills (FSC 2018) and serves as a water catchment area for Lake Kyoga.

Bululu hills CFR covers 425 ha and lies on the shores of Lake Kyoga between 1°38′21"N 33°15′38"E and 1°38′55"N 33°15′22"E within an altitudinal range of 1030 – 1080 m. It protects lake Kyoga and its slopes are swamps or/wetlands for fish breeding (FSC, 2018). Its vegetation is characterized by *Euphorbia candelabrum, Harrisonia abyssinica, Terminalia schimperiana, Combretum collinum* with *Cyperus papyrus* and *Phragmites mauritianum* on the lake shores. The climate of Kaberamaido District is marked by wet and dry seasons modified by the large swamp area surrounding it. The mean annual rainfall normally ranges from 1,000 mm to 1,500 mm spread over two rainy seasons; March – July and September – November. Rainfall is at its minimum in June, and with bimodal maxima in April—May and August – October. The area is underlain by rocks of the basement complex of precambrian age that include granites, mignalites, gneiss, schists and quartzites. The landscape is a flat plateau with a few scattered rock outcroppings with mostly sandy loam soils of ferralitic type and alluvium in the bottomlands [48]. This reserve is used to provide trees for charcoal production, livestock (cattle) grazing, human settlement and cultivation which culminate to soil erosion on the slopes.

Data collection

The study used the gradient oriented transect (gradsect) sampling technique [1] to establish transect lines in each CFR. This ensures that the environmental diversity is adequately represented amidst budget, time and staff constraints. There is a strong evidence that gradsects are superior in capturing information about vegetation diversity than randomly placed transects of similar length [15]. In this study, the gradients considered were topography (bottom-middle-top slope), drainage patterns namely rivers and alignment to the direction of the sun (aspect).

The plant data was collected from nested quadrats (20 × 20 m for trees, 10 × 10 m for shrubs and 5 × 5 m for herbaceous climbers, forbs and grasses) which were placed systematically along the line transects (1000 1500m) at intervals of 100 m. Any woody plant with a straight trunk of at least 2 m which supports branches was regarded as a tree while a shrub was any woody plant with multiple branches usually growing to a height of 3m. The line transects were spaced at an interval of 1000 m from each other. The use of quadrats in vegetation studies makes it easy to standardize data and facilitates comparative analysis [10]. The nested quadrats capture spatial patterns and heterogeneity simultaneously [4]. The plant parameters measured in each quadrat were species identity and number of individuals present or cover in the case of herbaceous plants. The identity of trees and shrubs were identified by their local names following the local guides [22, 23] while the grasses were identified following Phillips et al. [38]. The voucher specimens of all the plants encountered were collected and pressed for confirmatory taxonomic determination at Makerere University Herbarium. The adequacy of the sampling effort in each CFR was assessed using the species accumulation curves while in the field (Fig. 2) and percentage increase in species richness with cumulative plots (Table 1).

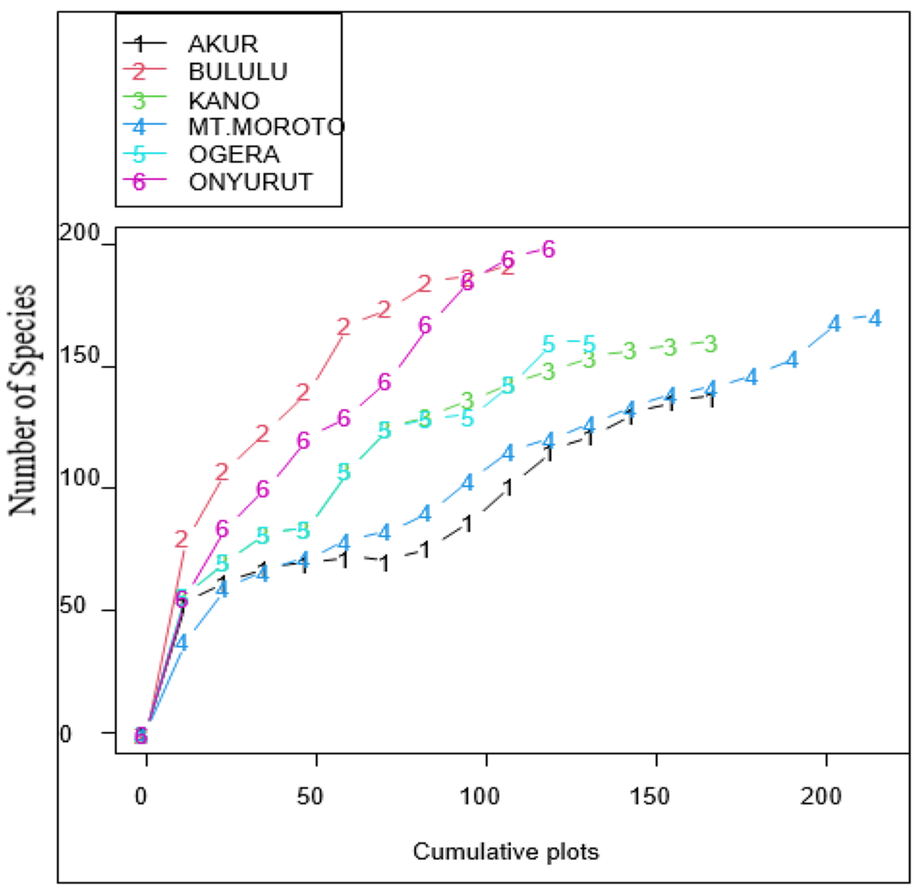

Fig. 2 Species accumulation curves in selected central forest reserves of north eastern Uganda

Table 1 Percentage increase of species richness in the CFRs of north eastern Uganda

Cumulative plots	Percentage (%) increase in species richness					
	Onyurut	*Ogera hills*	*Akur*	*Mt. Moroto*	*Bululu hills*	*Kano*
12	28.1	35.6	39.1	22.2	41.7	35.6
24	14.6	8.8	5.8	12.9	14.6	8.8
36	8.0	6.9	4.3	4.1	8.3	6.9
48	10.1	1.3	1.4	2.9	8.3	1.3
60	4.5	15.0	1.4	4.1	14.1	15.0
72	7.5	10.6	0.7	2.3	3.6	10.6
84	11.6	2.5	2.2	4.7	5.7	3.1
96	9.0	0.6	8.0	7.6	1.0	4.4
108	2.0	8.1	10.9	7.0	2.6	3.8
120	4.5	10.6	10.1	2.9		3.8
132		0.0	4.3	3.5		3.1
144			6.5	4.1		1.9
156			3.6	2.9		1.3
168			1.4	1.8		0.6
180				2.9		
192				4.1		
204				8.8		
216				1.2		

The methods applied in this study were informed by the available literature on the most popular methods for reporting floristic information. These include species accumulation curves, rarefaction curves and the Shannon–Wiener indices (alpha diversity) and Sørensen, Jaccard or Bray–Curtis indices (beta diversity) [29]. In terms of comparing the species composition (biodiversity) of two or more assemblages, the similarity (or overlap) or dissimilarity (complementarity, turnover, beta diversity or distance) indices are often used [26]. These indices are classified into two categories namely; binary similarity coefficients when only presence/absence data are available and quantitative similarity coefficients when some measure of relative abundance is available [9]. The other important components of floristic assessment include species richness and diversity [40], population structure and distribution [5, 36].

