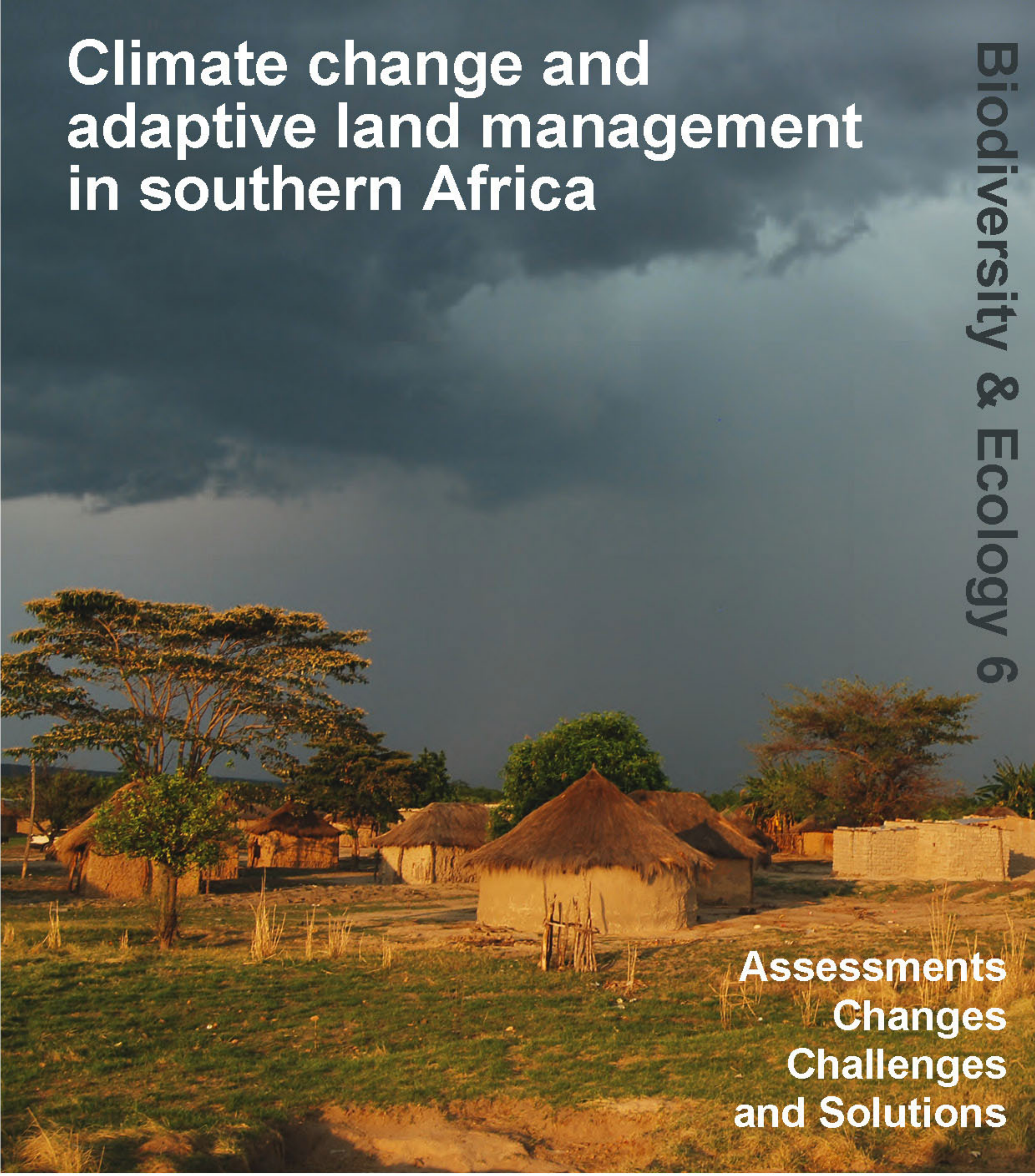
Climate change and adaptive land management in southern Africa

Biodiversity & Ecology 6



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Changes
Challenges
and Solutions

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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

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Biodiversity

Vegetation survey of the woodlands of Huíla Province

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Abstract: We conducted a vegetation survey in the woodlands of Huíla Province, Angola, with the aim of investigating woodland tree communities and species associations. Vegetation sampling was conducted using vegetation plots of 1 000 m^2 where all tree species with or above 5 cm trunk diameter (DBH) were measured. A total of 456 vegetation plots were assessed and a total of 32 080 individual trees measured. Vegetation classification using the ISOPAM algorithm resulted in 13 distinct tree communities. The most dominant family was Fabaceae, subfamily Caesalpinioideae, followed by Combretaceae and Euphorbiaceae. The classification resulted in seven tree communities belonging to the miombo woodlands, two tree communities from Mopane, two from the Baikiaea-Baphia-Terminalia woodlands, and two other distinct tree communities. In general, the miombo communities were the most diverse. The study represents the first plot-based vegetation survey for the region, and will provide the basis for the elaboration of the first vegetation map of Huíla Province.

