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RESEARCH ARTICLE

Changes in floristic composition, diversity and anthropogenic perturbations in an east African tropical forest

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Abstract

We assessed changes in floristic composition, diversity and anthropogenic activities in an East African forest; Echuya Central Forest Reserve (ECFR). Using 272 permanent sample plots, comparisons between 2015 and 2021 were made. Twenty-two tree species were recorded with *Macaranga capensis* being the most dominant. Tree species density increased significantly from 152 stems/ha in 2015 to 306 stems/ha in 2021. Similarly, trees basal area increased significantly from 19 m^2/ha in 2015 to 38 m^2/ha in 2021. The bamboo stem density decreased significantly from 11,931 stems/ha in 2015 to 1807 stems/ha in 2021. Shrubs, lianas, vines and herbs' densities did not show significant differences between 2015 and 2021. Furthermore, a number of human activities significantly increased from 22 activities per hectare in 2015 to 83 per hectare in 2021. The Non-Metric Multidimensional Scaling (NMDS) ordination shows that the human activities with the strongest impact on tree species composition and basal areas were fuelwood collection, human trails, livestock grazing and pole cutting. In conclusion, ECFR is floristically poor; secondary forest tree species are replacing the bamboo forest and human activities could be negatively affecting the ECFR flora. We recommend interventions of increasing people's livelihood incomes to decrease their dependence on forest resources.

KEYWORDS
anthropogenic activities, floristic composition, species density and diversity

1 | INTRODUCTION

Tropical forests are arguably the most biologically diverse places on the planet and with many endemic and rare species (Ghazoul & Sheil, 2010; Smith, 1996). Tropical forests are important globally for their unique contributions to biodiversity conservation, climate stability and human well-being. These tropical forests occupy less than 10% of the terrestrial surface yet constitute the largest repository of terrestrial biomass and host more than half of the world's known and unknown species (Owusu et al., 2022). The forests support various life forms, including humans who dwell in settlements in and around those forests (Shiferaw et al., 2019). Furthermore, tropical forests provide various ecosystem services important to sustain rural livelihoods and national developments (Kayombo et al., 2022).

According to Jayakumar and Nair (2013), the diversity of floral species is a fundamental component of total biodiversity in many tropical ecosystems because those flora are ecosystem engineers that provide resources and habitats for almost all other organisms. However, human activities have continued to operate as dominant drivers of biodiversity change and disruption of ecosystem processes in these tropical forest ecosystems (Martínez-Ramos et al., 2016). Bentsi-Enchill et al. (2022) and Shiferaw et al. (2019) have demonstrated that human activities have significant impacts of decreasing floral compositions in tropical forests. Unlike the

Type of audience: Protected area managers, conservationists, researchers, policymakers and planners.

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gaps created by treefalls and other 'natural' disturbances, the regeneration of secondary forests that have been disturbed anthropogenically do not always follow a predictable recovery pathway (Bruna & Ribeiro, 2005). In worst-case scenarios this can lead to extinction among tropical forest species (Wright & Muller-Landau, 2006).

In East Africa, the tropical forests are considered as centers of botanical endemism (Lovett, 1998) and have been recorded to contain various species of flora and fauna. The East African tropical forests are among the most diverse and richest in Africa and include the Albertine Rift forests (Yirga et al., 2019). These forests are not only important for biodiversity but also for ecological processes and ecosystem services (Plumptre et al., 2007). At the extreme corner of southwestern Uganda, lies Echuya Central Forest Reserve (ECFR) juxtaposed between Mgahinga Gorilla and Bwindi Impenetrable National Parks. The ECFR is a unique Afromontane tropical forest with high-species endemism and rarity but less species diversity (Plumptre et al., 2007).

Despite its importance, the ECFR has been less studied for its biodiversity. Bitariho et al. (2015); Bitariho and Babaasa (2022); Plumptre et al. (2007) have compiled the known species' list of ECFR and reported that the biodiversity of ECFR is under threat from anthropogenic activities. In June 2018, the biodiversity threats to ECFR were exacerbated by National Forest Authority (NFA) massively clearing the bamboo forest understory of all tree saplings and climbers covering an area of more than 50 ha (Bitariho & Babaasa, 2022). This was done ostensibly to stimulate increased growth of the bamboo forest that was observed to be reducing in area. Apart from the few mentioned studies, no detailed scientific study has ever been carried out to assess the floristic and anthropogenic changes in ECFR. Yet such information is important in determining the magnitude and trends of the anthropogenic perturbations on biodiversity in protected areas (Shiferaw et al., 2019). We therefore undertook to answer the research question of; what are the floristic and anthropogenic activities changes that have occurred in ECFR? As such, we hypothesized that; there has been a significant increase in flora diversity, flora density and human activities in ECFR. The results of this study are of immense importance to forest managers and other conservationists in the region and elsewhere for better planning, and conservation of protected areas and the overall conservation of biodiversity.

2 | METHODS

2.1 | Study site

ECFR is an Afromontane forest located between latitude 1°14′–1°21′ south and longitude 29°47′–29°52′ east in southwestern Uganda. It is located 15 km west of Kabale town, and 11 km east of Kisoro town and is surrounded by eight local administrative parishes (Figure 1). The ECFR covers an area of 34 km^2 with an elevational range between 2270 and 2570 meters above sea level (Bitariho & McNeilage, 2008). The area immediately surrounding the forest is densely populated, with a density of 500 people km^2. The majority of the people live below the poverty line, with over 74% of the local population depending heavily on forest resources (Bitariho et al., 2016). The vegetation in ECFR is dominated by the montane bamboo *Arundinaria alpina* (*K. Schum*) to the south and southeast of the forest reserve. Other major vegetation types include the secondary forest tree dominated by *Macaranga capensis* (Banana & Tweheyo, 2001; Bitariho & McNeilage, 2008).

2.2 | Sampling procedure

A systematic sampling procedure was used to collect data on vegetation and human activities following Kengne et al. (2022); Shiferaw et al. (2019); Yirga et al. (2019). In June 2015, after a reconnaissance survey of the forest, six parallel transects separated from each other by 1 km intervals were systematically laid out across the forest running from the Northwest to the Southeast of ECFR (Figure 1). The first transect was randomly established using random numbers generated by the ArcGIS software of the eastings and northings of ECFR map. The randomization involved first laying a coordinate grid on top of the ECFR map and then selecting coordinates of transect locations at random using paper pieces placed in a hat (Bitariho et al., 2020). The length of each transects varied depending on the entire width of ECFR and was 4.63 km, 4.52 km, 4.85 km, 4.96 km, 5.16 km and 5.16 km respectively (Figure 1).

A total of 272 nested quadrats (Figure_1_SuppInfo) were then placed systematically at every 100 m interval (starting from the forest edge) and alternating from left and right on the six transects following similar procedures by Fashing et al. (2004); Kengne et al. (2022); Yirga et al. (2019). The nesting of the quadrats involved laying out main plots within which subplots were then embedded. The main plots of size 100 m^2 were established to assess trees, then within them, subplots of sizes 25 m^2 and 6.25 m^2 were embedded to assess other lifeforms (Table S1). After laying out the transects and plots, all the six transects and 272 plots were then permanently marked using a Global Positioning System (GPS) and metallic markers for further reassessment in 2021.

