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LONG DATABASE REPORT

ECOINFORMATICS

A new Vegetation-Plot Database for the Coastal Forests of Kenya

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Abstract

Biodiversity data based on standardised sampling designs are key to ecosystem conservation. Data of this sort have been lacking for the Kenyan coastal forests despite being biodiversity hotspots. Here, we introduce the Kenyan Coastal Forests Vegetation-Plot Database (GIVD ID: AF-KE-001), consisting of data from 158 plots, subdivided into 3,160 subplots, across 25 forests. All plots include data on tree identity, diameter and height. Abundance of shrubs is presented for 316 subplots. We recorded 600 taxa belonging to 80 families, 549 of which identified to species and 51 to genus level. Species richness per forest site varied between 43 and 195 species; mean diameter between 13.0 ± 9.8 and 30.7 ± 20.7 cm; and mean tree height between 5.49 ± 3.99 and 12.29 ± 10.61 m. This is the first plot-level database of plant communities across Kenyan coastal forests. It will be highly valuable for analysing biodiversity patterns and assessing future changes in this ecosystem.

Taxonomic reference: African Plant Database (African Plant Database version 3.4.0).

Abbreviations: DBH = diameter at breast height; GIVD = Global Index of Vegetation-Plot Databases; KECF-VPD = Kenyan Coastal Forests Vegetation Plot Database.

Keywords

Coastal forests, conservation, Global Index of Vegetation-Plot Databases, biodiversity hotspots, Kaya, Kenya, plant species diversity, sacred forests, vegetation plot

GIVD Fact Sheet: Kenya Coastal Forests Vegetation-Plot Database (KECF-VPD)

GIVD Database ID: AF-KE-001			**Last update:** 2020-03-20
Kenya Coastal Forests Vegetation Plot Database		**Web address:** http://www.givd.info/ID/AF-KE-001	
Database manager(s): Maria Fungomeli (maria.fungomeli2@unibo.it); Alessandro Chiarucci (alessandro.chiarucci@unibo.it)			
Owner: Maria Fungomeli, PhD Student-University of Bologna, Dept of Biology, Geology & Envtal Sci. Senior Curator & Research Scientist, Coastal Forests Conservation Unit, Center for Biodiversity National Museums of Kenya e-mail: mfungomeli@museums.or.ke; maria.fungomeli2@unibo.it; fungomaria@yahoo.com			
Scope: A plant species diversity survey of the Coastal Forests of Kenya. The survey covered 25 forests with details of trees and shrubs species, DBH & Height, georeference of sites & transects. Plants were identified to species level where possible otherwise genus level used.			
Availability: according to a specific agreement		**Online upload:** no	**Online search:** no
Database format(s): Excel		**Export format(s):** Excel, Open Document, PDF, CSV file	
Plot type(s): nested plots		**Plot-size range:** 50 to 1000	
Non-overlapping plots: 158	**Estimate of existing plots:** 158	**Completeness:** 100%	**Status:** finished
Total no. of plot observations: 158	**Number of sources (biblioreferences, data collectors):** 0		**Valid taxa:** 600
Countries (%): KE: 100%			
Formations: Forest: 100% = Terrestrial: 100%			
Guilds: [NA]			
Environmental data (%): altitude: 100%			
Performance measure(s): presence/absence only: 100%; number of individuals: 100%; measurements like diameter or height of trees: 100%			
Geographic localization: GPS coordinates (precision 25 m or less): 100%			
Sampling periods: 2010-2019: 100%			
Information as of 2020-03-20 further details and future updates available from http://www.givd.info/ID/AF-KE-001			

Introduction

Eastern African coastal forests are tropical forests known for their rich biodiversity and high levels of endemism, including a concentration of rare and threatened taxa and high diversity of endemic plant and animal species (Wass 1995; Burgess et al. 1998; Lovett 1998; Burgess and Clarke 2000; Myers et al. 2000; Luke 2005; Azeria et al. 2007). According to Burgess and Clarke (2000), this vegetation type hosts more than 4,500 plant species and 1,050 plant genera, the majority of which are woody. This rich biodiversity has been largely attributed to favourable climatic conditions and a wide range of ecological niches (Moomaw 1960; Lovett 1998; Burgess and Clarke 2000; Montagnini and Jordan 2010). Overall, these forests extend along the coastal edge of Eastern Africa along the Indian Ocean stretching from Somalia in the north, through coastal Kenya and Tanzania, and all the way to Mozambique in the south. They have been defined as the "Swahilian centre of endemism", which constitutes a hotspot of endemism in Africa (Burgess et al. 1998; Luke 2005).