Resumo: O levantamento da vegetação foi realizado nos bosques da Província da Huíla, Angola, com o objectivo de investigar as comunidades arbóreas e associações de espécies. O processo de amostragem da vegetação foi realizado em parcelas de 1 000 m^2, onde todas as árvores com diâmetro à altura do peito (DBH) igual ou acima de 5 cm foram medidas. Avaliámos no total 456 parcelas de vegetação, que resultou num total de 32 080 indivíduos medidos. A classificação da vegetação foi feita com recurso ao algorítimo ISOPAM que resultou em 13 comunidades distintas. A família mais dominante foi Fabaceae, subfamília Caesalpinioideae, seguida da família Combretaceae e Euphorbiaceae. A classificação da vegetação resultou em sete comunidades de miombo, duas comunidades de Mopane, duas comunidades de Baikiaea-Baphia-Terminalia, e duas outras comunidades distintas. Em geral, as comunidades de miombo foram as mais diversas. O estudo representa o primeiro levantamento feito na região com uso de parcelas, e poderá proporcionar as bases para a elaboração do primeiro mapa de vegetação da Província da Huíla.

Introduction

Angola harbours an enormous variety of habitats, with the miombo woodlands covering about 47% of the land area of the country (Huntley & Matos, 1994). Within Huíla Province, miombo is also the dominant vegetation type. Other important vegetation types include Afromontane forests and grasslands in the area of the escarpment, and *Baikiaea plurijuga* and *Colophospermum mopane* woodlands in the southwestern parts of the province. Although the region is probably one of the most botanically studied parts of the country and hosts one of the largest botanical collections in Angola at the Herbarium of Lubango (LUBA), it remained unstudied in terms of species composition and distribution of vegetation communities, as most of the previous documentation of tree species diversity conducted in the country was based commonly on floristic itineraries and not on detailed vegetation surveys (dos Santos, 1982).

Huíla Province, like many parts of Angola, faces challenges such as land degradation and deforestation, and as a result thereof, loss of biodiversity (Cabral et al., 2011). The main drivers of these processes are demand for agricultural land, fire frequency, fuelwood extraction, charcoal production, and rapid urban development (Röder et al., 2015; De Cauwer et al., 2016; Schneibel et al., 2017). There is no doubt that conservation actions are needed, aimed at preventing and mitigating ecologically harmful consequences caused by habitat modifications and land use change (Simila et al., 2006). To do so effectively first requires knowledge of the present ecosystems as well as plot-based inventories that document the floristic diversity and species composition of the woodlands.

Due to the long period of civil war experienced by Angola, information on vegetation is scarce and is generally based on early botanical work, such as the phytogeographic map of Angola (Barbosa, 1970). For the woody vegetation of Angolan miombo, only a single study is known, which resulted in the first