2.3 | Vegetation data collection

Vegetation data collections were carried out in 2015 and again in 2021 using similar plots/transects that were established in 2015. In both years, the trees of dbh ≥10 cm were enumerated in plots of 100 m^2 and recorded for diameter at breast height (Dbh) and number of stems rooted in the plots. Sprouts, coppices, or multi-stemmed individuals of the trees were counted as separate individuals if the branching was below 1.3 m from the ground (Cunningham, 2001). The Dbh of each tree was measured 1.3 m above the ground using a tree Calliper and Diameter tape (Yirga

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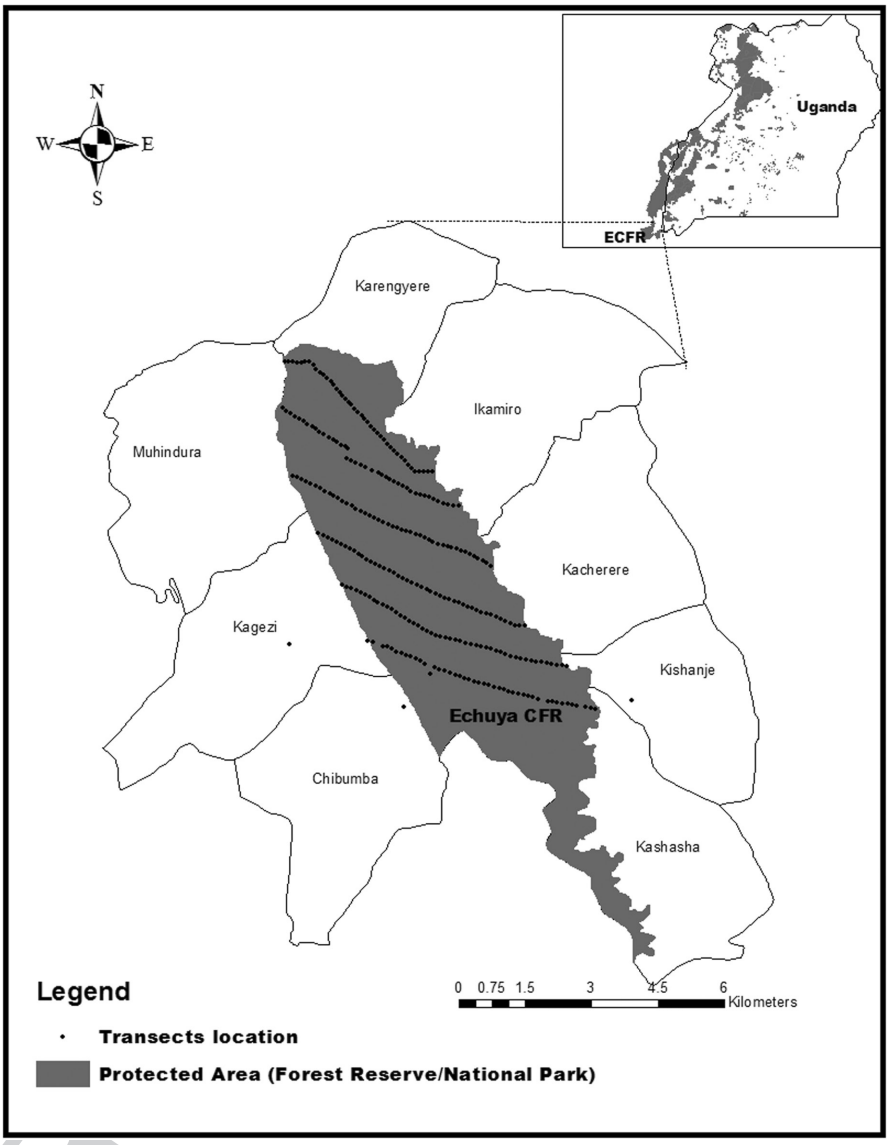


FIGURE 1 Map of ECFR showing sampling transects location and surrounding administrative parishes in South. Western Uganda

et al., 2019). Shrubs, bamboo and lianas were enumerated in plots of 25 m^2 and recorded for number of stems rooted in the plots while vines, herbs and tree seedlings were enumerated in plots of 6.25 m^2 and also recorded for number of stems rooted in the plots (Shiferaw et al., 2019). For the bamboo, the bamboo stems rooted in the 25 m^2 plots were counted after categorising them into age classes of 'shoots', 'young green stems', 'mature yellowish stems', 'old greyish stems' and 'dead/dry stems' following Bitariho and McNeilage (2008).

Lianas were considered as those large, woody bare-stemmed climbers while vines were the predominantly herbaceous, leafy smaller climber plants (Bitariho, 2013; Cunningham, 2001). In cases where the stems of shrubs, lianas and vines were formed by clonal extensions of adults, these were treated and counted as separate individuals (Cunningham, 2001). All the plant species located in the plots were identified by their local names, and scientific names where possible. Specimens for each plant species were collected and pressed for Herbarium botanical name confirmation and identification at the field herbarium of the Institute of Tropical Forest Conservation (Shiferaw et al., 2019; Temesgen & Warkineh, 2020). The botanical identifications were later reconfirmed with the Royal botanical Gardens–KEW website (https://powo.science.kew.org/).

2.4 | Human activities data collection

The human activities data was the visually identified direct signs and indirect signs of all the human livelihood activities within the ECFR. These were recorded for type and number in each of the 272 main plots (100 m^2) in 2015 and later in 2021. The categories of human activities identified were tree pole cutting, firewood collections, wild climber collections, beekeeping, fresh human trails, fire signs, bamboo harvesting and livestock grazing. The procedure of recording the human activities data following Bernhard et al. (2021); Bitariho et al., 2022; McNeilage et al. (2006); Mugume et al. (2015); Olupot et al. (2009). The fresh human trails were the directly observed human paths including trampling of vegetation crossing the plots,