Data analysis

The species richness, diversity and evenness were determined for each CFR using the Shannon-Index ($H^{/}$) and Evenness (E) (Magurran 1988) in Vegan, R Statistical Package (version 4.0.3). A One-way ANOVA was used to test the difference in the actual species richness, $Chao_2$ and $Jackknife_1$ species estimators. The normality of data was tested using Shapiro–Wilk test prior to running ANOVA test. Further, an independent samples t-test was carried out to analyse the difference species richness and diversity indices among the CFRs. The Sørensen similarity index (Eq. 1) was used to assess the species similarity amongst CFRs because only presence data was recorded following Chao et al. [9]. Further, cluster analysis was performed on the presence data to compare the richness of plant species in the CFRs. The co-occurrence based clustering approach was applied whereby species were clustered based on their co-occurrence as opposed to traditional distance metrics. A table was also constructed to show the complementarity of the CFRs in form of accumulation of new species not recorded elsewhere following Howard et al. [18]. The conservation status of the plant species was obtained from IUCN Red List database and National Red list [30, 53].

$$\text{S}\phi\text{rensen Similarity index} = \frac{2a}{2a + b + c} \quad (1)$$

Where a = shared species
b = species in community 1
c = species in community 2

Table 2 Actual and estimated species richness in the CFRs of north eastern Uganda

Central forest reserve	Actual species richness Richness	Estimated species richness		Standard deviation (±)	
		$Chao_2$	$Jackknife_1$	$Chao_2$	$Jackknife_1$
Akur	142	149	161	3.5	9.5
Bululu Hills	187	205	176	9	5.5
Kano	148	163	174	7.5	13
Mt. Moroto	160	136	144	12	8
Ogera Hills	161	154	173	3.5	6
Onyurut	171	172	169	0.5	1

Table 3 Shannon–Wiener diversity indices (H$^{/}$) and Equitability of floristic diversity in the CFRs of north eastern Uganda

Central forest reserve	Shannon–Wiener diversity index (H$^{/}$)	Equitability (*J*)
Akur	4.20	0.83
Bululu hill	4.47	0.84
Kano	4.20	0.83
Mount Moroto	4.40	0.86
Ogera Hills	4.27	0.83
Onyurut	4.43	0.84

Results

Floristic richness and diversity

A sum of 417 species in 76 families were recorded in the CFRs of NE Uganda (Appendix 1). Fabaceae had the highest number of species (77) followed by Poaceae (35). The lowest actual species richness was recorded in Akur CFR (142) while the highest was in Bululu hills CFR (187) (Table 2). This species richness was significantly different across the CFRs (t = 24.482, df = 5, p = 0.0000212). In terms of richness estimators, $Chao_2$ estimator values ranged from 136 in Mt. Moroto to 205 in Bululu hills. The $Jackknife_1$ estimator values ranged from 144 in Mt. Moroto to 176 in Bululu hills (Table 2). The Shapiro–Wilk normality test showed that data was normally distributed. Thereafter, the one-way ANOVA showed no significant difference in the actual species richness, $Chao_2$ and $Jackknife_1$ estimated values ($df = 2$, $F = 0.046$, $p > 0.956$) for the sites. The majority of the species are native to Uganda (81.3%), the origin of 9.8% could not be established and 8.9% are introduced. On one hand, $Chao_2$ under estimated species richness in Ogera hills and Mt. Moroto but overestimated in Akur, Bululu, Kano and Onyurut. On the other, $Jackknife_1$ under estimated species richness in Bululu hills, Mt. Moroto and Onyurut but overestimated in Akur, Kano and Ogera (Table 2). Bululu hill CFR has the highest Shannon–Wiener diversity index (H$^{/}$) of 4.47 followed by Onyurut at 4.43 while Akur and Kano (4.2) have the least (Table 3). These indices are significantly different (t = 85.291, df = 4, p = 0.00). All the CFRs have Equitability indices ranging from 0.83 to 0.86 (Table 3).

The species accumulation curves for each CFR (Fig. 2) were plotted as a function of the number of species detected and number of quadrats sampled. Bululu hills had the highest accumulation of species at less than 100 plots while Akur had the lowest (Table 1). The curve in Onyurut indicates that there was a possibility of adding new species with additional sampling effort just like in Akur and Ogera hills CFRs.

Floristic similarity across CFRs

The dendrogram on the relatedness of the CFRs in NE Uganda depicts two main clusters namely: Onyurut and Ogera hills; Akur, Kano, Bululu hills and Mt. Moroto (Fig. 3). However, the latter cluster is branched into two sub-clusters namely; Akur and Kano; and Bululu hills and Mount Moroto. The CFRs with the highest similarity in species were Kano and Akur (0.63 or 63%) followed by Ogera and Bululu hills (0.57 or 57%) and the least was Ogera hills and Mount Moroto (0.39 or 39%) (Table 4).

Complementarity analysis

Table 5 shows that the CFRs complement one another by hosting some plant species not recorded in others. It further shows that three CFRs (Bululu hills, Mt. Moroto and Onyurut) account for 81.53% of the plant taxa in the sites studied. The addition of the fourth CFR (Ogera hills) accommodates nearly 90% of the species recorded in this study. In order to account for more than 95% of the species, it would require five CFRs (Bululu hills, Mt. Moroto, Onyurut, Ogera hills and Akur) to be protected whereas a more complete protected-area system (accounting for 100% of species) would include all the CFRs surveyed.

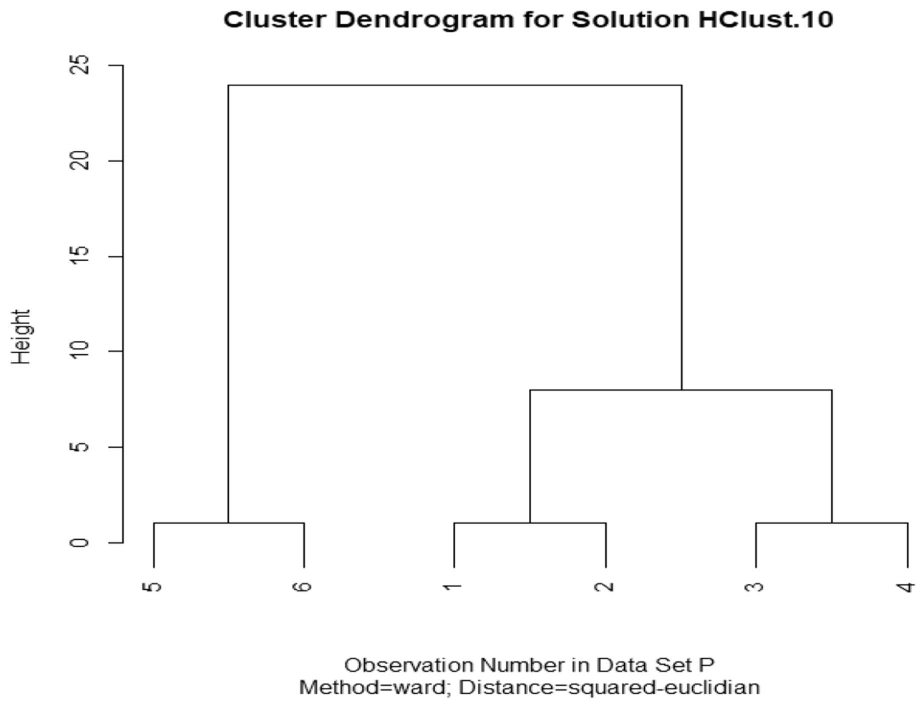

Fig. 3 Cluster analysis of the six Central Forest reserves in north eastern Uganda. Key: 1 = Akur, 2 = Kano, 3 = Bululu hills, 4 = Mt. Moroto, 5 = Onyurut, 6 = Ogera hills

Table 4 Sørenson similarity indices for floristic richness in CFRs of NE Uganda

	Kano	Mt. Moroto	Ogera hills	Onyurut	Bululu hills	Akur
Kano	1.0					
Mt. Moroto	0.49	1.0				
Ogera hills	0.51	0.37	1.0			
Onyurut	0.45	0.40	0.48	1.0		
Bululu hills	0.47	0.39	0.57	0.47	1.0	
Akur	0.63	0.46	0.48	0.44	0.43	1.0

Table 5 Complementarity table for the minimum critical set of CFRs in north eastern Uganda based on floristic richness

Central forest reserve	Species richness	Cumulative percentage (%)[a]
Bululu Hills	187	44.84
Mt. Moroto	91	21.82
Onyurut	62	14.87
Ogera Hills	33	7.91
Akur	27	6.47
Kano	17	4.08

Key: [a]Shows the percentage added to the total by each CFR through the addition of species not already represented in sites higher on the table

Conservation status of the plant taxa

The 417 species reported in this study (Appendix 1) belong to five IUCN Red list categories. These are summarized in Table 6. More than half of the species recorded (271) representing 65.0% have not been evaluated (NE). Amongst those that have been evaluated, Least Concern (LC) comprises the highest number (137 or 32.8%. The Vulnerable (VU) species (1.0%) are *Albizia malacophylla*, *Vitex amanuensis, Entandrophragma cylindricum* and *Vitellaria paradoxa* while the Near Threatened (NT) species (1.0%) are *Albizia ferruginea, Dalbergia melanoxylon, Eucalyptus grandis* and *Milicia excelsa*. The only Data deficient species recorded is

Table 6 IUCN Global Conservation Status of plant species in the CFRs of north eastern Uganda

IUCN Red list category	Total number of species	Percentage (%)	Central Forest Reserve					
			BUL	KAN	OGE	MOR	AKU	ONY
Vulnerable (VU)	4	1	2	1	0	1	2	0
Near Threatened (NT)	4	1	1	1	2	1	2	1
Least Concern (LC)	137	32.9	68	59	64	58	57	55
Data Deficient (DD)	1	0.2	0	0	0	0	1	0
Not Evaluated (NE)	271	64.9	115	87	95	100	80	115
Total	417	100	187 (3.9)	148 (3.1)	161 (3.4)	160 (3.3)	142 (2.9)	171 (3.5)

The figure in brackets () shows the percentage of species in each central forest reserve from known plant species in Uganda

Key: *BUL* Bululu hills, *KAN* Kano, *OGE* Ogera hills, *AKU* Akur, *ONY* Onyurut

Mangifera indica (0.2%) which is also cosmopolitan. In the national red lists [30, 53], the conservation status of some species previously assessed by the IUCN Redlists has been elevated. For example,*E. cylindricum* is Vulnerable according to global IUCN Red Lists but Endangered at a national level.