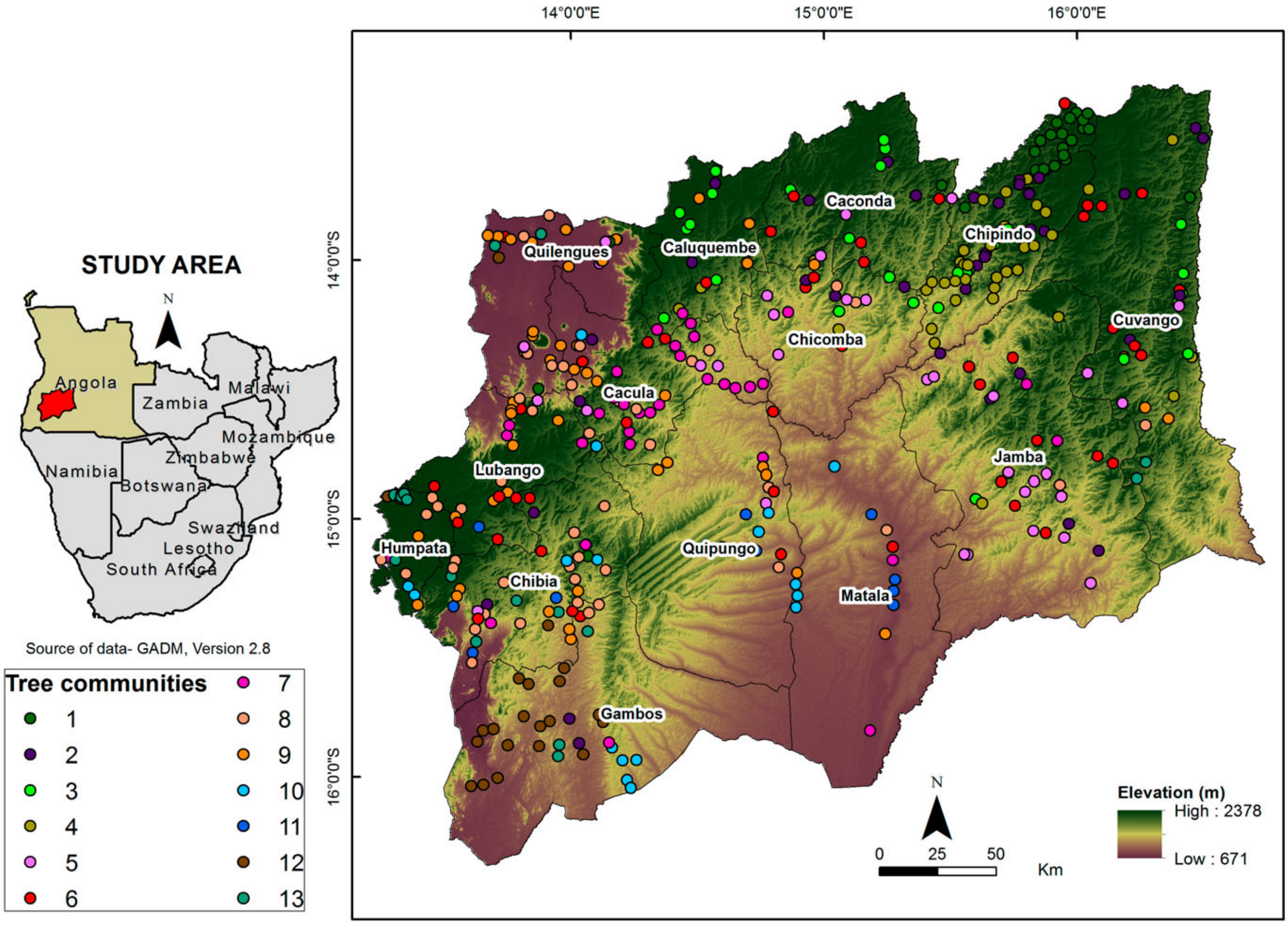

Figure 1: Map of Southern Africa with the location of the study area corresponding to Huíla Province (in red) and its administrative division into 14 municipalities. Plot locations are coloured by their corresponding woodland community types, derived from the ISOPAM algorithm.

provincial map of the Bié Province based on 144 plots (Monteiro, 1970). Recently, a few initiatives have started to document the floristic diversity of the region, though attention has been paid mostly to areas of particular botanical interest, such as the Angolan escarpment (Barker et al., 2015; Gonçalves & Goyder, 2016; Gonçalves et al., in prep.). Studies addressing floristic diversity and woody species recovery following disturbance of the miombo woodlands in south-central Angola have also been conducted (Gonçalves et al., 2017; Revermann et al., 2018). However, much remains to be done in terms of vegetation assessment to characterise the main vegetation types and species associations of Huíla Province. Thus, this study aims to provide an initial classification of the woodland plant communities of the region. This will ultimately lead to the creation of vegetation maps that are urgently needed as a tool for conservation planning and forest management.

Materials and methods

Study site

The woody vegetation was assessed in the woodlands of Huíla Province, located in southwestern Angola. The province occupies an estimated area of about 78 879 km^2, divided into 14 municipalities (Fig. 1). The climate of the region is considered tropical, with dry and cold winters and temperate rainy summers; the mean annual temperature varies from 18°C in the highlands of Humpata to 20°C in the eastern parts of the province (Köppen-Geiger, 1936). Annual precipitation increases from 700 mm in the southwest of Huíla Province to 1 000 mm in the east (Azevedo et al., 1972). According to Barbosa (1970), Huíla Province comprises at least eight vegetation types. The woodlands include the miombo, Angolan Mopane and the Zambezian *Bakiaea-Baphia* woodlands.

Vegetation sampling

We used the preliminary classification of a time-series (2001-2013) of MODIS satellite imagery and derived phenology metrics to identify major vegetation units (Stellmes et al., 2013). The map so obtained was used to create a random stratified plot sample design across the vegetation units of the study area. A total of 456 vegetation plots of 20 m x 50 m were used to assess the vegetation; within each plot, all woody species reaching a diameter at breast height (DBH) ≥ 5 cm were measured. The taxonomy of woody species followed the Angolan checklist of vascular plants (Figueiredo & Smith, 2008).