For millennia, Eastern African coastal forests have supported livelihoods both locally and regionally and played a major role as high conservation value ecosystems (Wass 1995). However, they are increasingly facing a number of threats which include a growing population and increased anthropogenic activities such as illegal logging, poaching, charcoal burning and agriculture expansion, all activities leading to increased deforestation (Burgess et al. 1998; Burgess and Clarke 2000; Habel et al. 2017). According to Wass (1995) and Burgess et al. (1998), these threats have had severe impacts and resulted in the heavy fragmentation of once connected forests. Some 10% of the original forest cover is estimated to remain, of which only 17% are under some kind of protection (Wass 1995; Burgess and Clarke 2000). Conserving and sustainably managing the remaining forests of the region requires a developed and enhanced biodiversity monitoring system, which is currently lacking. Developing such a system requires baseline biodiversity data, which are currently scant, limited and outdated.

The Kenyan coastal forests fall within the Eastern African coastal forests. Despite their global significance as biodiversity hotspots (Burgess et al. 1998; Myers et al. 2000; Hobohm et al. 2019), systematic biodiversity data survey based on a standard design are still lacking. The first-ever vegetation survey of the coastal forests of Kenya was carried out in 1987 without using a vegetation plot design (Robertson and Luke 1993), with the aim to create a list of species found in these forests (Robertson and Luke 1993; Luke 2005). A standardised dataset based on vegetation plots and suitable for analysing spatial and temporal patterns across the whole area does still not exist. Filling this knowledge gap is even more urgent given the continuing deforestation and the uncertainty of future climate change projections. There is need to undertake ecological studies that can provide baseline data required for sound ecological monitoring and evaluation.

This paper provides a basic description of a new vegetation-plot database, developed as part of a collaboration between the University of Bologna and the National Museums of Kenya. The database contains data of 25 different forest patches and was developed with the goal to produce a solid sample-based (Chiarucci 2007) overview of the plant communities in the Kenyan coastal forests. The resulting vegetation-plot database represents the first standardised plant data set for these forests and a fundamental tool for future assessments and monitoring of a key biodiversity hotspot.

Study Area: the coastal forests of Kenya in the context of Eastern African forests

The coastal forests of Kenya are part of the Eastern African coastal forests ecoregion and are isolated patches of evergreen to semi-evergreen closed canopy forests. They present unique remnants of indigenous ecosystems and are part of the North Zanzibar-Inhambane Regional Mosaic, which extends from southern Somalia through coastal Kenya to southern Tanzania, including the islands of Zanzibar and Pemba (Burgess et al. 1998, Burgess and Clarke 2000; Githitho 2004; Peltorinne 2004; Luke 2005), and part of the biodiversity hotspot known as the Eastern Arc and Coastal Forests of Kenya and Tanzania (Myers et. al. 2000). They stretch from the north to south along the Kenyan coast, and are mostly found on ancient coral reef bed rocks formed as a result of sea level drops. Therefore, they span over a variety of altitudinal gradients and climatic zones.

The climatic range of the Kenyan coastal forests is tropical with coastal high humidity (Burgess and Clarke 2000). The annual rainfall follows distinctive rainy seasons and generally increases towards the southern coast and at higher altitudes. The rainfall pattern differs from the north to the south. In the northern region, there are two rainy seasons made of long rains (April to June) and short rains (November to December), while in the south, there is only one long rain season between April and June. However, both south and north regions have an annual rainfall variability where the seasons may vary from year to year. Overall, the mean annual rainfall ranges from 900 mm to 1200 mm (Glover et al. 1954; Moomaw 1960; Burgess et al. 1998; Burgess and Clarke 2000). The mean temperature ranges between 30°C during the dry season (December-March) to 25°C during the long rain season (April-September), with relatively cooler temperatures in the southern coast.