Discussion

The CFRs have comparatively high floristic richness and diversity (Table 1) with the recorded species representing about 8.7% of the 4800 plant species known in Uganda [21]. The diversity indices within CFRs are above the threshold (2.0) for high diversity [26]. Similarly, the equitability values are close to 1 which is considered high and signifies fairly even representation of individuals from different species in the population [37]. Although the common range of Shannon Wiener diversity index is 1.5 – 3.5 are rarely exceeds 4.5 [3]. The high indices obtained in this study are reminiscent of the high richness of species and the near even distribution of individuals and the inclusion of larger plot sizes which ensure more species are captured.

The species accumulation curves (Fig. 2) denote that as the size of the sampling area increased, the number of species also increased but the occurrence of new species eventually decreased. Roswell et al. [41] refer to this reduction in addition of new species as an asymptote. In order to judge whether or not a sampling area is representative, Taherdoost [44] states that a representative sampling area is reached if the increase of number of species per unit area is below 10% with an additional 10% expansion of the sampling area. In Ogera hills, Bululu hills and Onyurut, the addition of new species reduced after sampling at least 120 plots possibly due to their small sizes. In the case of Mount Moroto CFR, up to 200 sampling plots were required to reach an asymptote because it is the largest CFR surveyed with heterogeneous habitats due to the altitudinal differentiation. These accumulation curves provide a rationale to formalize the ecological survey to allow more rigorous and quantitative comparisons between lists, provide a planning tool for collections expeditions and a predictive tool for the total number of species present in a given area [43].

The grouping of CFRs into clusters (Fig. 3) and similarity indices (Table 4) suggests a plausible influence of altitudinal differences whereby the CFRs in mountainous or hilly areas (Akur, Kano, Bululu hills and Mt. Moroto) being clustered together. The relationship between Onyurut and Ogera hills can be attributed to propagule exchange (Fig. 3). The numerous edaphic and microclimatic factors that diverge across different tropical forest types exert significant impacts on recruitment, growth, and survival, (Augspurger 1984, cited in [52]). A higher similarity index value, conversely, signifies relatively homogenous environmental conditions, while a lower value signifies pronounced variability (Ekta, 2012 cited in [52]). One part (Teso sub-region) receives a humid and hot climate with rainfall between 1000 and 1350 mm per annum while the other (Karamoja) has a drier and semi-arid climatic pattern with rainfall ranging from 500 to 800 mm per annum although the highlands receive slightly higher amounts [13].

The complementarity analysis in Table 3 shows that there is incremental gain of plant species conserved by adding new CFRs into the protected area network. The presence of unique species in each CFR highlights their ecological distinctiveness and emphasizes the importance of conserving both forest types [57]. According to Williams et al. [56], this incremental approach leads to identification of important areas for conservation that can add as much biodiversity as possible to a plan. Although Akur and Kano CFRs contribute only 10.55% of the species, Howard et al. [18] assert that it is better to protect the country's biodiversity in a larger number of sites, if these are areas with potential for other uses and where protection would provide additional complementary benefits such as watershed protection.

The results in Table 3 also bring out the aspect of irreplaceability of sites in systematic conservation planning. In particular, it shows the number of species that can be lost due to site loss. For example, Bululu hills, Mount Moroto and Onyurut account for 81.53% of the plant species in the CFRs of north eastern Uganda. This information is helpful in determining priorities for conservation action (Pressey 1998 cited in [6]). The practical limitation of this approach arises when there are many alternative sets of sites that can meet targets, and many of these might be similarly efficient in terms of cost [6]. This however, can be overcome by setting a critical cut off point to facilitate decision making.

The conservation status of the plant taxa (Table 4) shows that all the CFRs have taxa of national and global conservation importance albeit in small numbers and low threat categories. In some species, the IUCN conservation assessment rates the extinction risk at low level compared to the national assessment [30, 53]. For instance, *Albizia ferruginea* is VU in the IUCN Global Red lists but EN in the national red list [53], *Milicia excelsa* is NT in the IUCN Global Red list while it is EN in WCS [53], *Mondia whitei* is NE in IUCN redlist but VU in WCS [53], and *Entandrophragma cylindricum* is VU in IUCN Global Red list but EN in WCS [53]. According to WCS [53], all the threatened species recorded in these CFRs also occur in other parts of Uganda. The DD species in Akur is (Mangifera indica),an introduced species which occurs widely outside the CFRs. According to the IUCN (https://www.iucnredlist.org/), a taxon is Data Deficient (DD) when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. The species in the NE category can be reduced if more effort and resources are directed towards investigation of their distribution and conducting conservation assessments. This will facilitate evidence-based conservation planning and management of the CFRs.

The information on threat levels is key in applying the Important Plant Areas (IPAs) sub-criterion A(i) for sites which contain one or more globally threatened species [11]. IPAs are the most important places in the world for wild plant and fungal diversity that can be protected and managed as specific sites. They provide a means for systematic and evidence-based identification of priority areas for plant species in order to promote the conservation and management of these sites. In light of this information, four CFRs namely Bululu hills, Mount Moroto, Kano and Akur would qualify to be IPAs because of presence of one or two VU species. At present, Mount Moroto CFR is already being profiled as an IPA under the Tropical Important Plant Areas (TIPAs) project between Makerere University and Royal Botanic Gardens, Kew (https://www.kew.org/science/our-science/projects/tropical-important-plant-areas-uganda).

Conclusion

The study findings show that botanical richness and diversity in the six CFRs in NE Uganda is comparatively high. Up to 417 plant species representing nearly 8.7 percent of the known taxa in Uganda have been recorded. The least floristic similarity is between Ogera hills CFR and Mount Moroto while the highest is between Akur and Kano CFRs which are proximally close to each other. The CFRs are complementary to each other in terms of floristic composition with four sites (Bululu hills, Mt. Moroto, Onyurut and Ogera hills) accounting for 90% of the species. Furthermore, four CFRs (Bululu hills, Mt. Moroto, Kano and Akur) contain Vulnerable species making them candidate IPA sites in Uganda. The baseline information on the floristic composition in the six CFRs of north eastern Uganda can be used for future monitoring of species composition, studying the population ecology (especially structure and regeneration) of the threatened species, environmental parameters that influence plant distribution patterns, developing species management plans to reduce the extinction risk of threatened species, and conducting conservation assessments of the species that are currently not evaluated.