Data analysis

To understand variation in tree species and diversity within each of the derived tree communities, we calculated species richness (S) and Shannon diversity index (H'). The number of individual tree

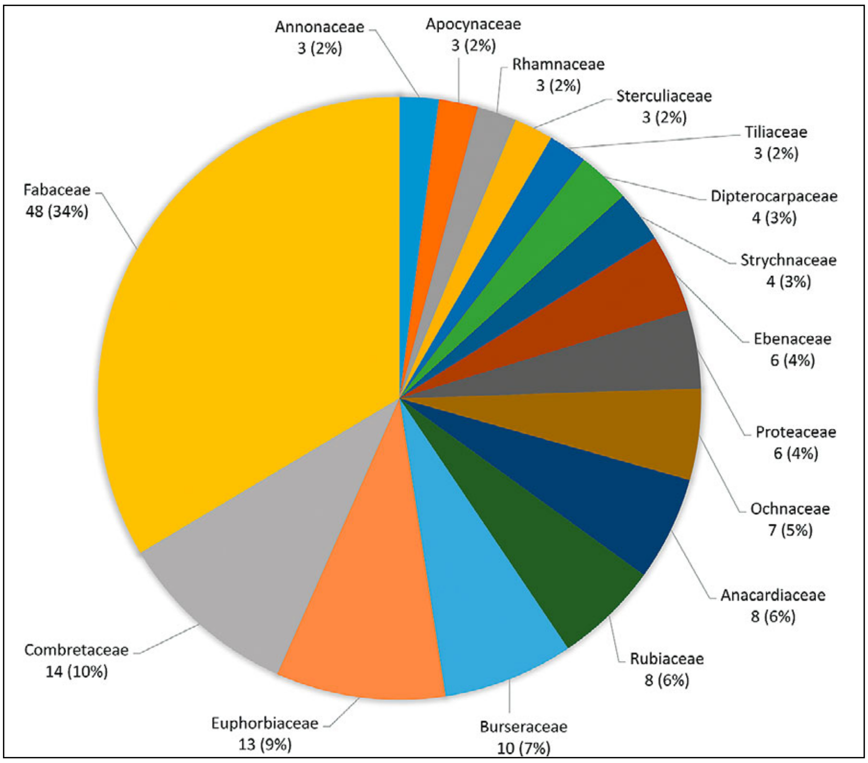

Figure 2: Number of tree species per botanical family found in Huíla Province; only families with more than two species are shown in the pie chart.

species per plot was subject to a vegetation classification using the ISOPAM algorithm in hierarchical capacity, which is based on the ordination scores from isometric feature mapping and partitioning around medoids (Schmidtlein et al., 2010). These were performed in R Version 3.2.3 (R Development Core Team, 2017) with the package ISOPAM. We selected the third hierarchical level of the dendrogram to describe tree communities and determined the diagnostic species using the phi coefficient with a threshold of 30 and a p-value of $p < 0.05$.

Results

Tree species richness

Within the 456 vegetation plots surveyed in the woodlands of Huíla Province, we recorded a total of 32 080 tree individuals corresponding to 176 tree species of 94 genera and 43 botanical families. The Fabaceae family was the most abundant in the study, reaching 34% of the total number of species. According to a recent classification, the Leguminosae/Fabaceae family comprises six subfamilies (Azani et al., 2017). Of all Fabaceae, 20% of species belonged to subfamily Caesalpinioideae, 9% to Detarioideae, and 5% to Papilionoideae, while the subfamilies Cercidoideae and Dialioideae were each represented by one species only. Other abundant families included Combretaceae (10%), Euphorbiaceae (9%), Burseraceae (7%), and other smaller families (Fig. 2).

The species accumulation curve shows that the 456 plots used in this study were sufficient to cover much of the variation observed and species diversity encountered in the studied area. At 400 plots, the graph has not yet reached its asymptotic level but is starting to converge (Fig. 3).

Vegetation classification

The vegetation classification of the ISOPAM algorithm resulted in a dendrogram in which the tree species communities can be seen. At the second hierarchical level of the dendrogram, five major floristic groups were differentiated. The dendrogram featured 13 terminal clusters corresponding to the 13 tree communities differentiated from the fourth hierarchical level (Fig. 4).

The tree species communities and species associations can be detailed as seen in Table 2. The first tree communities (**Communities 1, 2, 3, 5, 6, 7,** and **8**), with the exception of Community 4 [*Combretum collinum-Pericopsis angolensis* woodlands], constitute typical miombo woodlands with open, dense, or medium dense tree canopy, sometimes with dense understorey development (Figs. 7, 8, 9, 11, 12, 13, and 14). These communities were dominated by multiple key miombo species such as *Brachystegia boehmii*,

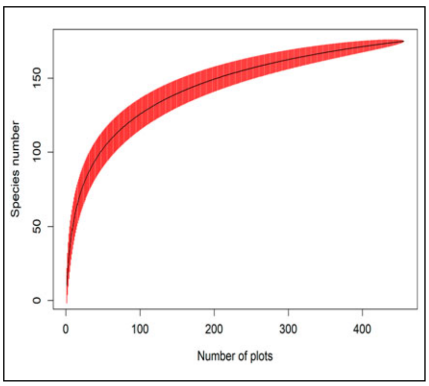

Figure 3: Species accumulation curve for trees with a diameter at breast height ≥ 5 cm measured within the sampling plots of the study area.