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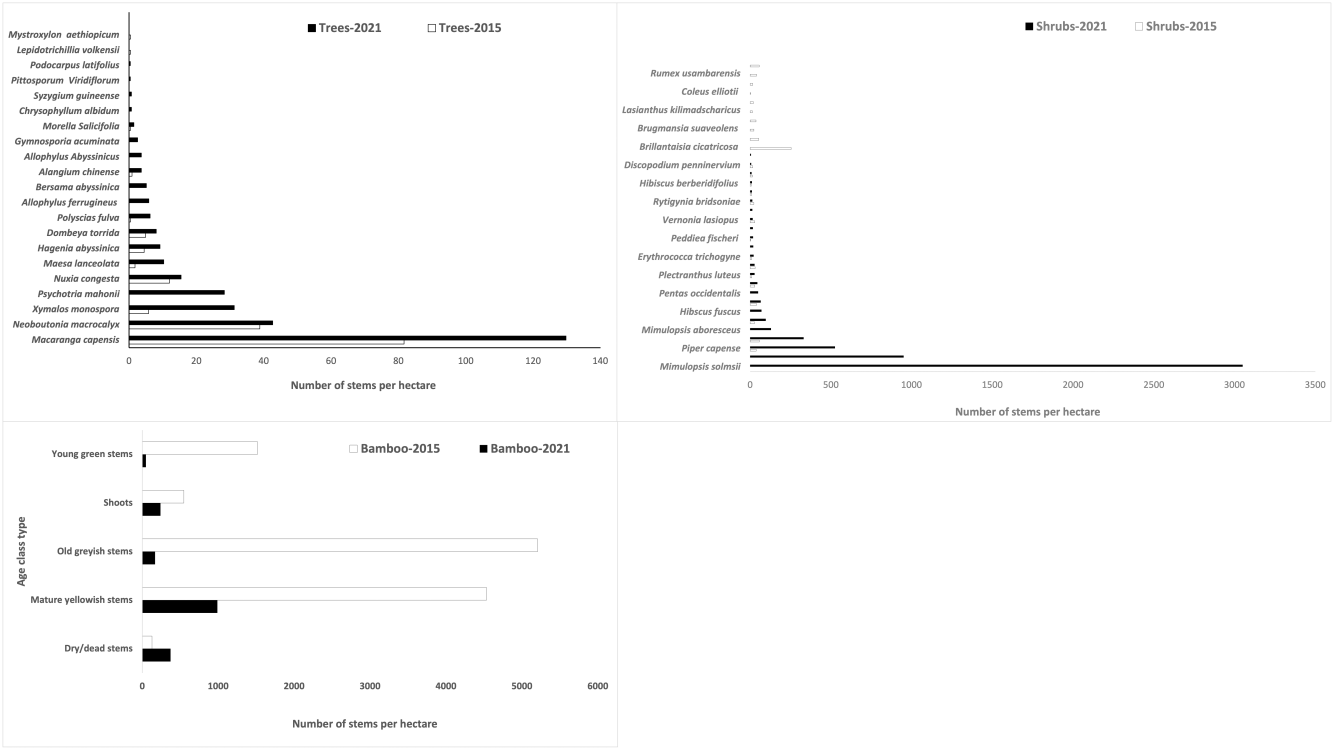


FIGURE 2 Comparison between 2015 and 2021 for trees and shrubs abundances and bamboo age class distribution

pole cutting were the fresh signs of leftover stumps after cutting, firewood collection were the dry tree branches cut from trees and leftover remains of dry twigs, fire signs were the fresh leftovers of fire evidences like ash and burnt wood, wild climber harvests were the cuts/leftovers of climber bases, bamboo harvests were leftover stumps of bamboo, livestock grazing were the signs of cow dung and goat droppings and fresh vegetation grazing signs within the plots, while beekeeping were the physical evidences of beehives found in the plots.

2.5 | Data analysis

2.5.1 | Vegetation data

All the vegetation data was analysed using R open-source statistical software version 3.2.2 (R Core Team., 2018). The vegetation data was categorised into trees, shrubs, bamboo, lianas, vines and herbs and each category analysed separately. The floristic composition for 2015 and 2021 was obtained by determining the total number of species and families of all the recorded plants (Kengne et al., 2022). Stem densities for each category of plant lifeforms were determined from the 272 plots data, pooled together and calculated following Kayombo et al. (2022) with the formular;

$$D = \frac{n(\text{no. of individuals})}{\text{PA(Ha)}}$$

where; D=density; n=number of stems; PA=plot area in hectares.

Plant diversity was measured using the Shannon–Weiner diversity index and species richness (evenness) using Shannon Equitability Index (Shiferaw et al., 2019). The Shannon diversity index of each flora category was compared for 2015 and 2021. Furthermore, the Shannon Equitability Index was used to calculate species evenness for the different flora taxa and compared for the different study years.

The Shannon index formular used was.

$$H = H = -\sum (n_i / N) \log (n_i / N)$$

where n_i=Importance value for each species, N=total of importance values.

The Shannon Equitability Index formular used was.

$$E_H = H / \ln (S)$$

where: H: The Shannon Diversity Index, S: The total number of unique species, ln: Natural log

Furthemore, based on the Bray–Curtis index, we used the Non-Metric Multidimensional Scaling (NMDS) analysis to assess the change in tree species composition in the six study transects (pooled 272 plots) between the years 2015 and 2021 following Martínez-Ramos et al. (2016). For this analysis, we constructed a matrix, in which the columns contained the species recorded in all plots and years, the rows contained the plots subdivided in years (2015, 2021), and the cells contained the species basal areas (Martínez-Ramos et al., 2016). Finally, statistical inferences were made to test for the differences in stem density and diversity for each taxon over the study years (2015 and 2021)

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TABLE 1 A comparison of 2015 and 2021 for the different flora species density, diversity, evenness and human activities.

Species category	Total number per hectare (density)		Shannon–Weiner diversity index (species diversity)		Shannon equitability index (species evenness)	
	2015	2021	2015	2021	2015	2021
Trees	152	306	1.12	**2.15**	0.21	0.34
Shrubs	1118	7187	**2.80**	1.97	0.43	0.23
Bamboo	11,931	1807	NA	NA	NA	NA
Lianas	255	2781	**1.45**	1.28	0.29	0.17
Vines	3671	1200	**1.71**	0.30	0.27	0.05
Herbs	32,236	58,529	2.76	**2.81**	0.33	0.31
Human activities	22	83	NA	NA	NA	NA

Abbreviation: NA, not applicable.

TABLE 2 A comparison of 2015 and 2021 for the top nine tree species basal areas in ECFR.

Tree species	Year 2015		Year 2021	
	Basal area (M^2/ha)	%	Basal area (M^2/ha)	%
Macaranga capensis	10.6	55	15.6	41
Nuxia congesta	2.0	10	2.9	7.6
Neoboutonia macrocalyx	1.7	9	2.4	6.4
Psychotria mahonii	1.7	9	2.5	6.5
Dombeya torrida	1.4	7	1.0	2.6
Maesa lanceolata	0.6	3	1.6	4.1
Xymalos monospora	0.5	2.6	1.9	4.9
Polyscias fulva	0.3	1.3	5.3	14
Hagenia abyssinica	0.1	0.6	0.6	1.6
Total for all tree species	**19.17**	100	**38.04**	100

using a Kruskal–Wallis chi-squared test and Kruskal's NMDS test for stem density and diversity, respectively. The bamboo stem density per unit hectare was also compared between 2015 and 2022 and tested for statistical differences using the Kruskal–Wallis chi-squared test.