Appendix 1

List of plant species in the Central Forest Reserves of north eastern Uganda

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
Acanthaceae	*Barleria* sp.	0	1	0	0	0	0	UNK	NE
	Crabbea velutina S. Moore	1	0	0	1	1	0	NAT	NE
	Hypoestes forskaolii (Vahl) R.Br.	0	0	0	1	0	0	NAT	NE
	Justicia ladanoides Lam	1	0	0	0	0	0	NAT	NE
	Justicia exigua S. Moore	0	0	1	0	0	0	NAT	NE
	Justicia heterocarpa T.Anderson	0	0	1	0	0	0	NAT	EN
	Thunbergia alata Bojer ex Sims	1	0	1	1	1	0	NAT	NE
Adiantacae	*Pellaea involuta* (Sw.) Bak. var. *obscura* (N.C.Anthony)Verdc.	1	1	1	0	0	0	NAT	NE
Amaranthaceae	*Achyranthes aspera* L.	1	1	1	1	0	0	NAT	NE
	Amaranthus hybridus L.	0	0	1	0	0	1	INT	NE
	Amaranthus spinosus L.	0	0	1	0	0	0	INT	NE
	Celosia trigyna L.	0	0	1	0	0	0	NAT	NE
	Iresine diffusa Humb. & Bonpl. ex Willd.	0	0	0	1	0	0	INT	NE
	Ouret lanata (L.) Kuntze	0	0	0	0	1	0	NAT	NE
Amaryllidaceae	*Scadoxus cyrtanthiflorus* (C.H.Wright) Friis & Nordal	1	0	1	0	1	1	NAT	NE
Anacacrdiaceae	*Lannea fruticosa* (Hochst. ex A. Rich.) Engl.	0	0	0	0	0	1	NAT	NE
	Lannea fulva (Engl.) Engl.	0	1	0	0	1	0	NAT	NE
	Lannea humilis (Oliv.) Engl.	1	0	1	1	1	1	NAT	NE
	Lannea schimperi (Hochst. ex A. Rich.) Engl.	1	1	1	1	1	1	NAT	NE
	Lannea schweinfurthii (Engl.) Engl.	0	0	1	0	0	1	NAT	NE
	Mangifera indica L.	1	0	0	0	0	0	INT	DD
	Ozoroa insignis Delile	0	0	0	0	1	1	NAT	NE
	Sclerocarya birrea (A. Rich.) Hochst.	1	1	1	1	1	1	NAT	NE
	*Searsia natalensis (*Bernh. ex C.Krauss) F.A.Barkley	0	0	1	0	0	0	NAT	LC
	Searsia pyroides (Burch.) Moffett	1	1	1	1	1	1	NAT	LC
Annonaceae	*Annona senegalensis* Pers.	1	1	0	0	1	0	NAT	LC
	Monanthotaxis buchananii (Engl.) Verdc.	0	1	1	0	1	1	NAT	NE
Apiaceae	*Steganotaenia araliacea* Hochst.	1	0	1	1	1	1	NAT	LC
Apocynaceae	*Carissa spinarum* L.	1	1	1	1	1	1	NAT	LC
	Funtumia africana (Benth.) Stapf	0	1	0	0	0	0	NAT	LC
	Gomphocarpus semilunatus A. Rich	0	0	0	1	0	0	NAT	NE
	Leptadenia lanceolata subsp. *Lanceolata*	0	0	1	0	1	0	NAT	NE
	*Mondia whitei (*Hook.f.) Skeels	0	0	1	1	0	0	NAT	NE
	Orbea vibratilis (E.A.Bruce & P.R.O.Bally) Bruyns	0	0	0	0	1	0	NAT	NE
	Pachycarpus eximius (Schltr.) Bullock	0	0	0	0	0	1	NAT	NE
	Saba comorensis (Bojer ex A.DC.) Pichon	1	1	0	0	0	0	NAT	NE
	Sarcostemma viminale (L.) R. Br.	0	0	0	0	1	0	NAT	NE
	Secamone parviflora Klack.	0	0	0	0	1	0	UNK	NE

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Stathmostelma pedunculatum (Decne.) K.Schum.	0	0	1	0	0	0	NAT	NE
Araceae	*Amorphophallus abyssinicus* (A. Rich.) N.E.Br.	1	0	0	0	0	0	NAT	NE
Araliaceae	*Cussonia arborea* Hochst. ex A.Rich.	1	1	1	0	1	1	NAT	NE
Arecaceae	*Borassus aethiopum* Mart.	0	1	0	0	0	0	NAT	LC
	Phoenix reclinata Jacq.	0	1	0	0	0	0	NAT	LC
Asparagaceae	*Asparagus racemosus* Willd.	1	1	1	1	1	1	NAT	NE
	Chlorophytum comosum (Thunb.) Jacques	1	1	1	0	1	1	NAT	NE
	Dracaena dawei (Stapf) Byng & Christenh.	1	1	1	0	1	1	NAT	NE
	Dracaena fragrans (L.) Ker Gawl.	1	0	0	0	0	0	NAT	LC
Asphodelaceae	*Aloe volkensii* Engl. subsp.. *multicaulis* Carter	1	0	0	1	1	0	NAT	LC
	Kniphofia paludosa Engl.	1	0	0	0	1	0	UNK	NE
Asteraceae	*Acanthospermum hispidum* DC.	0	0	0	0	1	1	INT	NE
	Ageratum conyzoides L.	0	1	1	1	0	1	INT	LC
	Aspilia kotschyi (Sch.Bip. ex Hochst.) Oliv.	1	1	0	1	1	0	NAT	NE
	Baccharoides adoensis (Sch.Bip. ex Walp.) H.Rob.	1	1	1	1	0	1	NAT	NE
	Bidens lineariloba Oliv.	0	0	0	1	0	0	INT	NE
	Bidens pilosa L.	1	1	1	1	1	1	INT	LC
	Bidens ugandensis Sherff	0	0	0	0	0	1	NAT	NE
	Chromolaena odorata (L.) R.M.King & H.Rob.	0	0	1	0	0	0	UNK	NE
	Crassocephalum crepidioides (Benth.) S.Moore	1		1	1	1	1	NAT	NE
	Crassocephalum gracile Milne-Redh. ex Guinea	0	0	0	0	1	0	UNK	LC
	Crepis carbonaria Sch.Bip.	0	0	0	0	1	0	NAT	NE
	Cyanthillium cinereum (L.) H.Rob.	0	0	1	0	0	0	UNK	NE
	Distephanus biafrae (Oliv. & Hiern) H.Rob.	0	0	0	0	0	1	NAT	NE
	Emilia discifolia (Oliv.) C.Jeffrey	0	1	1	0	0	1	NAT	NE
	Erigeron bonariensis L.	0	0	1	0	0	0	UNK	NE
	Erigeron floribundus (Kunth) Sch.Bip.	1	1	1	1	1	1	INT	NE
	Guizotia scabra (Vis.) Chiov.	1	1	1	0	0	0	NAT	NE
	Gutenbergia petersii Steelz	0	0	0	1	1	0	UNK	NE
	Gutenbergia cordifolia Benth. ex Oliv.	1	0	0	0	0	0	NAT	NE
	Gymnanthemum amygdalinum (Delile) Sch.Bip.	0	0	1	0	0	0	NAT	NE
	Gymnanthemum auriculiferum (Hiern) Isawumi	0	0	1	0	0	1	NAT	LC
	Helichrysum nudifolium (L.) Less.	0	0	0	0	0	1	NAT	NE
	Helicrysum glumaceum DC	0	0	0	1	0	0	NAT	NE
	Lactuca inermis Forssk. L.	1	0	0	0	0	1	NAT	NE
	Laggera alata (D. Don) Sch.Bip. ex Oliv.	0	0	1	1	1	0	UNK	NE
	Microglossa pyrifolia (Lam.) Kuntze	0	0	1	0	0	0	NAT	NE
	Pluchea bequaertii Robyns	0	0	0	1	0	0	NAT	LC
	Senecio hadiensis Forrsk.	0	0	0	1	1	0	NAT	NE
	Senecio hochstetteri A.Rich.	0	0	0	1	0	0	NAT	NE
	Solanecio angulatus (Vahl) C.Jeffrey	0	1	1	0	1	0	NAT	NE