It is estimated that approximately 3,170 km^2 of Eastern African coastal forests remains in Somalia, Kenya, Tanzania, Mozambique, Zimbabwe and Malawi. Approximately 20% of these forests are found in Kenya (Burgess et al. 1998; Burgess and Clarke 2000; Azeria et al. 2007). The number of Kenyan coastal forests patches was estimated to be 107 patches in early 1990s (Robertson and Luke 1993; Wass 1995; Burgess et al. 1998; Burgess and Clarke 2000; Githitho 2004; Luke 2005; Azeria et al. 2007).

The size and protection status of the Kenyan coastal forests is highly variable. The two largest remaining forests are Arabuko Sokoke (42,000 ha) and Shimba Hills (25,300 ha), which are government protected forest reserves (Table 1). Other government protected forest reserves include Marenje (1,480 ha), Gogoni (832 ha), Buda (670 ha), Dzombo (650 ha) and Mrima (377 ha). The other forest remnants spread over small patches (10 to 75 ha)

Table 1. Overview of the forest sites included in the Kenyan coastal forest vegetation-plot database, with an indication of their protection status, geographical coordinates, area, number of plots and recorded total species richness per forest site.

Forest ID	Forest name	Protection status	Latitude decimal degree	Longitude decimal degree	Area (ha)	Number of plots	Species richness
Arabuko	Arabuko Sokoke forest	Forest reserve	-3.32138	39.92917	42,000	26	178
Bomu	Kaya Bomu	Sacred forest	-3.93354	39.59635	409	8	154
Buda	Buda forest	Forest reserve	-4.45812	39.39683	670	6	121
Chivara	Kaya Chivara	Sacred forest	-3.69452	39.69132	150	8	140
Chonyi	Kaya Chonyi	Sacred forest	-4.06953	39.53038	200	4	62
Diani	Kaya Diani	Sacred forest	-4.27523	39.58520	20	3	66
Dzombo	Dzombo forest	Forest reserve	-4.42945	39.21545	650	6	90
Fungo	Kaya Fungo	Sacred forest	-3.80068	39.51047	204	4	60
Gandini	Gandini forest	Sacred forest	-4.03443	39.50988	150	5	80
Gogoni	Gogoni forest	Forest reserve	-4.41013	39.47628	832	6	123
Jibana	Kaya Jibana	Sacred forest	-3.84048	39.67382	140	8	195
Kambe	Kaya Kambe	Sacred forest	-3.86766	39.65363	75	6	109
Kauma	Kaya Kauma	Sacred forest	-3.62968	39.73778	75	7	77
Kinondo	Kaya Kinondo	Sacred forest	-4.39427	39.54703	30	3	56
Marenje	Marenje forest	Forest reserve	-4.48458	39.25906	1,480	6	76
Mrima	Mrima forest	Forest reserve	-4.48573	39.26883	377	6	101
Mtswakara	Kaya Mtswakara	Sacred forest	-4.00017	39.51997	248	4	64
Muhaka	Kaya Muhaka	Sacred forest	-4.32568	39.52328	150	5	90
Muvya	Kaya Mudzimuvya	Sacred forest	-3.94175	39.58190	171	4	85
Mwiru	Kaya Mudzimwiru	Sacred forest	-3.95913	39.57372	147	4	70
Ribe	Kaya Ribe	Sacred forest	-3.89922	39.63363	36	5	95
Shimba	Shimba Hills forest	Forest reserve	-4.26940	39.37208	25,300	12	190
Teleza	Kaya Teleza	Sacred forest	-4.14147	39.50342	67	6	91
Tiwi	Kaya Tiwi	Sacred forest	-4.25704	39.59817	10	3	53
Waa	Kaya waa	Sacred forest	-4.19970	39.61565	30	3	43

many of which are considered sacred forests and are managed traditionally and culturally by the local communities (Table 1). These forest patches are locally referred to as *'Kaya'* (Robertson and Luke 1993; Wass 1995; Burgess and Clarke 2000; Githitho 2004; Luke 2005; Metcalfe et al. 2010; Githitho 2016; Luke and Githitho 2016).

