

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; (i) determine the floristic richness and diversity in six central forest reserves of north eastern Uganda and (ii) evaluate the similarity and complementarity of floristic composition. Data was collected from nested quadrats (20 x 20 m for trees, 10 x 10 m for shrubs and 5 x 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 forest reserve. 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. All the CFRs had high diversity indices ranging from 4.2 in Kano CFR to 4.47 in Bululu hill CFR. In terms of floristic similarity, the CFRs clustered into two groups namely Onyurut and Ogera hills cluster and Akur, Kano, Bululu hills and Mount Moroto cluster. The CFRs complement one another by supporting plant species not recorded elsewhere. Notably, three CFRs (Bululu hills, Mount Moroto and Onyurut) account for 81.53% of the plant taxa. Addition of the fourth (Ogera hills) accommodates nearly 90% of the species and the fifth (Akur CFR) accounts for more than 95% of the species. The highest threat level on taxa in these CFRs is Vulnerable (4 species) and Near Threatened (4 species) with 137 Least Concern and 270 Not Evaluated. The CFRs in NE Uganda have richness and floristic diversity with up to 8.7% of the known plants in Uganda present. The two similarity clusters depict variation in altitudinal, proximity and climatic conditions. Five CFRs are required to conserve 95% of the species recorded. There is need to assess the population of the threatened species, and investigate the edaphic factors which influence plant distribution.

1.0 Introduction

As 2 in 5 (or 39%) of the world's vascular plant species are threatened with extinction (Nic Lughadha et al. 2020), understanding the patterns of distribution (Sosef et al. 2017), and identification of areas with a high value for biodiversity protection is paramount (Haq et al. 2023). The warm mixed forest, savannahs, shrub, tropical forest, and tropical woodlands are projected to lose the most species (van Vuuren et al. 2006) mainly due to anthropogenic activities which endanger the ecosystems (Malhi et al. 2014). These activities include habitat loss, introduction of alien species, direct exploitation, climate change and pollution (Hilton-Taylor 2000, Sala et al. 2000).

Biodiversity is crucial for ecosystem functioning and human well-being (van Vuuren et al. 2006) as nearly 1.5 billion people globally directly depend on tropical forests for food, timber, medicines, and other important ecosystem functions and services (Lewis et al. 2015). 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 have been put in place (CBD 2012) and the Kuming-Montreal global biodiversity framework (July 2022). 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 (Vellend et al. 2017). The origin of this interest is twofold; first the desire to conserve biodiversity and secondly; the potential for biodiversity changes to have an impact on the benefits that people derive from nature (MEA 2005).

The most popular methods for reporting floristic information include species accumulation curves, rarefaction curves and the Shannon–Wiener indices (alpha diversity) and Sørensen, Jaccard or Bray–Curtis indices (beta diversity) (Moreno et al. 2018). 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 (Magurran 2004). 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 (Chao et al. 2006). The other important components of floristic assessment include species richness and diversity (Pullaiah et al. 2015), population structure and distribution (Okia 2010, Byakagaba et al. 2011). The scarcity of this critical information explains why plants are usually not well represented in either global or national conservation planning schemes (Corlett 2016).

Most often, plant conservation efforts are hampered by lack of suitable data for prioritising conservation actions. Information on the rarest and most threatened plants and habitats, is often diffuse and difficult to access or is outdated (Darbyshire et al. 2017). Floristic composition and its distribution remains scarcely known in the species-rich tropical Africa (Sosef et al. 2017). In the case of Uganda, the available floristic data in most sites comprises of plant lists for trees and shrubs which were recorded by the Forest Department in 1990's as indicator taxa (Davenport *et al.* 1996). In savannah forest reserves (such as Ogera hills, Bululu and Onyurut investigated in this study), there is no record of botanical surveys carried out. In view of this situation, the study sought to (1) to determine the botanical richness and diversity in the six central forest reserves of north eastern Uganda and (ii) to evaluate the similarity and complementarity of these reserves for the conservation of plants. In achieving these objectives, the study presents floristic diversity within communities (alpha diversity) and between communities or the degree of community differentiation (beta diversity) (Whittaker 1960). This information will guide resource managers to prioritize conservation strategies since sites with exceptional or poor diversity (Pullaiah et al. 2015) are known. Additionally, it can aid in the evaluation of the relative importance of environmental and spatial drivers in shaping species assemblages (Valli et al. 2019).