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Synedrella nodiflora (L.) Gaertn.	0	0	1	0	0	1	NAT	NE
	Tagetes minuta L.	1	1	1	1	0	1	INT	NE
	Tridax procumbens L.	0	0	0	0	1	0	NAT	NE
	Vernonia galamensis subsp. *galamensis*	0	0	0	1	0	0	NAT	NE
	Vernonia perrottetii Sch.Bip. ex Walp.	0	1	1	0	1	0	NAT	NE
Bignoniaceae	*Stereospermum kunthianum* Cham.	1	1	1	1	1	1	NAT	LC
	Kigelia africana (Lam.) Benth.	0	0	0	1	0	0	NAT	LC
Boraginaceae	*Cordia monoica* Roxb.	0	1	1	0	0	0	NAT	LC
	Trichodesma zeylanicum (Burm.f.) R.Br.	1	0	1	0	1	0	NAT	NE
Burseraceae	*Commiphora africana* (A. Rich.) Engl.	1	1	1	1	1	0	NAT	LC
Cactaceae	*Opuntia monacantha* Haw.	0	0	0	1	0	0	INT	LC
Capparaceae	*Boscia integrifolia* Oliv.	1	1	1	1	0	0	NAT	NE
	Cadaba farinosa Forssk.	0	0	1	0	0	1	NAT	LC
	Capparis fascicularis DC.	0	0	0	1	0	0	NAT	LC
	Capparis tomentosa Lam.	0	0	0	0	1	0	NAT	NE
	Crateva adansonii DC.	0	0	1	0	0	0	NAT	LC
	Maerua angolensis DC.	0	1	1	0	1	0	NAT	LC
	Maerua duchesnei (De Wild.) F.White	0	0	0	0	1	0	NAT	LC
Caryophyllaceae	*Polycarpaea corymbosa* (L.) Lam.	0	0	0	0	1	0	NAT	NE
Celastraceae	*Gymnosporia senegalensis* (Lam.) Loes.	1	1	1	0	1	1	NAT	LC
	Loeseneriella apocynoides (Welw. ex Oliv.) N.Hallé ex J. Raynal	1	0	1	0	1	1	NAT	NE
	Mystroxylon aethiopicum (Thunb.) Loes.	1	1	1	1	1	1	NAT	LC
	Pleurostylia africana Loes.	1	0	0	1	0	0	NAT	NE
Chrysobalanaceae	*Parinari curatellifolia* Planch. ex Benth.	0	0	0	0	0	1	NAT	LC
Clusiaceae	*Symphonia globulifera* L.f.	0	1	0	1	0	0	NAT	LC
Colchicaceae	*Gloriosa superba* L.	0	0	1	1	1	0	NAT	LC
Combretaceae	*Combretum adenogonium* Steud. ex A.Rich.	1	1	1	0	1	0	NAT	LC
	Combretum collinum Fresen	1	1	1	0	1	1	NAT	LC
	Combretum hereroense Schinz. subsp. *grotei* (Exell.) Wickens	0	0	0	1	0	0	UNK	NE
	Combretum molle R.Br. ex G.Don	1	1	1	1	1	1	NAT	LC
	Terminalia brownii Fresen.	0	0	0	1	0	0	NAT	LC
	Terminalia schimperiana Hochst.	0	0	0	0	1	1	NAT	LC
	Terminalia mollis M.A.Lawson	0	0	1	0	0	1	NAT	LC
	Terminalia schimperiana Hochst. ex Delile	1	1	1	0	1	1	NAT	NE
Commelinaceae	*Commelina africana* subsp. *africana*	1	0	0	0	1	1	NAT	NE
	Commelina benghalensis L.	0	0	1	1	0	0	NAT	LC
	Murdannia simplex (Vahl) Brenan	0	0	1	0	1	0	NAT	LC
Convolvulaceae	*Ipomoea aquatica* Forssk.	0	0	0	0	1	0	NAT	LC
	Ipomoea eriocarpa R. Br.	1	0	1	0	0	0	NAT	NE
	Ipomoea obscura (L.) Ker Gawl.	0	1	0	0	0	0	NAT	NE
	Ipomoea pileata Roxb.	0	0	0	0	1	0	NAT	NE
	Ipomoea prismatosyphon Welw.	1	0	0	0	0	0	NAT	NE
	Ipomoea rubes Choisy	0	0	1	0	0	0	NAT	NE
	Ipomoea spathulata Hallier f.	1	1	0	1	0	0	NAT	NE
	Ipomoea tenuirostris Choisy	0	1	0	0	1	1	NAT	NE

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Lepistemon owariense (Beauv.) Hall.f.	0	1	0	0	1	0	NAT	NE
	Lepistemon parviflorum Pilg. ex Büsgen	0	0	0	0	1	0	NAT	NE
Crussalaceae	*Kalanchoe lanceolata* (Forrsk.) Pers.	0	0	0	1	0	0	NAT	NE
Cucurbitaceae	*Cucumis* sp.	1	1	0	0	0	0	UNK	NE
	Cucumis aculeatus Cogn.	0	0	0	1	0	0	NAT	NE
	Cucumis maderaspatanus L.	0	0	0	0	1	0	NAT	NE
	Diplocyclos palmatus (L.) C.Jeffrey	0	0	1	0	0	1	NAT	NE
Cyperaceae	*Cyperus articulatus* L.	0	0	1	0	0	0	NAT	LC
	Cyperus cyperoides (L.) Kuntze	0	0	1	0	1	0	NAT	LC
	Cyperus latifolius Poir.	0	0	1	0	0	0	NAT	LC
	Cyperus papyrus L.	0	0	1	0	0	0	NAT	LC
	Bulbostylis abortiva (Steud.) C.B.Cl.	0	0	1	0	0	1	NAT	NE
Dioscoreaceae	*Dioscorea bulbifera* L.	0	0	1	0	1	1	NAT	NE
	Dioscorea quartiniana A. Rich.	1	1	1	0	1	1	NAT	NE
	Dioscorea praehensilis Benth.	0	0	0	0	0	1	NAT	LC
	Dioscorea sp.	1	1	0	1	1	0	UNK	NE
Ebenaceae	*Diospyros mespiliformis* Hochst. ex A.DC.	1	1	0	1	1	0	NAT	NE
	Diospyros abyssinica (Hiern) F.White	0	0	0	0	1	0	NAT	LC
	Diospyros scabra (Chiov.) Cufod.	0	0	0	0	1	0	NAT	NE
	Euclea divinorum Hierm	0	0	0	1	1	1	NAT	LC
	Euclea racemosa L.	0	0	0	0	1	0	NAT	LC
Erythroxylaceae	*Erythroxylum fischeri* Engl.	0	0	0	0	1	0	NAT	NE
Euphorbiaceae	*Acalypha villicaulis* A. Rich.	1	1	0	0	1	0	UNK	NE
	Euphorbia bongensis Kotschy & Peyr. ex Boiss	0	0	0	0	1	0	NAT	NE
	Euphorbia breviarticulata Pax	1	1	1	1	1	0	NAT	NE
	Euphorbia crotonoides Boiss	0	0	1	1	1	0	UNK	NE
	Ricinus communis L.	1	0	1	0	0	1	UNK	NE
	Tragia brevipes Pax	0	1	1	0	0	1	NAT	NE
Fabaceae	*Abrus precatorius* L.	0	1	0	0	1	0	NAT	NE
	Acacia amythethophylla A. Rich.	1	0	0	0	0	0	UNK	LC
	Acacia mearnsii De Wild.	1	1	1	1	1	0	INT	NE
	Acacia polyacantha Willd.	0	0	1	0	0	0	NAT	NE
	Aeschynomene abyssinica (A. Rich.) Vatke	0	0	0	1	0	0	NAT	NE
	Aeschynomene americana L.	0	0	1	0	0	1	INT	NE
	Aeschynomene elaphroxylon (Guill. & Perr.) Taub.	0	0	1	0	0	0	NAT	LC
	Alantsilodendron pilosum Villiers	1	1	1	0	0	0	UNK	LC
	Albizia coriaria Welw. ex Oliv.	1	0	1	0	1	0	NAT	LC
	Albizia malacophylla (A. Rich.) Walp.	0	0	0	1	0	1	NAT	VU
	Albizia zygia (DC.) J.F.Macbr.	1	1	1	0	1	1	NAT	LC
	Albizia ferruginea (Guill. & Perr.) Benth.	0	0	1	0	0	0	NAT	NT
	Canavalia africana Dunn	0	0	0	0	1	0	NAT	NE
	Caesalpinia sp.	0	0	0	1	0	0	UNK	NE
	Chamaecrista mimosoides (L.) Greene	0	0	0	0	1	0	NAT	LC
	Chamaecrista absus (L.) H.S.Irwin & Barneb	0	0	0	1	1	0	NAT	LC
	Chamaecrista hildebrandtii (Vatke) Lock	1	1	0	1	1	0	NAT	NE