Data collection

Sampling was based on a nested plot design consisting of 158 rectangular plots located in 25 forests sites of the Kenyan coastal forests spanning along the coastline, from north to south (Figure 1). The sampling was carried out from November 2018 to June 2019. The forests are a mixture of evergreen to semi-deciduous forests. During field work, we experienced a mix of wet and semi-dry season while in the field with a lot of light rains. Hence performing part of the fieldwork during the dry season did not affect plants identification, as most plants remained leafy and some flowering while the few deciduous were commonly locally known by botanist and could be easily identified.

To standardise sampling intensity, the number of plots per forest site was approximately proportional to the forest site area, although with some variation due to site accessibility and fragmentation. The location of the plots within each forest site was randomised with minor adaptations due to accessibility. A minimum distance of 200 m between plots per site was maintained to maximise spatial variation. The plots were laid with a north-south orientation, had a standard size of 10 m × 100 m and were further sub-divided into twenty 10 m × 5 m subplots for a total of 3,160 subplots across the entire study system. We sampled and identified at the species level all woody plant individuals with diameter at breast height (DBH) ≥ 5 cm (mostly trees) rooted within each subplot. For each tree, besides DBH, we also measured the height with a hand held clinometer (Suunto PM-5), or a calibrated measuring pole (50 m) in areas with dense forests where clinometer was difficult to use. Woody plant individuals with DBH < 5 cm, mostly shrubs, were sampled and identified in two of the twenty subplots within a plot, where one was randomly selected in the northern half (subplots 1–10) and the second in the southern half (subplots 11–20) of the plot. The abundance of shrub species was assessed by counting the number of individual shoots rooted within the subplot.

Plants were identified on-site to the species or at least genus level by local botanists and with the use of botanical manuals using standard references for the area (Noad and Birnie 1990; Beentje 1994; Luke 2005). When on-site identification was not possible, voucher specimens were collected for subsequent identification on the lab with the help of herbarium specimens. Finally, Global Positioning Systems (GPS) devices were used for recording the geographical coordinates and altitude of forest sites and plots (start and end points), and shrub subplots.