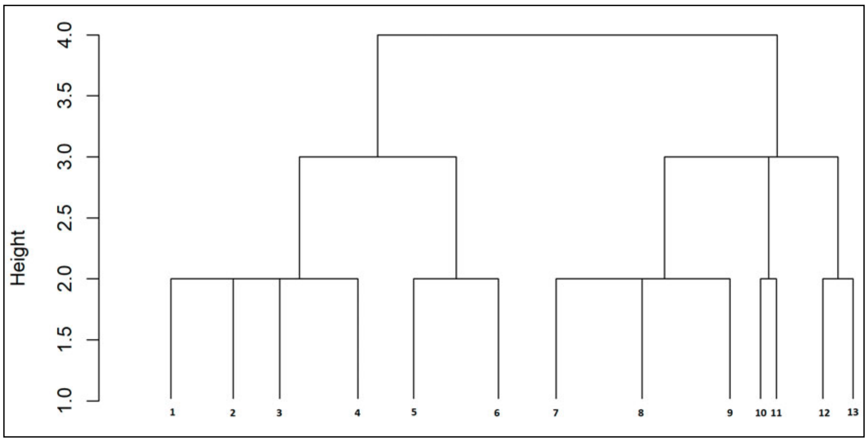

Figure 4: Community dendrogram from the ISOPAM algorithm classification with tree communities of Huíla Province; the numbered clades indicate the different tree communities.

Table 1: Overview of the tree communities of Huíla Province, their diversity values, number of indicator species, and total number of plots surveyed per tree community

Tree Communities	Cluster hierarchical level	Formation	Mean Shannon index	Mean richness	No. of indicator species	No. of plots per community
1: *Brachystegia spiciformis-Parinari curatellifolia*	1.1.1	Open woodlands	1.91	15.62	19	29
2: *Julbernardia paniculata-Brachystegia spiciformis*	1.1.2	Open woodlands	1.18	11.23	10	39
3: *Brachystegia longifolia-Diospyros kirkii*	1.1.3	Open woodlands	1.88	16.41	17	29
4: *Combretum collinum-Pericopsis angolensis*	1.1.4	Medium dense woodlands	2.07	18.29	24	49
5: *Julbernardia paniculata-Diplorhynchus condylocarpon*	1.2.1	Open dense woodlands	1.6	9.23	6	35
6: *Julbernardia paniculata-Combretum collinum*	1.2.2	Medium dense woodlands	1.43	8	3	53
7: *Brachystegia spiciformis-Pteleopsis anisoptera*	2.1.1	Open woodlands with dense understorey	1.4	6.78	3	36
8: *Julbernardia paniculata-Burkea africana*	2.1.2	Open woodlands with dense understorey	1.2	6.07	2	54
9: *Hexalobus monopetalus-Pteleopsis anisoptera*	2.1.3	Medium dense woodlands	1.74	9.53	6	55
10: *Baikiaea plurijuga-Baphia massaiensis*	2.2.1	Closed dense woodland	0.56	3	2	19
11: *Baphia massaiensis* subsp. *obovata-Terminalia sericea*	2.2.2	Medium open woodland	0.7	3.4	2	10
12: *Colophospermum mopane-Spirostachys africana*	2.3.1	Open woodlands	1.11	5.38	5	29
13: *Colophospermum mopane-Pterocarpus lucens* subsp. *antunesii*	2.3.2	Medium dense woodlands	1.79	9.53	11	19

B. floribunda, *B. longifolia* and *B. spiciformis*. The unique exception is *Julbernardia paniculata* found in four of the identified communities.

Community 4 [medium dense woodlands] This community, despite holding few key miombo species, can be considered a successional stage of miombo due to the high dominance of *Combretum* species (Fig. 10). These woodlands are normally accompanied by medium-sized tree species around 3-4 m in height, and hardwood trees of *Pericopsis angolensis*.

Community 9 [medium dense woodlands] This community occurred in lower-altitude areas covering large patches of the northwest of the region (Fig. 15). *Pteleopsis anisoptera* is the dominant tree species, and is a generally small tree. Occasionally it was found associated with other tree species such as *Cassia angolensis* and *Commiphora mollis*. In the highlands of Humpata, communities of *P. anisoptera* generally formed dense and impenetrable thickets where we also documented *Dichrostachys cinerea*, *Tarchonanthus camphoratus*, *Haplocoelum foliolosum*, *Combretum engleri,* and *Buxus benguellensis,* the latter being endemic to the region.