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Chamaecrista kirkii (Oliv.) Standl.	0	0	0	1	0	0	NAT	LC
	Chamaecrista mimosoides (L.) Greene	0	0	1	0	0	0	NAT	LC
	Crotalaria deserticola Taub. ex Baker f.	1	0	0	1	1	1	NAT	NE
	Crotalaria microcarpa Hochst. ex Benth.	0	0	0	0	1	0	NAT	NE
	Crotalaria natalitia Meisn. var. *rutschuruensis* De Wild.	0	1	0	0	0	0	NAT	NE
	Crotalaria vallicola Bak.f.	0	1	1	0	0	0	NAT	NE
	Dalbergia melanoxylon Guill. & Perr.	1	1	0	1	0	0	NAT	NT
	Desmodium tortuosum (Sw.) DC.	0	0	1	0	0	0	INT	NE
	Dichrostachys cinerea (L.) Wight & Arn.	0	0	0	1	1	1	NAT	LC
	Eriosema parviflorum E.Mey.	0	0	1	0	0	1	NAT	LC
	Erythrina abyssinica DC.	1	1	0	1	0	0	NAT	LC
	Grona hirta (Guill. & Perr.) H.Ohashi & K.Ohashi	0	0	1	0	0	0	UNK	NE
	Indigofera arrecta Hochst. ex A.Rich.	0	0	0	0	1	0	NAT	NE
	Indigofera brevicalyx Baker f.	0	1	1	0	0	1	NAT	NE
	Indigofera congesta Welw. ex Baker	0	0	1	0	1	1	NAT	NE
	Indigofera conjugata Baker	0	0	0	0	0	1	NAT	LC
	Indigofera garckeana Vatke	1	1	0	1	1	1	NAT	NE
	Indigofera hirsuta L.	0	0	0	0	0	1	NAT	NE
	Indigofera tanganyikensis Baker f.	0	1	1	1	1	1	NAT	NE
	Mimosa pudica L	0	0	0	0	1	1	INT	LC
	Mucuna stans Welw. ex Baker	1	1	0	1	0	0	NAT	NE
	Neonotonia wightii (Wight & Arn.) J.A.Lackey	0	0	0	0	0	1	NAT	LC
	Philenoptera laxiflora (Guill. & Perr.) Roberty	1	1	1	0	1	1	NAT	NE
	Piliostigma thonningii (Schumach.) Milne-Redh.	1	1	1	0	1	1	NAT	NE
	Polhillides velutina (Willd.) H.Ohashi & K.Ohashi	1	1	1	0	0	1	NAT	NE
	Prosopis africana (Guill. & Perr.) Taub.	1	1	1	1	1	1	NAT	LC
	Rhychosia goetzei Harms.	1	0	0	1	0	0	UNK	NE
	Rhychosia sp.	0	0	0	1	0	0	UNK	NE
	Rhynchosia hirta (Andrews) Meikle & Verdc.	0	0	1	1	0	0	NAT	NE
	Rhynchosia stipulosa A. Rich.	1	1	0	0	0	1	UNK	NE
	Rhyncosia albissima Gand.	0	0	0	1	0	0	NAT	NE
	Senegalia mellifera (Benth.) Seigler & Ebinger	0	0	0	1	0	0	NAT	LC
	Senegalia pennata (L.) Maslin	1	1	1	1	1	1	UNK	LC
	Senegalia polyacantha subsp. *campylacantha* (Hochst. ex A. Rich.) Kyal. & Boatwr.	0	0	0	0	0	1	NAT	NE
	Senegalia senegal (L.) Britton	0	1	1	1	1	1	NAT	NE
	Senna hirsuta (L.) H.S.Irwin & Barneby	0	0	0	0	0	1	NAT	NE
	Senna obtusifolia (L.) H.S.Irwin & Barneby	0	1	1	1	1	1	NAT	NE
	Senna occidentalis (L.) Link	0	1	0	0	0	0	INT	NE
	Senna petersiana (Bolle) Lock	0	0	0	0	0	1	NAT	LC
	Senna singueana (Delile) Lock	0	0	0	1	0	0	NAT	LC

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Senna spectabilis (DC.) H.S.Irwin & Barneby	0	1	1	0	0	1	INT	LC
	Senna bicapsularis (L.) Roxb	0	0	1	0	0	0	INT	LC
	Senna occidentalis (L.) Link	0	0	1	0	1	0	INT	NE
	Stylosanthes fruticosa (Retz.) Alston	0	0	0	1	0	0	NAT	NE
	Stylosanthes guianensis (Aubl.) Sw.	0	0	0	0	0	1	INT	NE
	Tamarindus indica L.	1	0	1	1	1	1	INT	LC
	Tephrosia elata Deflers	0	0	0	1	0	0	NAT	NE
	Tephrosia nana Kotschy ex Schweinf.	0	1	1	1	1	1	NAT	NE
	Tephrosia noctiflora Bojer ex Baker	0	0	1	0	0	0	UNK	NE
	Tephrosia villosa (L.) Pers.	0	0	1	0	0	0	NAT	LC
	Uraria picta (Jacq.) Desv. ex DC.	0	0	1	0	1	0	NAT	LC
	Vachellia gerrardii (Benth.) P.J.H.Hurter (Benth.) P.J.H.Hurter	0	0	0	0	1	0	NAT	NE
	Vachellia hockii (De Wild.) Seigler & Ebinger	1	1	1	1	1	1	NAT	NE
	Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	0	0	0	1	0	0	NAT	LC
	Vachellia seyal (Delile) P.J.H. Hurter	1	0	0	1	0	0	NAT	LC
	*Vachellia sieberiana (*DC.) Kyal. & Boatwr.	0	1	1	1	1	1	NAT	LC
	Vigna kirkii (Baker) J.B.Gillett	0	1	1	1	1	0	NAT	NE
	Vigna multinervis Hutch. & Dalziel	0	0	0	0	0	1	NAT	LC
	Vigna parkeri Bak. Subsp. *maranguensis* (Taub.) Verdc.	0	0	0	0	1	0	NAT	LC
	*Zornia glochidiata R*chb. ex DC.	0	0	1	1	1	0	NAT	NE
Hypericaceae	*Psorospermum febrifugum* Spach	0	0	1	0	1	1	NAT	LC
Lamiaceae	*Aeolanthus haliotropioides* Oliv. Forma	0	0	1	0	0	1	NAT	NE
	Clerodendrum umbellatum Poir.	0	0	1	0	0	1	NAT	NE
	Coleus caninus (Roth) Vatke	0	0	0	1	0	0	NAT	NE
	Equilabium flaccidum (Vatke) Mwany. & A.J.Paton	0	1	1	0	1	0	UNK	NE
	Hyptis suaveolens (L. Poit)	0	0	0	0	1	0	NAT	NE
	Hoslundia opposita Vahl	0	1	1	1	1	1	NAT	NE
	Leonotis nepetifolia (L.) R.Br.	1	1	1	1	0	1	NAT	NE
	Leucas calostachys Oliv.	0	0	0	1	0	0	NAT	NE
	Leucas martinicensis (Jacq.) R.Br.	0	0	0	1	0	0	NAT	NE
	Ocimum basilicum L.	0	1	1	1	1	1	INT	NE
	Ocimum gratissimum L.	0	0	0	1	0	0	NAT	NE
	Orthisiphon sp.	0	0	1	0	0	0	UNK	NE
	Plectranthus laxiflorus Benth.	0	1	0	0	0	0	NAT	NE
	Rotheca myricoides (Hochst.) Steane &	0	0	0	1	0	0	NAT	LC
	Tinnea aethiopica Kotschy ex Hook.f.	0	0	0	0	1	0	NAT	NE
	Vitex amaniensis W.Piep.	0	0	1	0	0	0	UNK	VU
	Vitex ferruginea Schumach. & Thonn.	1	1	1	0	0	1	NAT	LC
	Vitex doniana Sweet	1	1	0	0	0	1	NAT	LC
Loganiaceae	*Strychnos innocua* Delile	1	1	1	1	1	1	NAT	LC
	Strychnos spinosa Lam.	1	0	0	1	0	0	NAT	NE
Malvaceae	*Abutilon mauritianum* (Jacq.) Medik.	1	0	0	0	1	1	NAT	NE
	Corchorus trilocularis L.	0	0	0	1	0	0	NAT	NE
	Grewia mollis Juss.	1	1	1	1	1	1	NAT	LC