2.5.2 | Tree species basal area data

The measured tree diameters in centimetres were used to calculate the basal areas (BA) for each tree species following Kayombo et al. (2022); Shiferaw et al. (2019). The formular used and expressed in m^2 per hectare was (Bettinger et al., 2017; Kayombo et al., 2022);

$$BA(m^2) = \pi \times (DBH(cm)^2 / 4 \times 10{,}000\,cm)$$

where BA = basal area; DBH = diameter at breast height (1.3 m); and $\pi = 3.14$ (π & 4 are constants). Thereafter, the individual plots trees basal areas were pooled together for 2015 and 2021 and then compared and tested for statistical significancy using a Kruskal–Wallis chi-squared test.

2.5.3 | Human activities data

All the human activities data was analysed using R open-source statistical software version 3.2.2 (R Core Team., 2018). The human activities data from the 272 plots was pooled together and then calculated per unit hectare. Statistical inference to test for differences in the number and type of human activities between the study years (2015 and 2021) was made using a Kruskal–Wallis chi-squared test. We then used the NMDS ordination to analyse the impact of human activities on the tree species composition and basal areas. Data from the 272 plots was pooled together into the 6 transects and arranged as a matrix of transects by species. The species basal areas were natural log-transformed following McCune et al. (2002) to minimise the influence of large trees. Human activities data was also arranged as a matrix of transects by human activity type. Each entry was the sum of encounters of a human activity type recorded for all the plots where it occurred along a transect. A Kruskal's NMDS based on Bray–Curtis' coefficient was used to evaluate the relationship between tree composition/basal area and the human activities.

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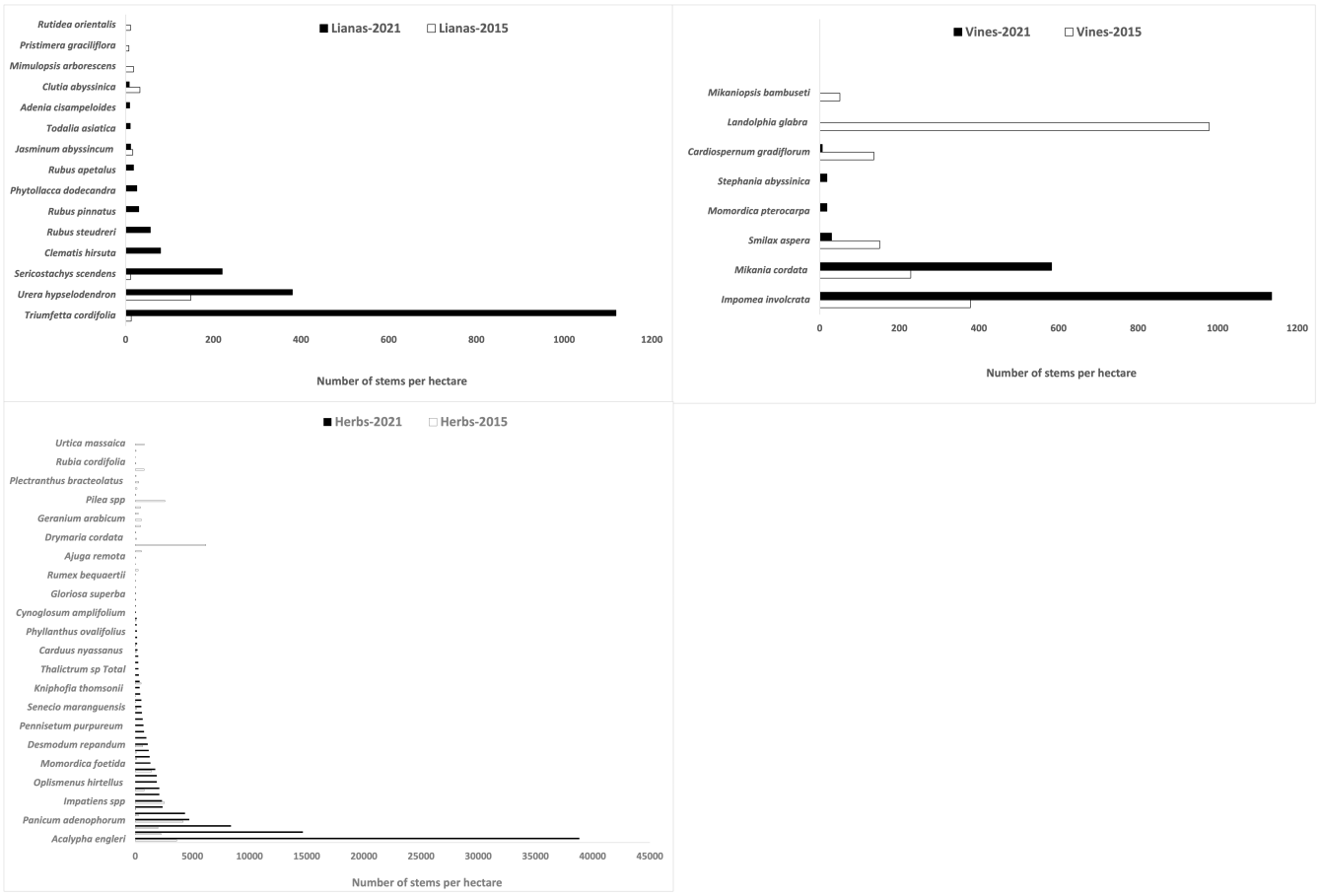


FIGURE 3 A comparison between 2015 and 2021 for Lianas, Vines and Herbs' abundance

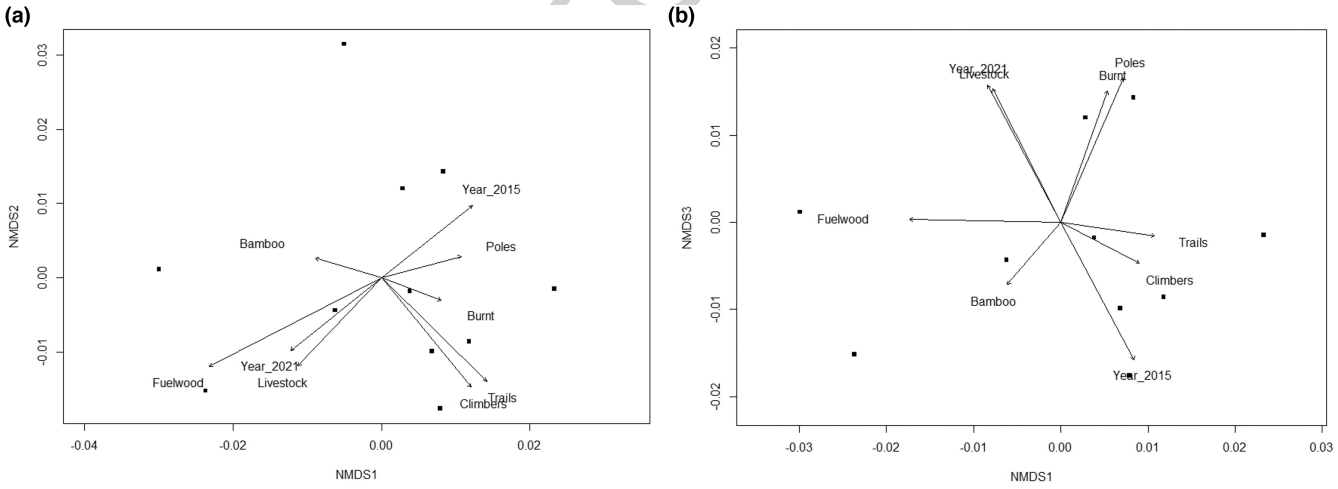


FIGURE 4 The NMDS ordination showing human activities impacts on tree species composition on (a) axes 1 and 2 and (b) axes 1 and 3 in 2015 and 2021