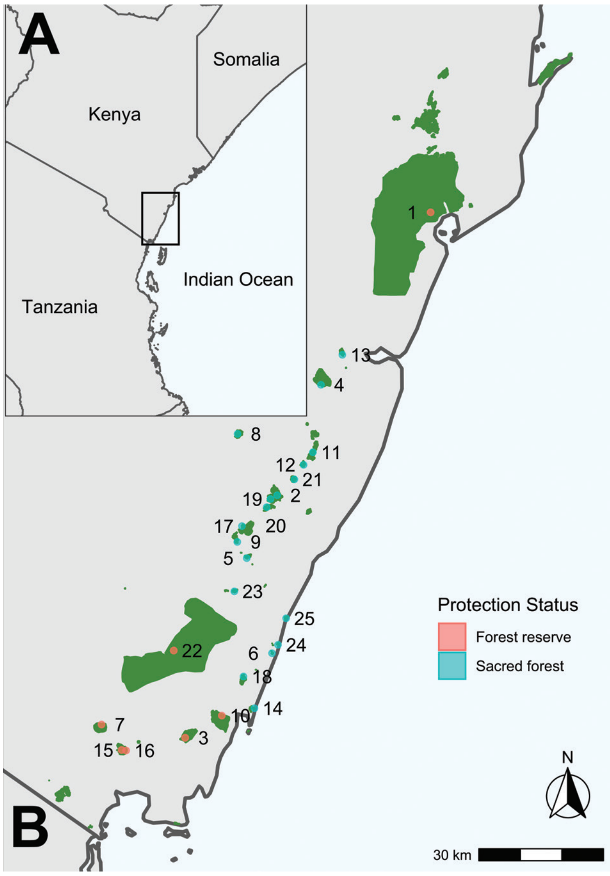

Figure 1. A Map of Eastern Africa area highlighting the coastal area of Kenya. **B** Coastal forests of Kenya spanning from North to South (all forests identified by green colour with and without numbers), the numbered are the sampled sites with their protection status. 1 = Arabuko, 2 = Bomu, 3 = Buda, 4 = Chivara, 5 = Chonyi, 6 = Diani, 7 = Dzombo, 8 = Fungo, 9 = Gandini, 10 = Gogoni, 11 = Jibana, 12 = Kambe, 13 = Kauma, 14 = Kinondo, 15 = Marenje, 16 = Mrima, 17 = Mtswaka, 18 = Muhaka, 19 = Muvya, 20 = Mwiru, 21 = Ribe, 22 = Shimba, 23 = Teleza, 24 = Tiwi, 25 = Waa.

Database content

The Kenyan coastal forests vegetation-plot database (KE-CF-VPD) is registered at the Global Index of Vegetation Database (http://www.givd.info/ID/AF-KE-001). It consists of vegetation data collected in 158 nested plots across 25 forests sites (Table 1). The total subplots were 3,160. The sampled forest sites are characterised by different area sizes and protection status, with seven government state forest reserves (377 to 42,000 ha) and 18 sacred sites (10 to 409 ha). Overall, the database includes 40,913 occurrence records relative to a total of 600 distinct taxa belonging to 80 families. 549 species were identified at the specific level and 51 at the genus level belonging to 43 genera. For taxonomy consistency and to avoid misspelt names, plant species names were standardised using the TAXONSTAND package in R statistical software (Cayuela et al. 2017).

In total, 19 families had more than 10 species (Table 2) with *Rubiaceae* presenting the highest number of spe-

Table 2. List of the most diverse families in the Kenyan coastal forests vegetation-plot database, defined as those having at least 10 different recorded species.

Family	Number of species
Rubiaceae	63
Leguminosae	61
Malvaceae	34
Euphorbiaceae	30
Annonaceae	24
Moraceae	23
Sapindaceae	22
Apocynaceae	20
Sapotaceae	18
Rutaceae	17
Celastraceae	16
Combretaceae	16
Lamiaceae	16
Capparaceae	15
Ebenaceae	14
Acanthaceae	12
Phyllanthaceae	12
Salicaceae	11
Anacardiaceae	10

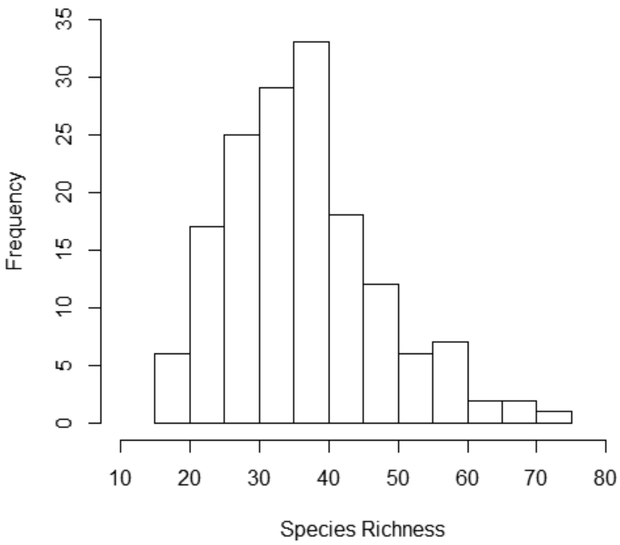

Figure 2. Distribution of species richness per plot in the Kenyan coastal forests vegetation-plot database (n = 158 plots).

cies (63), followed by *Leguminosae* (61), *Malvaceae* (34) and *Euphorbiaceae* (30). Species richness per site varied between 43 species at Waa sacred forest to 195 species at Jibana sacred forest (Table 1). The Shimba Hills and Arabuko forest reserves, the largest forest sites, were the richest after Jibana. The number of species increased relative to the area, as expected given the species-area relationship perspective. Some small forest areas, like Jibana, also exhibited high species richness, likely because other factors different from area may have a strong impact in driving local species richness.