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Grewia similis K.Schum.	0	0	0	1	0	0	NAT	NE
	Grewia trichocarpa Hochst. ex A.Rich.	1	0	0	0	0	0	NAT	NE
	Grewia villosa Willd.	1	1	0	1	0	1	NAT	LC
	Hibiscus cannabinus L.	1	0	1	1	1	1	NAT	NE
	Kosteletzkya adoensis (Hochst. ex A.Rich.) Mast.	0	0	0	1	0	0	NAT	NE
	Sida acuta Burm.f.	0	1	1	1	0	1	NAT	NE
	Sida alba L.	0	0	1	0	0	1	NAT	NE
	Sida rhombifolia L.	0	0	1	0	0	1	NAT	NE
	Sidastrum micranthum (A.St.-Hil.) Fryxell	0	1	1	1	0	0	NAT	NE
	Sterculia setigera Delile	1	1	0	1	0	0	NAT	LC
	Triumfetta annua L.	1	1	1	1	1	0	NAT	NE
	Triumfetta brachyceras K.Schum.	1	1	1	0	1	1	NAT	NE
	Triumfetta flavescens Hochst. ex A.Rich.	0	0	0	1	0	0	NAT	NE
	Waltheria indica L.	0	0	1	1	1	0	INT	NE
	Wissadula rostrata (Schumach. & Thonn.) Hook.	1	1	1	0	1	1	UNK	NE
Melastomataceae	*Antherotoma senegambiensis* (Guill. & Perr.) Jacq.-Fél.	0	0	0	0	0	1	NAT	NE
Meliaceae	*Ekebergia capensis* Sparm	0	0	0	1	0	0	NAT	LC
	Entandrophragma cylindricum (Sprague) Sprague	1	0	0	0	0	0	NAT	VU
	Justicia sp.	1	1	0	1	0	0	UNK	NE
	Pseudocedrela kotschyi (Schweinf.) Harms	0	0	0	0	0	1	NAT	LC
	Toona hexandra (Wall.) M.Roem.	1	1	0	0	0	0	INT	LC
Menispermaceae	*Chasmanthera dependens* Hochst.	0	0	1	0	1	0	NAT	NE
	Tinospora caffra (Miers) Troupin (Syn: *Hyalosepalum caffrum* (Miers) Troupin)	0	0	0	0	1	0	NAT	NE
Moraceae	*Antiaris toxicaria* (J.F.Gmel.) Lesch.	1	1	0	0	0	1	NAT	LC
	Ficus amadiensis De Wild.	0	0	0	1	0	0	NAT	NE
	Ficus glumosa Delile	1	1	1	1	0	1	NAT	LC
	Ficus laurifolia Lam.	0	1	1	0	0	0	NAT	NE
	Ficus thonningii Blume	1	0	1	0	1	1	NAT	LC
	Ficus sycomorus L.	1	0	0	0	1	0	NAT	LC
	Ficus platyphylla Delile	1	1	0	1	0	1	NAT	LC
	Ficus natalensis Hochst.	1	1	0	0	0	0	NAT	LC
	Ficus mucuso Welw. ex Ficalho	0	1	0	1	0	0	NAT	LC
	Ficus ingens (Miq.) Miq.	0	1	0	0	0	0	NAT	LC
	Ficus dicranostyla Mildbr.	1	0	0	0	0	0	NAT	LC
	Milicia excelsa (Welw.) C.C.Berg	0	0	1	0	0	0	NAT	NT
Musaceae	*Musa paradisiaca* L	1	0	0	0	0	0	UNK	NE
Myrtaceae	*Eucalyptus grandis* W.Hill ex Maiden	1	0	0	0	0	0	INT	NT
	Syzygium guineense (Willd.) DC.	1	0	1	0	0	1	UNK	LC
Nyctaginaceae	*Commicarpus pedunculosus* (A.Rich.) Cufod.	0	0	1	0	1	1	NAT	NE
Olacaceae	*Ximenia americana* L.	1	1	1	1	1	0	NAT	LC
Oleaceae	*Jasminum dichotomum* Vahl	0	0	1	0	0	0	NAT	NE
	Jasminum grandiflorum subsp. *floribundum* (R.Br. ex Fresen.) P.S.Green	0	0	0	0	0	1	NAT	NE

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		AKU	KAN	BUL	MOR	ONY	OGE		
	Olea hochstetteri Baker	0	0	0	0	1	0	NAT	NE
Opiliaceae	*Opilia amentacea* Roxb.	0	0	0	0	0	1	NAT	NE
Orchidaceae	*Eulophia* sp.	0	0	0	0	1	1	UNK	NE
Orobanchaceae	*Cycnium herzfeldianum* (Vatke) Engl.	0	0	1	0	0	0	NAT	NE
	Cycnium tubulosum (L.f.) Engl.	0	0	0	1	0	0	NAT	LC
Passifloraceae	*Adenia cissampeloides* (Planch. ex Hook.) Harms	1	1	1	1	0	1	NAT	NE
	Adenia venenata Forssk.	0	1	0	0	0	0	NAT	NE
	Passiflora caerulea L.	0	0	1	0	0	0	INT	NE
	Passiflora edulis Sims	0	0	1	0	0	1	INT	NE
Pedaliaceae	*Sesamum angustifolium* (Oliv.) Engl.	0	0	1	1	0	0	NAT	NE
Phyllancaceae	*Bridelia scleroneura* Müll.Arg.	1	1	1	1	1	1	NAT	LC
	Flueggea virosa (Roxb. ex Willd.) Royle	1	1	1	0	0	1	NAT	LC
	Hymenocardia acida Tul.	1	0	1	0	0	1	NAT	LC
	Margaritaria discoidea (Baill.) G.L.Webster	0	1	0	0	0	0	NAT	LC
	Phyllanthus maderaspatensis L.	1	0	1	0	1	0	NAT	LC
Piperaceae	*Peperomia molleri* C.DC.	0	0	0	0	1	0	NAT	NE
Pittosporaceae	*Pittosporum viridiflorum* Sims	1	0	0	0	0	0	NAT	LC
Poaceae	*Brachiaria decumbens* Stapf	0	1	0	0	0	0	NAT	NE
	Cenchrus unisetus (Nees) Morrone	1	0	0	1	0	0	NAT	LC
	Chloris radiata (L.) Sw.	0	0	0	0	1	0	UNK	NE
	Chloris pilosa Schumach. & Thonn.	0	0	1	0	0	0	NAT	NE
	Cymbopogon citratus (DC.) Stapf	0	0	0	0	0	1	INT	NE
	Cynodon dactylon (L.) Pers.	0	0	1	1	0	1	NAT	NE
	Digitaria leucites (Trin.) Henrard	0	0	0	0	1	0	INT	LC
	Digitaria ternata (A. Rich.) Stapf	0	0	0	0	1	0	NAT	NE
	Digitaria velutina (Forssk.) P.Beauv.	0	0	0	0	0	1	NAT	LC
	Eragrostis superba Peyr.	0	0	0	1	0	0	NAT	NE
	Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	0	0	0	1	0	0	NAT	NE
	Hyperthelia dissoluta (Nees ex Steud.) Clayton	1	1	1	1	1	1	NAT	NE
	Hyparrhenia rufa (Nees) Stapf	0	1	0	0	0	0	NAT	NE
	Hyparrhenia filipendula (Hochst.) Stapf	1	1	0	1	1	1	NAT	NE
	Hyparrhenia diplandra (Hack.) Stapf	0	1	0	0	0	0	NAT	NE
	Loudetia arundinacea (Hochst. ex A. Rich.) Hochst. ex Steud.	1	1	1	0	0	1	NAT	NE
	Megathyrsus maximus (Jacq.) B.K.Simon & S.W.L.Jacobs	1	1	1	1	1	1	NAT	NE
	Melinis repens (Willd.) Zizka	0	0	1	1	0	0	NAT	NE
	Melinis sp.	0	0	0	0	0	1	NAT	NE
	Oxytenanthera abyssinica (A.Rich.) Munro	1	1	0	0	0	0	NAT	NE
	Panicum atrosanguineum Hochst. ex A.Rich.	0	0	0	1	0	0	NAT	NE
	Paspalum scrobiculatum L.	0	0	0	0	0	1	NAT	LC
	Phragmites mauritianus Kunth	0	0	1	0	0	0	NAT	LC
	Setaria homonyma (Steud.) Chiov.	0	0	1	0	0	1	NAT	NE
	Setaria parviflora (Poir.) Kerguélen	1	0	1	0	1	1	UNK	NE