2.0 Materials and methods

2.1 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 (White 1983, Eustace et al. 2021). This region has been poorly surveyed due to prolonged insecurity caused by the armed cattle rustlers (Kalema 2005). Indeed, two CFRs namely Mt. Napak and Mt. Kadam were omitted during floristic surveys due to reports of

insecurity. With the exception of Onyurut, all the forest reserves studied are located on either hills or mountains.

Onyurut is a small CFR covering 158 ha in Katakwi district. Its vegetation is predominantly woodland savannah with species such as *Combretum adenogonium*, *C. molle*, *Acacia brevispica* and *Zanthoxylum lepriurii* with patches of grassland dominated by *Brachiaria decumbens*, *Hyparrhenia filipendula* and *Hyparrhenia dissoluta*. The CFR is encroached by adjacent communities majorly for farming and settlement, brick making, charcoal production, and cattle grazing. It serves as a water catchment area for Lake Bisina.

Mount Moroto covers an area of 483 km² (Davenport *et al.* 1996). It is 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 milanjanus*, *Afrocarpus* (*Podocarpus*) *gracilior*, and *Juniperus procera* (Langdale-Brown *et al.* 1964; Davenport *et al.* 1996). The mean annual rainfall is 887 mm with the peak period between April to August. Significant areas of the reserve, particularly at lower altitudes in the north and south, have been transformed by farming of crops.

Kano CFR is located in Labwor hills in the present day Abim district and covers an area of 8,293 ha. It is a key site for biodiversity conservation, hill reserve, and protects River Amal which serves the communities of Kano and Abim parishes (National Forestry Authority 2008). This 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 covers an area of 6,434 ha. within the Labwor hills of Abim district. It is a critical site for biodiversity conservation, hill reserve and River Ojulu originates from it (National Forestry Authority 2008). 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 (National Forestry Authority 2008). The most important factor limiting the vegetation is most probably soil depth and its associated character of soil moisture (National Forestry Authority 2008). 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 covers an area of 427 ha and an altitudinal range of 1036–1160 m (National Forestry Authority, 2012). Its 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 arundinaceum* 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 serves as a water catchment area of Lake Kyoga in the south.

Bululu hills CFR covers an area of 425 ha and is separated from Ogera hills CFR by Lake Kyoga. It serves as a water catchment for the Lake and its surrounding swamps. It is characterized by *Euphorbia candelabrum*, *Harrisonia abyssinica*, *Terminalia schimperiana*, *Combretum collinum* with *Cyperus papyrus* and *Phragmites mauritianum* on the lake shores. This reserve is used for indiscriminate tree cutting for charcoal production, livestock (cattle) grazing, human settlement and cultivation which culminate to soil erosion on the slopes. The situation is further exacerbated by the unclear boundary of the reserve.

2.2 Data collection

The nested quadrat method was used with quadrats of 20 x 20 m for trees, 10 x 10 m for shrubs and 5 x 5 m for herbaceous climbers, forbs and grasses were placed at intervals of 100 m along a transect of 1000–1500 m applied. The transects were spaced at an interval of 1000 m. The quadrat method is used for most plant communities (Cox 1990) because it allows the more abundant species to be recorded in the smaller quadrats while increasing the likelihood of encountering the less common species in the larger quadrats (Bonham 2013).

The transects were located on the ground using the gradient oriented transect (gradsect) sampling (Austin & Heyligers 1989) technique. This approach ensures that the environmental variability is adequately represented amidst budget, time and staff constraints. The gradsects have been shown to be superior in capturing information about vegetation attributes than randomly placed transects of similar length (Gillison & Brewer 1985). The gradients considered in the study are topography (bottom-middle-top slope), drainage patterns namely rivers and alignment to the direction of the sun (aspect).

The plant parameters measured in each quadrat included species identity and number of individuals present or cover for the herbaceous plants. The trees and shrubs were identified by their local names following the local guides (Katende et al. 1995, 1999) while the grasses were identified following Phillips et al. (2003). The voucher specimens of plants were collected and pressed for confirmatory taxonomic determination at Makerere University Herbarium. The adequacy of the sampling effort was assessed using the species accumulation curves in each CFR.