The frequency distribution of species richness per plot showed a slightly right-skewed distribution (Figure 2), with the highest number of plots harbouring between 35–40 species. The most frequent trees in plots across all sites were *Uvaria acuminata* and *Haplocoelum inoploeum* (Table 3). *Hymenaea verrucosa* exhibited the highest mean DBH and height. The shrubs *Monanthotaxis fornicata* and *Synaptolepis kirkii* were among the 20 most frequent woody species in plots (Table 3).

Basic forest structure varied across sites (Table 4). The highest mean DBH was recorded at Mtswaka sacred forest while the lowest at Chivara sacred forest. Kambe sacred forest exhibited the highest mean height, while Diani sacred forest the lowest. There was a high variation in tree heights from the small to tallest within sites, creating mean heights that would depict a bush rather than a forest, but this is not the case given the large mean DBH recorded. The largest number of tree individuals was sampled at Arabuko and Shimba forest reserves, the largest ones, and where more plots were sampled, while the lowest at Muvya sacred forest.

Conclusion

The KECF-VPD database represents the first vegetation dataset collected according to a standardised plot-based design across Kenyan coastal forests. This database represents a snapshot of the vegetation in a relevant fraction of the existing forest patches in the region. As such, the database provides the best available picture of the current patterns of woody plant biodiversity of these forests. Since the sampling design was based on different scale levels (forest sites, plots and subplots), the database also offers a unique opportunity for exploring the patterns and determinants of plant diversity in the Kenyan Coastal forests across spatial scales. These data will provide a tool and baseline for assessing future changes in the study system.

Future perspectives

The current KECF-VPD database covers 25 Kenyan coastal forests. There is potential to extend the survey to the remaining coastal forests not covered by this research. The database is presently being explored for analysing species diversity data, in terms of species-area relationships, beta diversity and species composition. A successive phase will also be to develop a biodiversity monitoring platform for these forests. Such a platform could be shared with the institutions, organisations and communities working and living around these forests to promote their conservation and sustainable management. Furthermore, integrating socio-economic aspects into the research would be essential to capture local level forest use by adjacent communities and their attitude towards forest management and conservation.

Data availability

The database is presently stored at the University of Bologna. Its availability is currently restricted to the PhD pro-

Table 3. List of the 20 most frequent species per plot (n = 158 plots), including family, habit, number of plots in which they have been recorded, and DBH and height (mean ± standard deviation) for species with DBH ≥ 5cm.