3 | RESULTS

3.1 | Floristic composition and structure

A total of 141 plant species belonging to 69 families were recorded (Appendix A). Of these, the herbs occupied the highest proportion with 61 (43.2%) species, followed by shrubs with 36 (25.5%) species, then trees with 22 (15.6%) species, lianas with 13 (9.2%) species, vines with 8 (5.7%) species and bamboo with 1 (0.7%) specie (Appendix A). The richest families recorded in ECFR in descending order were Rubiaceae (16 species), Asteraceae (11 species), Lamiaceae and Urticaceae (7 species), Poaceae (6 species) and Rosaceae (5 species).

3.2 | Tree species diversity and abundance

A total of 22 tree species belonging to 19 families, were recorded (Appendix A). Of these, *Macaranga capensis* (Pax) Friis & M.G.Gilbert, *Neoboutonia macrocalyx* Pax, *Xymalos monospora* (Harv.) Baill., *Psychotria mahonii* C.H.Wright and *Nuxia congesta* R.Br. ex Fresen, were the most dominant in descending order (Figure 2). Tree species stem density increased significantly from 152 stems/ha in 2015 to 306 stems/ha in 2021 (Kruskal–Wallis's chi-squared = 6.0063, df = 1, $p = 0.01425$ at 95% Confidence Interval, Table 1 and Figure S2). The NMDS shows that the tree species composition for 2015 were dissimilar from those of 2021 (Figure 4; $p = 0.0199$). Furthermore, the Shannon diversity index shows that tree species diversity in 2021 was higher than in 2015. Similarly, tree species evenness in 2021 was slightly higher than in 2015 (Table 1).

3.3 | Tree species basal area

The basal area of the trees significantly increased from 19.17 m^2ha^{-1} in 2015 to 19.17 m^2ha^{-1} in 2021 (the Kruskal–Wallis's chi-squared = 4.9701, df = 1, $p = 0.02579$; Table 1; Figure S4). This was also confirmed by the NMDS ordination that shows the tree basal areas for 2015 to be dissimilar from those of 2021 (Figure 4; $p = 0.002$). The *M. capensis* trees had the most dominant basal areas comprising of 55% and 41% of the total basal areas in 2015 and 2021, respectively. This was followed by *N. congesta* (10% in 2015 and 7.6% in 2021) and *Polyscias fulva* (Hiern) Harms (0.3% in 2015 etc.; Table 2) These trees belong to families of Euphorbiaceae, Stilibaceae, Araliace, etc., respectively (Appendix A).

3.4 | Tree diameter size distribution

The general pattern of diameter distribution of the trees in ECFR was an "inverted J-shaped" type of distribution (Figure S3). As the trees' diameters increased, the number of stems per hectare decreased. For both years, lowest diameter size class of less than 6 cm constituted of the most individuals, and these were the seedlings and saplings. Furthermore, the tree species with the largest diameters (above 66 cm) were few and mostly recorded in 2021. The tree seedlings and saplings (with dbh less than 6 cm) were more in 2021 than 2015 (Figure S3).

3.5 | Shrub species diversity and abundance

A total of 36 shrubs, belonging to 18 families, were recorded (Appendix A). Of these, *Mimulopsis arborescens* C.B.Clarke, *Dracaena laxissima* Engl and *Piper capense* L.f. var. *capense* were the most dominant in descending order (Figure 2). The shrubs stem density increased from 1118 stems/ha in 2015 to 7187 stems/ha in 2021 but the increase was not statistically significant (Table 1, Kruskal–Wallis's chi-squared = 2.1109, df = 1, $p = 0.1463$ at 95% Confidence Interval). The shrubs diversity and species evenness was higher in 2015 than in 2021.

3.6 | Bamboo stems abundance

Bamboo stem density decreased significantly from 11,931 stems/ha in 2015 to 1807 stems/ha in 2021 (Table 1; Kruskal–Wallis's chi-squared = 2.4545, df = 1, $p = 0.0378$ at 95% Confidence Interval; Figure S5). Overall, the most dominant bamboo age class in ECFR were the old stems that constituted 64% of all the bamboo stems (Figure 2). In 2015, the most dominant bamboo age class were the old stems that constituted of about 44% of all bamboo while in 2021 it was the mature stems that dominated and were 55% of all the bamboo stems.

3.7 | Liana species diversity and abundance

A collection of 13 lianas, belonging to 11 families, were recorded in ECFR (Appendix A). Of these, *Triumfetta cordifolia* A.Rich., *Urera hypselodendron* (Hochst. ex A.Rich.) Wedd., and *Sericostachys scandens* Gilg & Lopr., were the most dominant in descending order (Figure 3). The liana species stem density increased from 255 stems/ha in 2015 to 2781 stems/ha in 2021 but this increase was not statistically significant (Table 1, Kruskal–Wallis's chi-squared = 1.7215, df = 1, $p = 0.1895$ at 95% Confidence Interval). The diversity and species evenness of lianas was higher in 2015 than in 2021 (Table 1).

3.8 | Vine species diversity and abundance

Eight vines, belonging to 7 families, were recorded in ECFR (Appendix A). Of these, *Ipomoea involucrata* P.Beauv., *Landolphia glabra* (Pierre ex Stapf) Pichon, *Mikania cordata* (Burm.f.) B.L.Rob and *Smilax aspera* L., were the most dominant in descending order (Figure 3). The vines stem density decreased from 3671 stems/ha in 2015 to 1200 stems/ha in 2021 but this decrease was not statistically significant (Table 1; Kruskal–Wallis's chi-squared = 3.6314, df = 1, $p = 0.0567$ at 95% Confidence Interval). The diversity and species evenness of the vines was higher in 2015 than in 2021 (Table 1).

3.9 | Herb species diversity and abundance

Sixty-one herbs belonging to 32 families were recorded in ECFR (Appendix A). Of these, *Acalypha engleri* Pax, *Alchemilla johnstonii* Oliv and *Droguetia iners* (Forssk.) Schweinf., were the most dominant in descending order (Figure 3). The herbs stem density increased from 32,236 stems/ha in 2015 to 58,529 stems/ha in 2021 but this increase was not statistically significant (Table 1; Kruskal–Wallis's

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chi-squared = 2.4865, df = 1, $p = 0.1148$ at 95% Confidence Interval). The diversity of herbs was lower in 2015 than in 2021 and further, the herb species evenness in 2015 was slightly higher than that of 2021 (Table 1).