Community 10 [closed dense woodlands] In the study area, this community occurs in southeastern parts of the municipality of Gambos, where it forms closed dense woodlands dominated by *Combretum celastroides, C. engleri, Hippocratea parvifolia,* and sparsely trees of *Baikiaea plurijuga.* In the herbaceous layer, we documented *Adenium boehmianum*, *Gloriosa superba*, and *Hibiscus phoeniceus,* among others. These communities give way to shrublands dominated by *Baphia massaiensis* subsp. *obovata.* In reality, most of these areas are occupied by private farmers, moving towards more open woodlands in the municipality of Quipungo, where *Baikiaea plurijuga* constitutes the tallest canopy tree, occasionally associated with *Phylenoptera nelsii*, *Combretum apiculatum* subsp. *apiculatum, C. collinum*, *C. psidioides,* and *C. zeyheri*. Below the tree canopy, the vegetation is dense, being dominated again by *Baphia massaiensis* subsp. *obovata*, *Bauhinia urbaniana*, *Croton gratissimus, C. mubango,* and *Ochna pulchra* (Fig. 16). Communities of *Baikiaea-Baphia* also cover large parts of Bicuar National Park (BNP). Here, these woodlands formerly appeared associated with *Schinziophyton rautanenii*, though at present, we found few and sparse trees at the woodland edges of the park and also in the municipal limits of Quipungo and Chicomba.

Community 11 [medium open woodlands] Patches of *Baphia-Terminalia* were also found in the municipality of Matala, and partially along Bicuar moving south on the way to Mulondo (Fig. 17). The understorey was commonly dominated by *Mundulea sericea, Vitex mombassae, Ximenia americana* and *X. caffra*, while in the herbaceous layer we documented *Scadoxus multiflorus*, *Grewia monticola,* and *Erithrina baumii*.

Community 12 [open woodlands] This community represents woodlands dominated primarily by *Colophospermum mopane* and normally occurs at low altitudes below 1 000 m, as in the municipalities of Chibia, Gambos, and Quilengues. Here, *C. mopane* constitutes the most dominant tree species (Fig. 18), and appears occasionally associated with *Spirostachys africana*, *Acacia nilotica,* and *Pterocarpus rotundifolius*. The shrub layer is dominated by *Commiphora africana*, *Grewia welwitschii, Bolusanthus speciosus,* and *Pseudomussaenda monteiroi,* mostly in the Mopane woodlands of Quilengues. In some of drier areas of the region, we found *Commiphora mollis, Commiphora multijuga, Terminalia prunioides*, *Schrebera alata*, and *Rhigozum obovatum,* also associated with *Colophospermum mopane* woodlands.

Community 13 [medium dense woodlands]

These communities cover areas in the southwestern parts of the region around Chibia and Gambos. *Colophospermum mopane* is sparsely distributed along with *Pterocarpus lucens* spp. *Antunesii*; other tree species include *Commiphora angolensis*, *Kirkia acuminata*, *Peltophorum africanum*, *Ptaerxylon obliquum,* and *Entada abyssinica*. The generally closed understorey is dominated by thorny species such as *Acacia nilotica*, *A. ataxacantha*, *A. welwitschii*, *A. tortilis,* and *Commiphora africana* (Fig. 19).

Figure 7: *Brachystegia spiciformis-Parinari curatellifolia* woodlands [open woodlands] (photo: F. Gonçalves).

Figure 8: *Julbernardia paniculata-Brachystegia spiciformis* woodlands [open woodlands] (photo: F. Gonçalves).

Figure 9: *Brachystegia spiciformis-Diospyros kirkii* woodlands [open woodlands] (photo: F. Gonçalves).

Figure 10: *Combretum collinum-Pericopsis angolensis* woodlands [medium dense woodlands with dense understorey] (photo: F. Gonçalves).

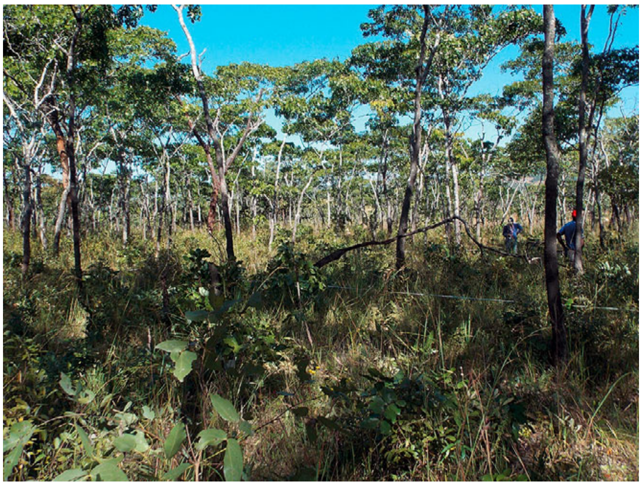

Figure 11: *Julbernardia paniculata-Diplorhynchus condylocarpon* woodlands [open dense woodlands] (photo: F. Gonçalves).

Figure 12: *Julbernardia paniculata-Combretum collinum* woodlands [medium dense woodlands] (photo: F. Gonçalves).

Figure 13: *Brachystegia spiciformis-Pteleopsis anisoptera* woodlands [open woodlands with dense understorey] (photo: F. Gonçalves).