2.3 Data analysis

The species richness, diversity and evenness were determined for each forest reserve using the Shannon-Index (H') and Evenness (E) (Magurran 1988) in Vegan, R Statistical Package (version 4.0.3). The study used binary similarity coefficients because only presence/absence data of plant species was recorded in each CFR following Chao et al. (2006). Although there are many similarity indices based on presence/absence (incidence-based) data in literature (Chao et al. 2006), only the Jaccard and Sørensen indices were used in this study because they are generally functions of three incidence counts namely the number of species shared and the number of species unique to each. Magurran (2004), assert that

these are the most classic, simple and widely indices in comparing species assemblages. They are also modifiable into coefficients of *dissimilarity* by taking their inverse (Chao et al. 2006). However, as a limitation, Chao et al. (2006) noted that these binary indices do not take into account the abundance of species. In so doing, they treat abundant and rare species equally. They further assert that as a result of this limitation, the estimates are generally biased downward and the bias increases when either sample sizes are small or species richness is high. On the contrary, Krebs (1999) asserts that it is theoretically possible that the Jaccard and Sorensen indices could be upwardly biased but this seems to be most unusual.

3.0 Results

3.1. 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 1). 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 1). A 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 underestimated species richness in Ogera hills and Mt. Moroto but overestimated in Akur, Bululu, Kano and Onyurut. On the other, *Jackknife*₁ underestimated species richness in Bululu hills, Mt. Moroto and Onyurut but overestimated in Akur, Kano and Ogera (Table 1). 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 2). 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 2).

Table 1: Actual and estimated species richness in the CFRs of north eastern Uganda

Central Forest Reserve	Actual Species richness Richness	Estimated Species Richness		Variance	
		Chao ₂	Jackknife ₁	Chao ₂	Jackknife ₁
Akur	142	149	161	-7	-19
Bululu Hills	187	205	176	-18	11
Kano	148	163	174	-15	-26
Mount Moroto	160	136	144	24	16
Ogera Hills	161	154	173	7	-12
Onyurut	171	172	169	-1	2

The species accumulation curves for each CFR (Figure 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. 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.

Table 2: 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

3.2 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 (Figure 3). However, the latter cluster is branched into two sub-clusters namely; Akur and Kano; and Bululu hills and Mount Moroto.

3.3 Complementarity analysis

Table 3 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.

Table 3: Complementarity table for the minimum critical set of CFRs in north eastern Uganda based on plant taxa

Central Forest Reserve	Species richness	Cumulative percentage (%) ^{***}
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: ^{***} shows the percentage added to the total by each Central Forest Reserve through the addition of species not already represented in sites higher on the table

3.4 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 4. More than half of the species recorded (270) have not been evaluated (NE). Amongst those that have been evaluated, Least Concern (LC) comprises the highest number (137). The Vulnerable (VU) species are *Albizia malacophylla*, *Vitex amanuensis*, *Entandrophragma cylindricum* and *Vitellaria paradoxa* while the Near Threatened (NT) species are *Albizia ferruginea*, *Dalbergia melanoxydon*, *Eucalyptus grandis* and *Milicia excelsa*. The only Data deficient species recorded is *Mangifera indica* which is also cosmopolitan. 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. In the national red lists (WCS 2016), the conservation status of some species previously assessed by the IUCN Redlists has been elevated. For example; *E. cylindricum* is Vulnerable according to IUCN Red lists but Endangered at a national level.

Table 4: 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
<i>Total</i>	417	100	187 (3.9)	148 (3.1)	161 (3.4)	160 (3.3)	142 (2.9)	171 (3.5)

Key: BUL = Bululu hills, KAN = Kano, OGE = Ogera hills, AKU = Akur and ONY= Onyurut; the figure in brackets () shows the percentage of species in each central forest reserve from known plant species in Uganda.

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 (Kalema et al. 2016). The diversity indices within CFRs are above the threshold (2.0) for high diversity (Magurran 2004). 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 (Paclibar & Tadiosa 2020). The species accumulation curves (Figure 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. (2021) 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 (2016) 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 (Roswell et al. 2021).

The grouping of CFRs into clusters (Figure 3) 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 (Figure 3). The dissimilarity of sites can also be attributed to the distinct climatic conditions in north eastern Uganda. 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 (Egeru 2012).