3.10 | Human activities and impacts

The types of human activities recorded were fresh human trails, wild climber harvests, tree pole cutting, livestock grazing, beekeeping, bamboo stem harvesting, fire signs and firewood collections. The total number of human activities significantly increased almost fourfold from 22 activities/ha in 2015 to 83 activities/ha in 2021 (Kruskal–Wallis chi-square = 5.625, df = 1, $p = 0.01771$; Table 1; Figure S7). In 2021, the most prevalent human activities in descending order were fresh human trails (25/ha), pole cutting (15/ha), livestock grazing (12/ha), firewood collection (12/ha) and bamboo stems harvesting (9/ha).

(Figure S6). In 2015, the most common human activities were fresh human trails (12/ha), bamboo stems harvesting (6/ha), livestock grazing (2/ha) and firewood collection (1/ha). The NMDS ordination confirms that the human activities in 2015 and 2021 were significantly different (Figure 4). The human activities with the strongest impact on tree species were fuelwood collection, fresh human trails, livestock grazing and pole cutting (Figure 4). These four human activity types had the strongest correlation with tree species composition and basal area and were statistically significant at $p < 0.05$.

4 | DISCUSSION

4.1 | The floristic composition of ECFR

Compared with other tropical forests in the region and elsewhere, ECFR is floristically poor. With a total of 141 plant species belonging to 69 families recorded, the floristic composition in ECFR is probably the lowest in the region. For example, Bwindi Impenetrable National Park was reported to have over 1405 plant species, 393 of which were tree species (Plumptre et al., 2007). Similarly elsewhere, Kakamega forest in Kenya was reported to have 986 plant species, Aberdare National Park in Kenya 778 plant species (Yirga et al., 2019), Virunga National Park in Rwanda 2077 plant species and the Nyungwe National Park in Rwanda 1105 plant species (Plumptre et al., 2007). According to (Yirga et al., 2019), differences in floristic species composition between ECFR and the other tropical forests in the region could be attributed to the dissimilarities in human impacts, rainfall and other biotic and abiotic factors. Furthermore, according to Kengne et al. (2022); Kessler et al. (2005), the presence and dominance of the tree families of Euphorbiaceae, Monimiaceae, Stilibaceae, Rosaceae, Rubiaceae, Sapotaceae, Myrtaceae and Araliaceae in ECFR illustrates the secondary and non-climax character of the tree species in the forest.

4.2 | Floristic density and diversity in ECFR

Determining the plant species densities and diversity is an important component of assessing how dominant certain species are, and thus contributing to the judgement of its abundance compared to other species (Kayombo et al., 2022). This study has shown that the total tree species stem densities, basal areas and diversity in ECFR for the year 2015 and 2021 were significantly different with 2021 having the highest stem densities, basal areas and diversity. The other flora species (shrubs, lianas, vines and herbs) did not show significant differences in diversity and density. The tree species diameter size class general pattern showed the predominance of small-sized individuals (inverted "J"-shape), a characteristic of good reproductive capacity of the trees. The high densities of small sized individuals of the trees is an indication that the trees are responding to forest disturbances (Kengne et al., 2022). This is a characteristic of forest succession by the secondary forest tree species (Jayakumar & Nair, 2013; Kengne et al., 2022). The tree species Shannon diversity index of 2.15 the maximum recorded in ECFR in 2021is low when compared with other tropical forests of Ethiopia (H = 4.02–3.93) by Yirga et al. (2019) and (H = 3.25–2.67) by Shiferaw et al. (2019) and Ghana (H = 3.83–3.2) by Bentsi-Enchill et al. (2022). Further confirming that ECFR floristic composition is poor (Plumptre et al., 2007). Poor or highly degraded habitats possess very little or no diverse flora and fauna (Bentsi-Enchill et al., 2022).

4.3 | Tree species takeover of the bamboo forest in ECFR

This study has shown that the bamboo stem density in ECFR has significantly reduced since 2015. The fact that the bamboo stem density is reducing at the expense of the trees density is consistent with what other studies have reported that the bamboo forest is slowly being replaced by secondary forest trees in ECFR (Banana & Tweheyo, 2001; Bitariho & McNeilage, 2008; Sheil et al., 2012). Floral components of species diversity respond differently to various environmental conditions and most especially habitat changes (Bruna & Ribeiro, 2005). As reported by Banana and Tweheyo (2001); Bitariho and McNeilage (2008), the climate change impacts exacerbated by the overharvesting of the bamboo stems by the local people, has stimulated the invasion and taking over of the bamboo forest by the secondary forest tree species of *M. capensis*, *N. macrocalyx*, *N. congesta*, etc. This is the reason why those tree species belonging to families of Euphorbiaceae, Monimiaceae, Rubiaceae, etc. (Kengne et al., 2022; Kessler et al., 2005) are the most dominant in ECFR.

4.4 | Anthropogenic activities and impacts in ECFR

Anthropogenic disturbances in forest ecosystems are important drivers of ecosystem structure, function and biodiversity (Martínez-Ramos et al., 2016; Pao, 2017; Shiferaw et al., 2019).

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These disturbances can cause abrupt changes in understory light and resource availability and can have a lasting legacy on long-term forest dynamics, both of which also influence understory herb communities too (Kanieski et al., 2018; Kutnar & Kermavnar., 2019). This study has shown a significant increase in human activities in ECFR after 2015. ECFR is a small forest covering an area of only 34 km^2 and is an "island" surrounded by a high-human population density of about 500 people per km^2 that are very poor and dependent on the forest (Bitariho & McNeilage, 2008). As such, the use and demand for forest resources by the local people continually puts immense pressure on the forest. Although this study did not conclusively investigate the causal relationships between human activities and floristic composition, anecdotal evidence and other studies, e.g., Banana and Tweheyo (2001); Bitariho and McNeilage (2008); Plumptre et al. (2007) suggest that human activities within ECFR have highly degraded the forest. The relative obvious and rapid change in vegetation types can be used as management indicators of habitat change by anthropogenic perturbations in ECFR. Indeed, the relative dominance of the secondary forest tree species in ECFR could be an indication of the impacts of past and present anthropogenic disturbances (Kengne et al., 2022; Kessler et al., 2005). This has further been shown by the NMDS ordination analysis that has demonstrated that the tree species composition in ECFR were mainly influenced by fuelwood collection, fresh human trails, livestock grazing and pole cutting.

5 | CONCLUSION

Our study has shown that ECFR is floristically poorer than most other tropical forests in the region and elsewhere. Furthermore, of all the flora types of ECFR, it is only the tree species and the bamboo that have experienced significant changes since 2015. The tree species such as *M. capensis*, *N. macrocalyax* and *N. congesta* have increased in stem densities and size at the expense of the bamboo. The anthropogenic activities within the ECFR have more than tripled since 2015, and these may have affected the vegetation composition and diversity in ECFR. It is, therefore, plausible to conclude that the anthropogenic activities in ECFR may have had an impact on the vegetation types of ECFR. The anthropogenic disturbances seem to have favoured the seconday forest tree species takeover of the bamboo forest. More studies are needed to investigate the linkage between the anthropogenic activities with the threats to biodiversity in ECFR. We recommend government interventions of boosting livelihood income of local people around ECFR to decrease their dependence on ECFR. Furthermore, we recommend increased and facilitated law enforcement efforts (financial and equipment) in ECFR to deter/reduce the anthropogenic activities in ECFR.

