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)

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 season patterns 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 km² 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    | -3.32538                | 39.52917                 | 42,000    | 26              | 178             |
| Bomu      | Kaya Bomu                    | Sacred forest     | -3.93354                | 39.59635                 | 409       | 8               | 154             |
| Buda      | Buda forest                  | Forest reserve    | -4.45812                | 39.39638                 | 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                | 39.5906                  | 1,480     | 6               | 76              |
| Mrima     | Mrima forest                 | Forest reserve    | -4.48573                | 39.26883                 | 377       | 6               | 101             |
| Mtsuwakara| Kaya Mtsuwakara              | Sacred forest     | -4.00017                | 39.51997                 | 248       | 4               | 64              |
| Muhaka    | Kaya Muhaka                  | Sacred forest     | -4.32568                | 39.52328                 | 150       | 5               | 90              |
| Muvya     | Kaya Muvya                   | Sacred forest     | -3.94175                | 39.58190                 | 171       | 4               | 85              |
| Mwiru     | Kaya Mwiru                   | Sacred forest     | -3.95913                | 39.57372                 | 147       | 4               | 70              |
| Ribe      | Kaya Ribe                    | Sacred forest     | -3.89932                | 39.63633                 | 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.

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-
Vegetation Classification and Survey

Species (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 KEVCF-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 KEVCF-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           |
| Haplocladium insulorum       | Sapindaceae      | tree  | 94              | 7.4 ± 7.46           | 5.51 ± 2.71           |
| Polyphaea parvifolia         | Rubiaceae        | tree  | 69              | 5.6 ± 0.57           | 2.75 ± 6.67           |
| Salacia elegans              | Celastraceae     | liana | 69              | 7.3 ± 1.87           | 7.14 ± 2.78           |
| Combretum schumanni          | 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 kiriki            | Apocynaceae      | liana | 66              | 9.5 ± 3.79           | 8.21 ± 3.33           |
| Monanthotaxis feroxatica     | Annonaceae       | shrub | 66              | –                    | –                     |
| Synaptolepis kiriki          | Thymelaeaceae    | shrub | 64              | –                    | –                     |
| Cassypourea eryoideae        | Rhizophoraceae   | tree  | 63              | 14.7 ± 8.64          | 8.21 ± 4.02           |
| Asteranthe aenestus          | Annonaceae       | tree  | 57              | 6.2 ± 1.80           | 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 bibacteaeata       | Rubiaceae        | tree  | 56              | 8.6 ± 5.38           | 4.25 ± 2.46           |
| Combretum illinni            | Combretaceae     | liana | 54              | 11.1 ± 13.82         | 6.00 ± 5.51           |
| Lecaniodiscus fraxinifolius  | Sapindaceae      | tree  | 54              | 20.4 ± 15.06         | 8.29 ± 5.15           |
| Deinbolla barbonica          | Sapindaceae      | tree  | 52              | 6.7 ± 1.75           | 2.90 ± 0.66           |
| Allophyus 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            | 2763 |
| Bomu            | 25.2 ± 22.28         | 9.99 ± 8.07            | 275  |
| Budu            | 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  |
| Funga           | 17.0 ± 14.80         | 8.74 ± 5.74            | 208  |
| Gandini         | 17.3 ± 12.02         | 7.39 ± 4.45            | 270  |
| Gogani          | 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  |
| Mrema           | 15.7 ± 15.56         | 7.12 ± 7.72            | 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  |
| Mviri           | 24.6 ± 20.19         | 10.64 ± 6.79           | 153  |
| Ribe            | 15.5 ± 17.67         | 7.62 ± 5.74            | 299  |
| Shamba          | 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  |

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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