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. According to Williams et al. (2006), 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. (2000) 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 Carwardine et al. 2007). 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 (Carwardine et al. 2007). 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 (WCS 2016). For instance, *Albizia ferruginea* is VU in the IUCN Global Red lists but EN in the national red list (WCS 2016), *Milicia excelsa* is NT in the IUCN Global Red list while it is EN in WCS (2016), *Mondia whitei* is NE in IUCN redlist but VU in WCS (2016), and *Entandrophragma cylindricum* is VU in IUCN Global Red list but EN in WCS (2016). According to WCS (2016), 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. 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 (Darbyshire *et al.* 2017). 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 findings of this study reveal the botanical richness, diversity, similarity and complementary in the six CFRs in NE Uganda. Up to 417 plant species representing nearly 8.7 percent of the known taxa have been recorded. 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. Although this study has provided baseline information on the floristic composition in the six CFRs of north eastern Uganda. Future research should be geared towards studying the populations (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 Vulnerable species, and conducting conservation assessments of the species that are currently not evaluated.

Declarations

Ethics approval and consent to participate

NA

Consent for publication

All the authors consent to publication

Availability of data and materials

All the material has been provided

Competing interests

The authors have no competing interests

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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.

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Figures

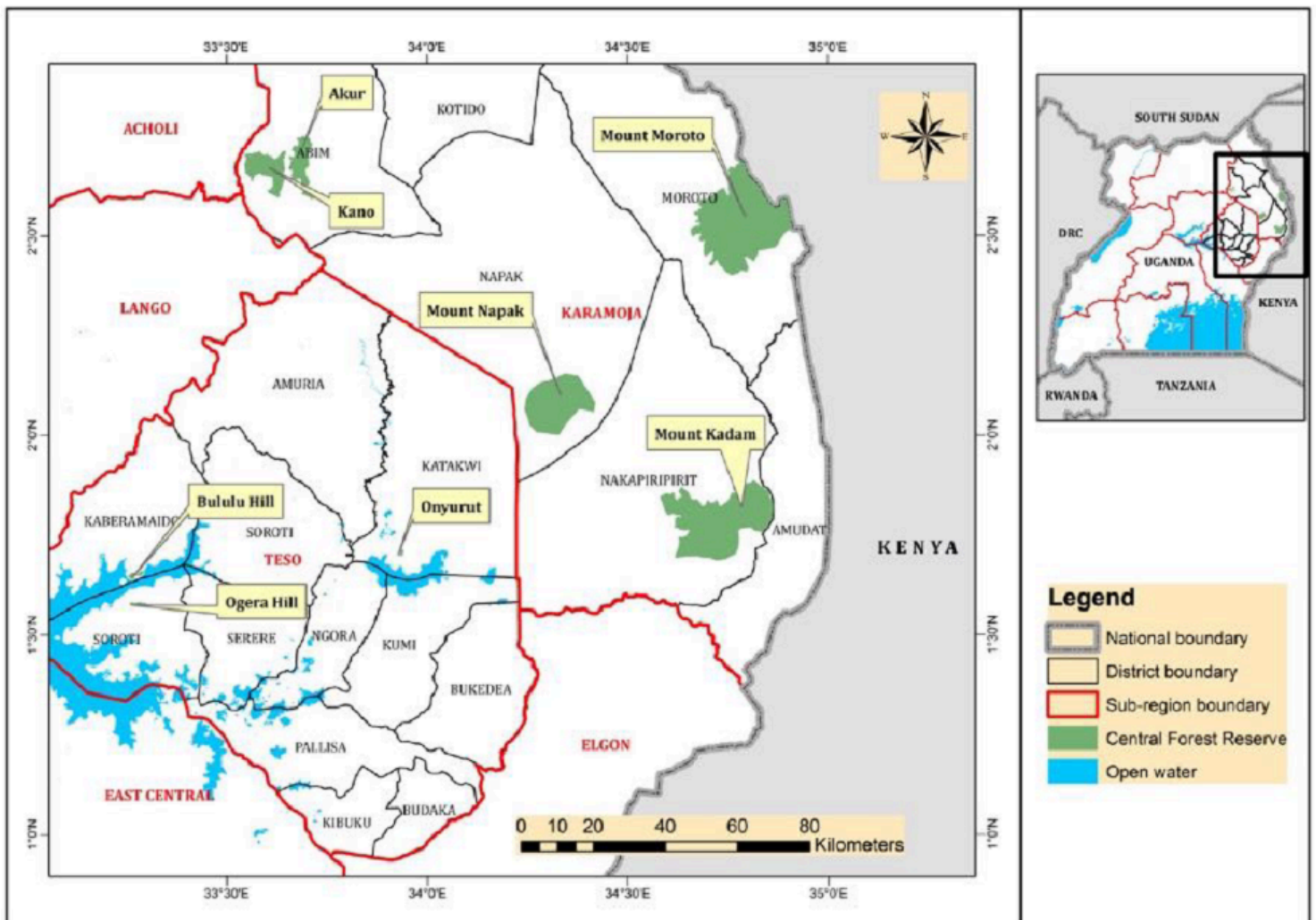


Figure 1

Location of forest reserves in north eastern Uganda

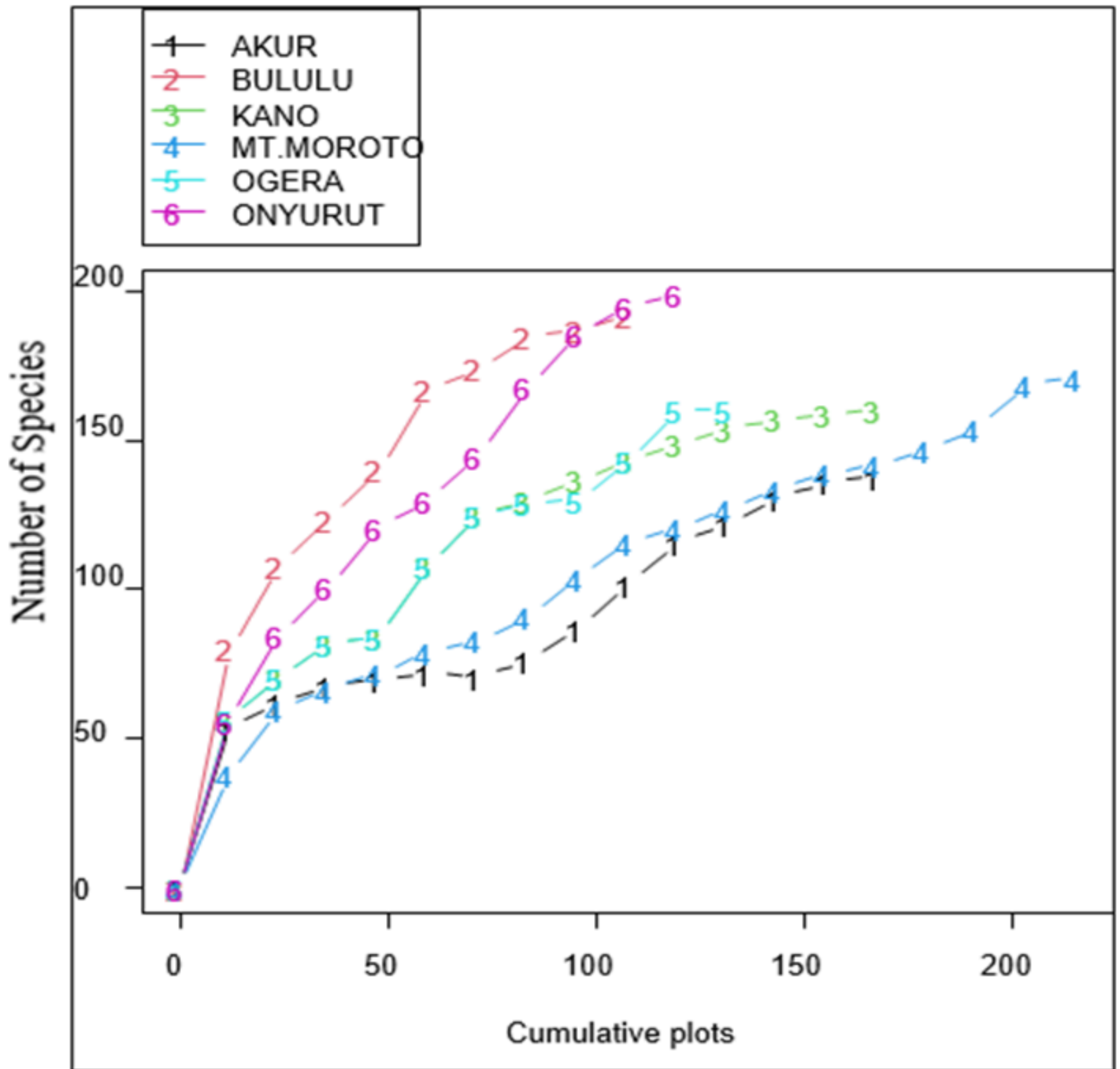


Figure 2

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

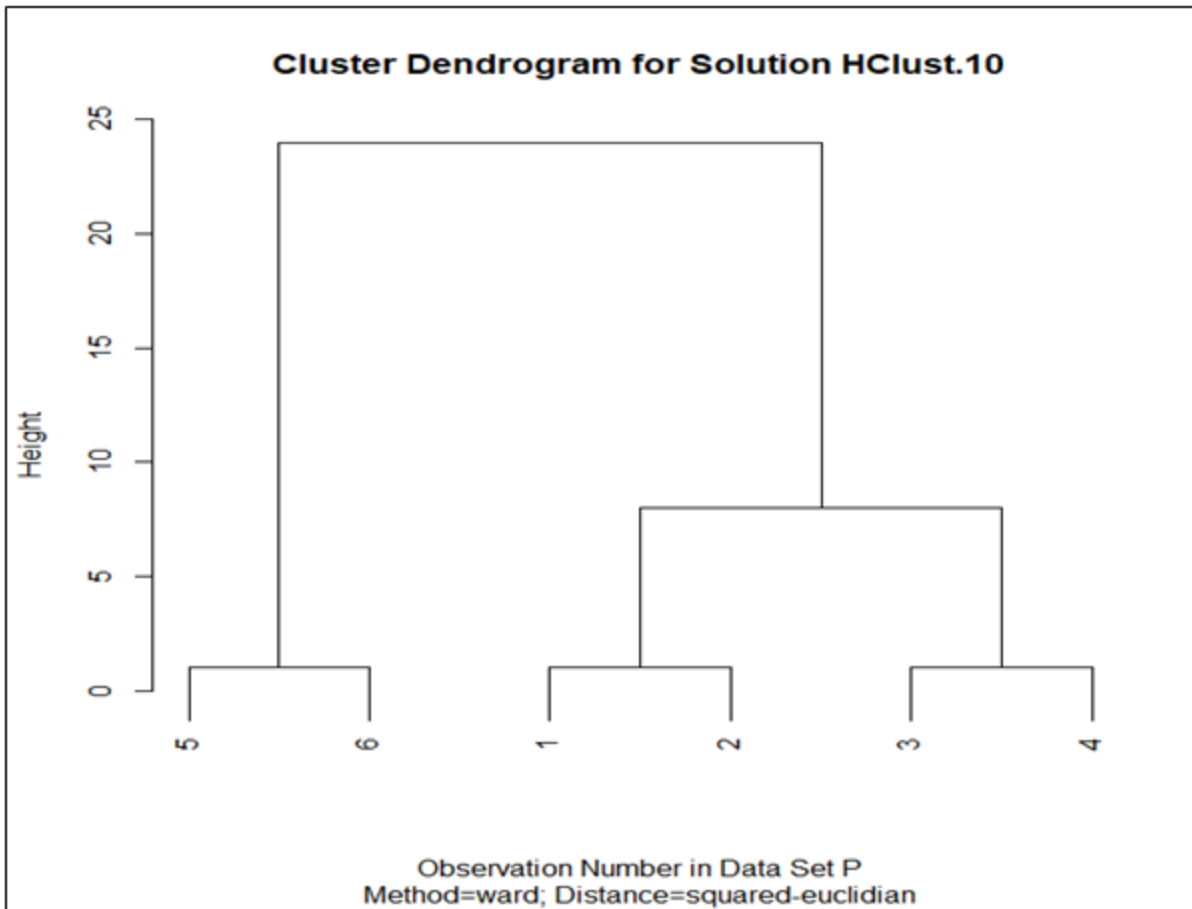


Figure 3

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.

Supplementary Files

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