Figure 14: *Julbernardia paniculata-Burkea africana* woodlands [open woodlands with dense understorey] (photo: F. Gonçalves).

Figure 15: *Hexalobus monopetalus-Pteleopsis anisoptera* woodlands [medium dense woodlands] (photo: F. Gonçalves).

Figure 16: *Baikiaea plurijuga-Baphia massaiaiensis* subsp. *obovata* woodlands [closed dense woodlands] (photo: F. Gonçalves).

Figure 17: *Baphia massaiensis* subsp. *obovata-Terminalia sericea* woodlands [medium open woodlands] (photo: F. Gonçalves).

Figure 18: *Colophospermum mopane-Spirostachys africana* woodlands [open woodlands] (photo: F. Gonçalves).

Figure 19: *Colophospermum mopane-Pteocarpus lucens* subsp. *antunesii* [medium dense woodlands] (photo: F. Gonçalves).

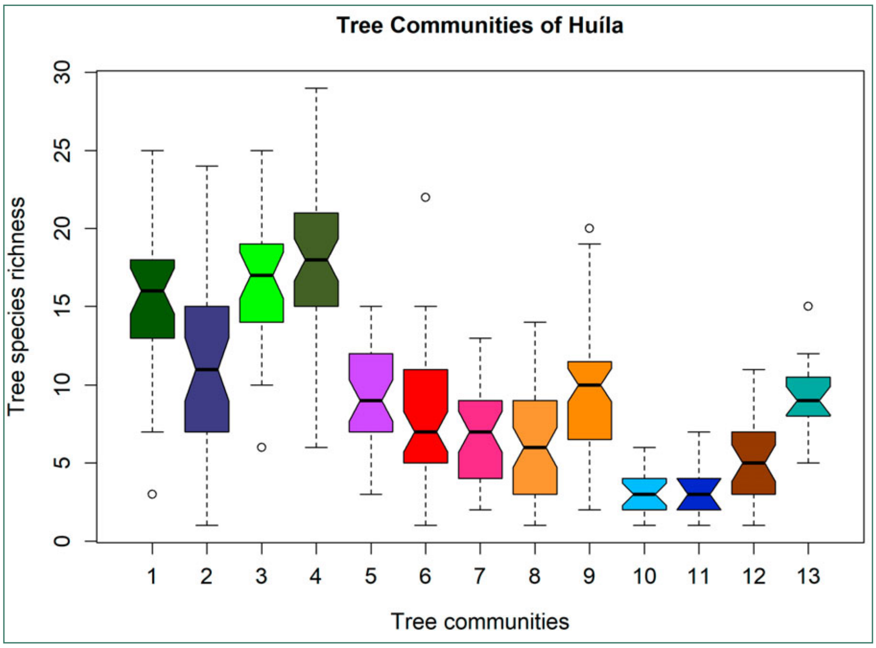

Figure 5: Box plots depicting the tree species richness in the 13 identified communities.

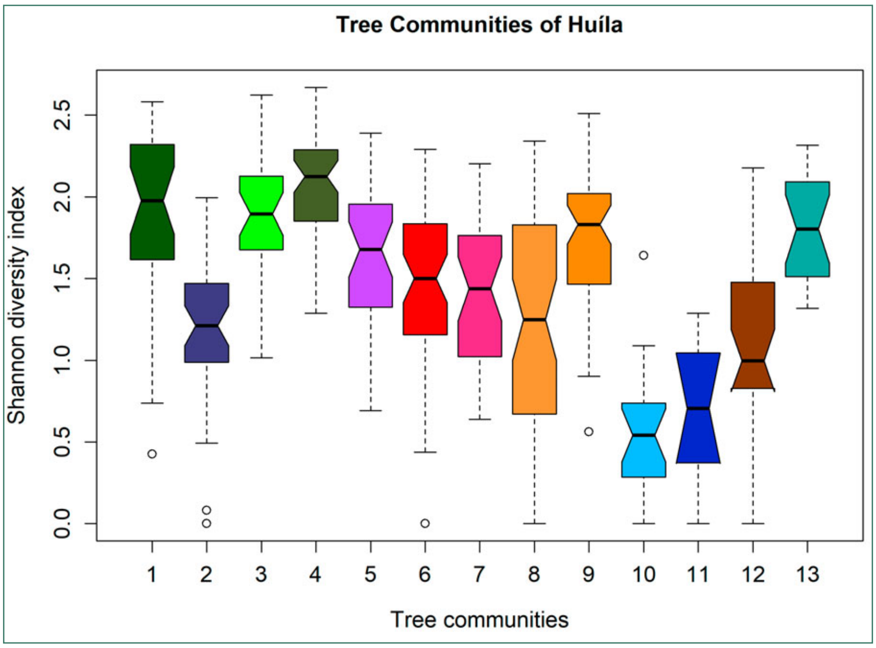

Figure 6: Shannon index of the plots of the 13 tree communities.