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CONFLICT OF INTEREST STATEMENT

The authors hereby declare that they do not have any conflict of interest in this study whatsoever.

DATA AVAILABILITY STATEMENT

The data that support findings of this study are available and can be accessed from the corresponding author after reasonable requests are made.

ETHICS STATEMENT

Ethical clearance and research approval was granted by the Uganda government. The Institute of Tropical Forest Conservation and Nature Uganda (authors' affiliate institutions) have a longstanding Memorandum of Understanding (MoU) with the Uganda National Forest Authority to undertake research in the Echuya Central Forest Reserve and other forests in Southwestern Uganda.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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APPENDIX A

The Floral species of echuya central forest reserve recorded in 2015 and 2021.

No.	Species	Life form	Family
1	*Arundinaria alpina* (*K. Schum*)	Bamboo	Poaceae
2	*Acalypha engleri* Pax	Herb	Euphorbiaceace
3	*Acalypha ornata* Hochst. ex A.Ric	Herb	Euphorbiaceace
4	*Achyranthes aspera Linn.*	Herb	Amaranthaceae
5	*Afroligusticum aculeolatum* (Engl.) P.J.D.Winter	Herb	Apiaceae
6	*Afroligusticum runssoricum* (Engl.) P.J.D.Winter	Herb	Apiaceae
7	*Argyrolobium schimperianum* Hochst.	Herb	Fabaceae
8	*Ajuga remota* Benth	Herb	Lamiaceae
9	*Alchemilla johnstonii* Oliv.	Herb	Rosaceae
10	*Asplenium aethiopicum* (Burm.f.) Bech.	Herb	Aspleniaceae
11	*Asplenium elliottii* C.H.Wright	Herb	Aspleniaceae
12	*Basella alba* L.	Herb	Basellaceae
13	*Begonia meyeri-johannis* Engl.	Herb	Begoniaceae
14	*Carduus nyassanus* R.E.Fr.	Herb	Asteraceae
15	*Crassocephalum montuosum* (S.Moore) Milne-Redh.	Herb	Asteraceae
16	*Crassocephalum vitellinum* (Benth.) S.Moore	Herb	Asteraceae
17	*Cymbopogon caesius subsp. giganteus* (Chiov.) Sales	Herb	Gramineae
18	*Cynoglossum amplifolium* Hochst. ex A.DC.	Herb	Boraginaceae
19	*Desmodium repandum* (Vahl) DC	Herb	Leguminosae
20	*Dicliptera laxata* C.B.Clarke	Herb	Acanthaceae
21	*Droguetia iners* (Forssk.) Schweinf.	Herb	Urticaceae
22	*Drymaria cordata (L)* Willd.ex Roem. & Schult	Herb	Caryophyllaceae
23	*Epilobium stereophyllum* Fresen.	Herb	Onagraceae
24	*Eriocaulon schimperi* Körn. ex Ruhland	Herb	Eriocaulaceae
25	*Galium ruwenzoriense* (Cortesi) Chiov.	Herb	Rubiaceae
26	*Galium* L.	Herb	Rubiaceae
27	*Geranium aculeolatum* Oliv.	Herb	Geraniaceae
28	*Geranium arabicum* Forssk.	Herb	Geraniaceae
29	*Gloriosa superba* L.	Herb	Colchicaceae
30	*Gynura scandens* O.Hoffm.	Herb	Asteraceae
31	*Helichrysum argyranthum* O.Hoffm.	Herb	Asteraceae
32	*Impatiens* Riv. ex L.	Herb	Balsaminaceae
33	*Justicia striata* (Klotzsch) Bullock	Herb	Acanthaceae
34	*Kniphofia thomsonii* Baker	Herb	Asphodelaceae
35	*Laportea aestuans* (L.) Chew	Herb	Urticaceae
36	*Laportea ovalifolia* (Schumach. & Thonn.) Chew	Herb	Urticaceae
37	*Lobelia wollastonii* Baker f.	Herb	Campanulaceae
38	*Momordica foetida* Schumach.	Herb	Cucurbitaceae
39	*Oplismenus hirtellus* (L.) P.Beauv.	Herb	Poaceae
40	*Orthosiphon thymiflorus* (Roth) Sleesen	Herb	Asteraceae
41	*Panicum adenophorum* K.Schum.	Herb	Poaceae
42	*Panicum eickii* Mez	Herb	Poaceae
43	*Pennisetum purpureum* Schumach	Herb	Poaceae

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APPENDIX A (Continued)

No.	Species	Life form	Family
44	*Cenchrus caudatus* (Schrad.) Kuntze	Herb	Poaceae
45	*Phyllanthus ovalifolius* Forssk.	Herb	Phyllanthaceae
46	*Pilea holstii* Engl.	Herb	Urticaceae
47	*Pilea rivularis* Wedd.	Herb	Urticaceae
48	*Plantago palmata* Hook.f.	Herb	Plantaginaceae
49	*Plectranthus strangulatus* A.J.Paton	Herb	Lamiaceae
50	*Plectranthus elegans* Britten	Herb	Lamiaceae
51	*Plectranthus bracteolatus* A.J.Paton	Herb	Lamiaceae
52	*Pteridium aquilinum* (L.) Kuhn	Herb	Dennstaediaceae
53	*Pteris dentata* Forssk	Herb	Pteridaceae
54	*Rubia cordifolia* L.	Herb	Rubiaceae
55	*Rumex bequaertii* De Wild.	Herb	Polgyonaceae
56	*Senecio subsessilis* Oliv. & Hiern	Herb	Asteraceae
57	*Senecio syringifolius* O.Hoffm.	Herb	Asteraceae
58	*Senecio maranguensis* O.Hoffm.	Herb	Asteraceae
59	*Solanum nigrum f. angulosum* Döll	Herb	Solanaceae
60	*Solenostemon autrani* (Briq.) J. K. Morton	Herb	Lamiaceae
61	*Thalictrum rhynchocarpum* Quart.-Dill. & A.Rich.	Herb	Ranunculaceae
62	*Urtica massaica* Mildbr.	Herb	Urticaceae
	Total Herb species	**61**	**32**
63	*Adenia cissampeloides* (Planch. ex Hook.) Harms	Liana	Passifloraceae
64	*Clematis hirsuta* Perr. & Guill.	Liana	Ranunculaceae
65	*Clutia abyssinica* Jaub. & Spach	Liana	Peraceae
66	*Mimulopsis solmsii* Schweinf.	Liana	Acanthaceae
67	*Phytolacca dodecandra* L'Hér.	Liana	Phytolaccaceae
68	*Pristimera graciliflora* subsp. *newalensis* (Blakelock) N.Hallé	Liana	Celastraceae
69	*Rubus apetalus* Poir.	Liana	Rosaceae
70	*Rubus pinnatus* Willd.	Liana	Rosaceae
71	*Rubus steudneri* Schweinf.	Liana	Rosaceae
72	*Sericostachys scandens* Gilg & Lopr.	Liana	Amaranthaceae
73	*Toddalia asiatica* (L.) Lam	Liana	Rutaceae
74	*Triumfetta cordifolia* A.Rich.	Liana	Malvaceae
75	*Urera hypselodendron* (Hochst. ex A.Rich.) Wedd.	Liana	Urticaceae
	Total Liana Species	**13**	**11**
76	*Allophylus africanus* P.Beauv.	Shrub	Sapindaceae
77	*Brillantaisia cicatricosa* Lindau	Shrub	Acanthaceae
78	*Clerodendrum johnstonii* Oliv.	Shrub	Lamiaceae
79	*Dalbergia lactea* Vatke	Shrub	Fabaceae
80	*Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.)Bercht. & J.Presl	Shrub	Solanaceae
81	*Discopodium penninervium* Hochst.	Shrub	Solanaceae
82	*Dracaena afromontana* Mildbr.	Shrub	Asparagaceae
83	*Dracaena laxissima* Engl	Shrub	Asparagaceae
84	*Embelia schimperi* Vatke	Shrub	Primulaceae
85	*Erica benguelensis* (Welw. ex Engl.) E.G.H.Oliv.	Shrub	Ericaceae