Family	Scientific name	Central Forest Reserve						Origin	GCS
		AKU	KAN	BUL	MOR	ONY	OGE		
	Setaria sphacelata (Schumach.) Stapf & C.E.Hubb. ex Moss	0	0	0	0	1	0	NAT	LC
	Setaria verticillata (L.) P.Beauv.	0	0	0	1	1	0	NAT	NE
	Setaria scandens Schrad.	0	1	0	0	0	0	UNK	NE
	Sporobolus microprotus Stapf	0	0	0	0	1	1	NAT	NE
	Sporobolus pyramidalis P.Beauv.	1	1	1	1	1	1	NAT	NE
	Tetrapogon roxburghiana (Schult.) P.M.Peterson	0	1	1	1	0	1	NAT	NE
	Themeda triandra Forssk.	0	0	0	1	0	0	NAT	NE
	Urochloa eminii (Mez) Davidse	0	0	0	0	1	0	NAT	NE
Polygalaceae	*Polygala acicularis* Oliv.	0	0	0	0	0	1	NAT	NE
	Securidaca longipedunculata Fresen	0	0	1	0	0	1	NAT	NE
Proteaceae	*Protea madiensis* Oliv.	1	1	0	0	0	1	NAT	LC
Ranunculaceae	*Clematis hirsuta* Guill. & Perr.	1	1	0	0	0	0	NAT	NE
Rhamnaceae	*Ziziphus abyssinica* Hochst. ex A.Rich	1	1	1	1	1	1	NAT	LC
	Ziziphus mucronata Willd	0	1	0	1	0	0	NAT	LC
Scrophulariaceae	*Alectra sessiliflora* (Vahl) Kuntze	0	0	0	1	0	0	NAT	NE
Rubiaceae	*Catunaregam nilotica* (Stapf) Tirveng.	0	0	0	0	1	1	NAT	NE
	Gardenia ternifolia Schumach. & Thonn.	1	1	1	1	1	1	NAT	LC
	Hymenodictyon floribundum (Hochst. & Steud.) B.L.Rob.	0	0	0	0	1	1	NAT	LC
	Mitracarpus hirtus (L.) DC.	0	0	1	0	0	1	INT	NE
	Mussaenda arcuata Poir	0	0	0	0	0	1	NAT	NE
	Nauclea latifolia Sm.	1	0	1	0	0	1	NAT	LC
	Oldenlandia corymbosa var. *corymbosa*	0	0	1	0	0	0	NAT	LC
	*Oldenlandia herbacea (*L.) Roxb.	0	0	0	0	0	1	NAT	LC
	Pavetta subcana Hiern var. *longifolia* (Vatke) Bridson	0	0	0	0	1	1	NAT	NE
	Pavetta ternifolia Hiern	0	0	1	0	0	1	NAT	NE
	Pentanisia ouranogyne S.Moore	0	0	0	1	0	0	NAT	NE
	Psychotria punctata var. punctata	0	0	0	0	0	1	NAT	NE
	Spermacoce natalensis Hoscht.	0	0	1	1	1	0	NAT	NE
	Spermacoce pusilla Wall.	1	0	0	1	0	1	INT	NE
	Tricalysia niamniamensis Schweinf. ex Hiern	0	0	1	0	0	0	NAT	NE
	Vangueria apiculata K.Schum.	1	1	1	1	1	1	NAT	LC
	Virectaria major (K. Schum.) Verdc. Var. major	0	0	0	1	0	0	NAT	NE
Simaroubaceae	*Harrisonia abyssinica* Oliv.	1	1	1	1	1	1	NAT	LC
Rutaceae	*Vepris nobilis* (Delile) Mziray	1	1	1	1	1	1	NAT	LC
	Zanthoxylum leprieurii Guill. & Perr.	1	1	0	1	1	1	NAT	NE
Salicaceae	*Dovyalis abyssinica* (A.Rich.) Warb.	0	0	0	1	0	0	NAT	LC
	*Oncoba spinos*a Forssk.	0	0	0	1	0	0	NAT	LC
Santalaceae	*Osyris lanceolata* Hochst. & Steud.	0	1	0	1	0	0	NAT	LC
	Osyris compressa (P.J.Bergius) A.DC.	0	0	0	0	1	0	INT	NE
Sapindaceae	*Allophylus ferrugineus* Taub.	0	0	1	1	0	0	NAT	LC
	Allophylus rubifolius (Hochst. ex A.Rich.) Engl.	0	0	0	0	1	0	NAT	LC
	Pappea capensis Eckl. & Zeyh.	1	1	0	1	0	0	NAT	LC

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		AKU	KAN	BUL	MOR	ONY	OGE		
Sapotaceae	*Gambeya gorungosana* (Engl.) Liben	0	0	0	0	1	0	NAT	NE
	Vitellaria paradoxa C.F.Gaertn.	1	1	0	0	1	1	NAT	VU
Solanaceae	*Capsicum annuum* L.	0	0	1	0	0	1	INT	LC
	Nicandra physalodes (L.) Gaertn.	0	0	0	0	0	1	INT	NE
	Solanum incanum L.	1	1	1	1	0	1	NAT	NE
	Solanum lycopersicum L.	0	0	0	0	0	1	INT	NE
	Solanum nigrum L.	0	0	1	0	1	1	NAT	NE
	Solanum tuberosum L.	0	0	1	0	0	0	UNK	NE
	Solanum terminale Forssk.	0	0	1	0	0	0	NAT	NE
Stilbaceae	*Nuxia oppositifolia* (Hochst.) Benth	1	1	0	1	0	0	NAT	LC
Ulmaceae	*Trema orientalis* (L.) Blume	0	0	1	0	0	0	INT	LC
Velloziaceae	*Vellozia* sp.	1	1	0	0	0	0	UNK	NE
Verbenacaeae	*Lantana camara* L.	1	1	1	1	0	1	INT	NE
	Lippia abyssinica (Otto & A.Dietr.) Cufod.	0	1	0	0	0	1	NAT	NE
	Stachytarpheta urticifolia Sims	0	1	0	1	0	0	UNK	NE
Vitaceae	*Ampelocissus africana* (Lour.) Merr.	1	1	1	1	0	0	NAT	NE
	Cissus cornifolia (Bak.) Planch.	1	1	0	1	1	0	NAT	NE
	Cissus petiolata Hook.f.	1	0	1	0	1	1	NAT	NE
	Cissus rotundifolia Vahl	0	0	0	0	1	0	NAT	NE
	Cyphostemma adenocaule (Steud. ex A.Rich.) Desc. ex Wild & R.B.Drumm.	1	1	1	0	1	1	NAT	NE
	Cyphostemma crinatum Planch	0	0	0	1	0	0	NAT	NE
	Cyphostemma serpens (A.Rich) Descoings	0	0	0	0	1	0	NAT	NE
	Rhoicissus tridentata (L.f.) Wild & R.B.Drumm.	0	0	1	0	1	1	NAT	LC
Zingiberaceae	*Aframomum alboviolaceum* (Ridl.) K.Schum.	0	1	0	0	0	1	NAT	LC
	Aframomum mildbraedii Loes	0	0	0	0	1	0	NAT	LC
Zygophyllaceae	*Balanites aegyptiaca* (L.) Delile	1	1	0	1	1	1	NAT	LC

Key:

(i) Central Forest Reserves: *AKU* Akur, *KAN* Kano, *BUL* Bululu Hills, *MOR* Mount. Moroto, *ONY* Onyurut

(ii) Species presence/absence: 1 = Present, 0 = absent

(iii) Orig(iii) Origin: *NAT* Native, *INT* Introduced, *UNK* Unknownin, *NAT* Native, *INT* Introduced, *UNK* Unknown

(iv) GCS = IUCN Global Conservation Status i.e. *EN* Endangered, *NT* Near Threatened, *VU* Vulnerable, *LC* Least Concern, *DD* Data deficient, *NE* Not Evaluated

Acknowledgements

We acknowledge the support from DAAD In-Country/In-Region towards SO for his doctoral studies at Makerere University. We also acknowledge the permission from the National Forestry Authority (NFA) to undertake this research within the forest reserves of north eastern Uganda. We also grateful for the support of various forest patrol men who supported SO during field surveys. Mr. Protase Rwaburindore who helped with determination of voucher specimens at the Makerere University Herbarium is sincerely appreciated.

Authors' contributions

SO conceptualized the research idea, collected the data and prepared the draft manuscript. EK, PM and JK supervised data collection, data analysis and reviewed the draft manuscript.

Funding

The study was supported by DAAD In-country/In-Region Programme and IDEA Wild.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

NA.

Consent for publication

All the authors consent to publication.

Competing interests
The authors declare no competing interests.

Received: 10 June 2024 Accepted: 17 October 2024
Published online: 18 January 2025

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