Species	Family	Habit	Number of plots	DBH (mean ± sd) (cm)	Height (mean ± sd) (m)
Uvaria acuminata	*Annonaceae*	tree	95	7.4 ± 2.13	7.54 ± 7.08
Haplocoelum inoploeum	*Sapindaceae*	tree	94	11.9 ± 7.46	5.51 ± 2.71
Polysphaeria parvifolia	*Rubiaceae*	tree	69	5.6 ± 0.57	2.75 ± 0.67
Salacia elegans	*Celastraceae*	liana	69	7.3 ± 1.87	7.14 ± 2.78
Combretum schumannii	*Combretaceae*	tree	66	18.5 ± 16.97	9.24 ± 5.74
Hymenaea verrucosa	*Leguminosae*	tree	66	33.9 ± 21.36	15.73 ± 8.50
Landolphia kirkii	*Apocynaceae*	liana	66	9.5 ± 3.79	8.21 ± 3.33
Monanthotaxis fornicata	*Annonaceae*	shrub	66	–	–
Synaptolepis kirkii	*Thymelaeaceae*	shrub	64	–	–
Cassipourea euryoides	*Rhizophoraceae*	tree	63	14.7 ± 8.64	8.21 ± 4.02
Asteranthe asterias	*Annonaceae*	tree	57	6.2 ± 1.60	3.09 ± 1.03
Manilkara sansibarensis	*Sapotaceae*	tree	57	18.2 ± 11.43	9.41 ± 5.06
Cola minor	*Malvaceae*	tree	56	12.8 ± 7.79	5.75 ± 3.18
Grewia plagiophylla	*Malvaceae*	tree	56	12.2 ± 5.71	5.15 ± 2.30
Pyrostria bibracteata	*Rubiaceae*	tree	56	8.6 ± 5.38	4.25 ± 2.46
Combretum illairii	*Combretaceae*	liana	54	11.1 ± 13.82	6.00 ± 5.51
Lecaniodiscus fraxinifolius	*Sapindaceae*	tree	54	20.4 ± 15.06	8.29 ± 5.15
Deinbollia borbonica	*Sapindaceae*	tree	52	6.7 ± 1.75	2.90 ± 0.66
Allophylus pervillei	*Sapindaceae*	tree	51	7.0 ± 1.92	3.36 ± 0.83
Suregada zanzibariensis	*Euphorbiaceae*	tree	51	7.0 ± 2.23	3.83 ± 1.42

Table 4. Basic structural data of the Kenyan coastal forest sites expressed as mean **(**± standard deviation) of the DBH and height, and number of measured trees (n).

Site	DBH (mean ± sd) (cm)	Height (mean ± sd) (m)	n
Arabuko	15.3 ± 12.55	7.73 ± 4.74	2163
Bomu	25.2 ± 22.28	9.99 ± 8.07	275
Buda	16.6 ± 15.14	7.94 ± 6.28	658
Chivara	13.0 ± 9.80	7.26 ± 4.78	539
Chonyi	17.3 ± 15.91	6.79 ± 5.10	216
Diani	16.0 ± 23.26	5.49 ± 3.99	412
Dzombo	18.9 ± 20.84	7.71 ± 5.77	470
Fungo	17.0 ± 14.80	8.74 ± 5.74	208
Gandini	17.3 ± 12.02	7.39 ± 4.45	270
Gogoni	17.5 ± 16.80	7.50 ± 6.10	709
Jibana	18.6 ± 19.45	9.71 ± 7.95	972
Kambe	24.5 ± 25.37	12.29 ± 10.61	274
Kauma	13.4 ± 28.18	7.29 ± 4.67	253
Kinondo	19.5 ± 17.83	9.56 ± 6.92	468
Marenje	16.3 ± 14.18	7.81 ± 5.91	579
Mrima	15.7 ± 15.56	7.12 ± 5.72	485
Mtswaka	30.7 ± 20.71	11.76 ± 7.42	176
Muhaka	24.1 ± 20.97	10.52 ± 8.39	414
Muvya	24.8 ± 20.57	10.69 ± 8.90	110
Mwiru	24.6 ± 20.19	10.64 ± 6.79	153
Ribe	15.5 ± 17.67	7.62 ± 5.74	299
Shimba	15.6 ± 17.16	7.51 ± 6.04	1345
Teleza	17.9 ± 11.03	8.83 ± 5.03	556
Tiwi	14.3 ± 17.73	5.59 ± 3.93	464
Waa	15.8 ± 11.84	6.47 ± 4.10	410

ject within which it was developed. Possible uses by other interested researchers are presently limited on the bases of specific agreement to be discussed with the database administrators. After an embargo period, the data will be contributed to sPlot – the global vegetation plot database (Bruelheide et al. 2019).

Author contributions

A.C conceptualised the idea and provided overall supervision. M.F, F.F and A.C developed the field work sampling design. A.G guided on overall study area briefing, forest sites selection and accessibility. M.F carried out the field work, collected, compiled, standardised data and prepared the manuscript. S.C contributed to field sampling and plant specimen identification. M.C reviewed the species data and verified taxonomy for African and tropical vegetation species. All authors contributed to the final manuscript.

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