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APPENDIX A (Continued)

No.	Species	Life form	Family
86	*Erythrococca trichogyne* (Müll.Arg.) Prain	Shrub	Euphorbiaceae
87	*Galiniera saxifraga* (Hochst.) Bridson	Shrub	Rubiaceae
88	*Hibiscus berberidifolius* A.Rich.	Shrub	Malvaceae
89	*Keetia gueinzii* (Sond.) Bridson	Shrub	Rubiaceae
90	*Lasianthus kilimandscharicus* K.Schum.	Shrub	Rubiaceae
91	*Mimulopsis arborescens* C.B.Clarke	Shrub	Acanthaceae
92	*Pavetta bagshawei* S.Moore	Shrub	Rubiaceae
93	*Coleus elliotii* (S.Moore) A.J.Paton	Shrub	Lamiaceae
94	*Peddiea fischeri* Engl.	Shrub	Thymelaeaceae
95	*Pentas bussei* K.Krause	Shrub	Rubiaceae
96	*Pentas schimperiana* subsp. *occidentalis* (Hook f.)	Shrub	Rubiaceae
97	*Piper capense* L.f. var. *capense*	Shrub	Piperaceae
98	*Plectranthus luteus* Gürke	Shrub	Labiatae
99	*Rhamnus prinoides* L'Hér.	Shrub	Rhamnaceae
100	*Rumex usambarensis* (Dammer)Dammer	Shrub	Polygonaceae
101	*Rutidea orientalis* Bridson	Shrub	Rubiaceae
102	*Rutidea smithii* Hiern	Shrub	Rubiaceae
103	*Rytigynia beniensis* (De Wild.) Robyns	Shrub	Rubiaceae
104	*Rytigynia bridsoniae* Verdc.	Shrub	Rubiaceae
105	*Rytigynia bugoyensis* (K.Krause) Verdc.	Shrub	Rubiaceae
106	*Rytigynia kigeziensis* Verdc.	Shrub	Rubiaceae
107	*Vernonia auriculifera* Hiern	Shrub	Compositae
108	*Vernonia kirungae* R.E.Fr.	Shrub	Compositae
109	*Vernonia lasiopus* O.Hoffm.	Shrub	Compositae
110	*Hibiscus fuscus* Garcke	Shrub	Malvaceae
111	*Lobelia mildbraedii* Engl.	Shrub	Campaunulaceae
	Total Shrub Species	**36**	**18**
112	*Alangium chinense* (Lour.) Harms	Tree	Alangiaceae
113	*Allophylus abyssinicus* (Hochst.) Radlk.	Tree	Sapindaceae
114	*Allophylus ferrugineus* Taub.	Tree	Sapindaceae
115	*Bersama abyssinica* Fresen.	Tree	Melianthaceae
116	*Chrysophyllum albidum* G Don.	Tree	Sapotaceae
117	*Dombeya torrida* (J.F.Gmel.) Bamps	Tree	Sterculiaceae
118	*Gymnosporia acuminata* (L.fil.) Szyszyl.	Tree	Celastraceae
119	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Tree	Rosaceae
120	*Hypericum revolutum* Vahl	Tree	Hypericaceae
121	*Lepidotrichilia volkensii* (Gürke) J.-F.Leroy	Tree	Meliaceae
122	*Macaranga capensis* var. *kilimandscharica* (Pax) Friis & M.G.Gilbert	Tree	Euphorbiaceae
123	*Maesa lanceolata* Forssk	Tree	Myrsinaceae
124	*Morella salicifolia* (Hochst. ex A.Rich.) Verdc. & Polhill	Tree	Myricaeae
125	*Mystroxylon aethiopicum* (Thunb.) Loes.	Tree	Celastraceae
126	*Neoboutonia macrocalyx* Pax	Tree	Euphorbiaceae
127	*Nuxia congesta* R.Br. ex Fresen.	Tree	Stilibaceae
128	*Pittosporum viridiflorum* Sims	Tree	Pittosporaceae
129	*Podocarpus latifolius* (Thunb.) R.Br. ex Mirb.	Tree	Podocarpaceae

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APPENDIX A (Continued)

No.	Species	Life form	Family
130	*Polyscias fulva* (Hiern) Harms	Tree	Araliaceae
131	*Psychotria mahonii* C.H.Wright	Tree	Rubiaceae
132	*Syzygium guineense* (Willd.) DC. *guineense* (Wild.) DC	Tree	Myrtaceae
133	*Xymalos monospora* (Harv.) Baill.	Tree	Monimiaceae
	Total Tree Species	**22**	**19**
134	*Cardiospermum grandiflorum* Sw.	Vine	Sapindaceae
135	*Ipomoea involucrata* P.Beauv.	Vine	Convolvulaceae
136	*Landolphia glabra* (Pierre ex Stapf) Pichon	Vine	Apocynaceae
137	*Mikania cordata* (Burm.f.) B.L.Rob.	Vine	Asteraceae
138	*Mikaniopsis bambuseti* (R.E.Fr.) C.Jeffrey	Vine	Asteraceae
139	*Momordica pterocarpa* Hochst. ex A.Rich	Vine	Cucurbitaceae
140	*Smilax aspera* L.	Vine	Smilacaceae
141	*Stephania abyssinica* (Quart.-Dill. & A.Rich.) Walp.	Vine	Menispermaceae
	Total Vine Species	**8**	**7**

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