Tree species diversity

The inspection of diversity of the main floristic groups showed that in general, miombo woodlands with *Brachystegia spiciformis-Parinari curatellifolia*, *B. longifolia-Diospyros kirkii,* and *Julbernardia paniculata-Diplorhynchus condylocarpon* [Communities 1, 3, 5] have the highest species richness (Tab. 1), followed by *Hexalobus monopetalus-Pteleopsis anisoptera* woodlands [Community 9] and *Colophospermum mopane-Pterocarpus lucens* subsp. *antunesii* woodlands [Community 13]. The tree community with the highest tree species richness was *Combretum collinum-Pericopsis angolensis* woodlands [Community 4]. Communities of *Julbernardia paniculata-Brachystegia spiciformis* [Community 2], *Baikiaea plurijuga-Baphia massaiensis* subsp. *obovata* [Community 10], *Baphia massaiensis* ssp *obovata-Terminalia sericea* [Community 11], and *Colophospermum mopane-Pterocarpus lucens* subsp. *antunesii* [Community 12] showed the lowest species richness (Fig. 5).

The communities of the first major cluster, Communities 1-5, were the most diverse as measured by the Shannon diversity index, with the exception of Community 2. These communities also showed the highest species richness and greatest number of indicator species of communities. The second most diverse community was represented by tree communities 6 to 9 and 13 (Fig. 6). Community 9 showed also the highest number of plots sampled. The second highest number of plots sampled was found in Community 8. Despite the high sampling effort in these communities, they demonstrated very low species richness as well as low numbers of indicator species (Tab. 1)

Discussion

Diversity of the woodlands of Huíla Province

This study represents the first plot-based woody vegetation assessment of Huíla Province in Angola, aiming to characterise and describe the woodlands of the region. A total of 456 plots were surveyed in the region, sufficient to document major floristic groups occurring in the study area, as evidenced by the species accumulation curve. This pattern may imply that any further increase of sampling effort would be expected to lead to inclusion of additional rare species, as the sample size of 456 was high and may capture almost all woody species occurring in the region, and can be useful to characterise the species diversity and relationship between woody species and site conditions. As mentioned before, most of the previous studies carried out in the country date to the colonial era. These studies characterised the vegetation types based on general aspects or were limited to dominant species only (but see Revermann et al., 2018). As with other parts of Angola, there is still a great deal of work to be done to describe the vegetation of Huíla Province. Barbosa (1970) recognises about eight vegetation types for the Huíla region, including the most important woodlands surrounding the study area. With the present study, we are able to document 13 distinct tree communities within the region; most of them constitute fairly typical miombo woodlands, dominated by the Fabaceae family, of which the subfamily Caesalpinioideae is the largest. The dominance of the Fabaceae family within the miombo eco-region has been widely reported in various studies (Byers, 2001; Munishi et al., 2011). Within the study area of Huíla Province, miombo woodlands occupy large areas, being relatively dense with canopy tree species around 12-15 m in height in the municipalities of Chipindo and Cuvango. The woodlands become open with increasing altitude, as observed in Caconda, Caluquembe, and patches of the Humpata plateau, and due to high land use pressure caused by agriculture, the woodlands appear also relatively open in the municipality of Jamba.

The mean Shannon index values found in the study area were generally low, with the exception of Community 4 [*Combretum collinum-Pericopsis angolensis* woodlands] with a mean H' equal to 2.07. The highest value of Shannon diversity found in this community supports the view that these woodlands may represent regrowth of typical miombo woodlands, as areas heavily impacted by agriculture are reported to hold tree species with high light demand and fast growth, like many *Combretum* species (Jew et al., 2016). These species recruit and establish easily following disturbance and in this way additional species are added to the otherwise typical miombo species (Banda et al., 2006; Gonçalves et al., 2017). The presence of standing trees of the hardwood species *Pericopsis angolensis* was also documented in early succession of the south-central Angolan miombo woodlands (Gonçalves et al., 2017). A threshold of H' = 2 has been mentioned as the minimum value above which an ecosystem can be regarded as medium to high diversity (Giliba et al., 2011). The mean Shannon diversity index found in the Mopane woodlands of the study area was relatively low compared to similar habitats in northern Botswana; this is attributed to anthropogenic disturbance, suggesting that non-protected woodlands are negatively impacted by human activity, with a direct effect on the composition and diversity of species (Teketay et al., 2018). Within the study area we found H' values below 1; this may not only be related to the minimum number of plots surveyed, but also to the mono-dominance of single tree species such as *Baikiaea plurijuga-Baphia massaiensis-Terminalia sericea*. The Shannon index may be strongly influenced by the occurrence of rare species such as *Entandrophragma spicatum,* which can be found in the area associated to the woodlands. *E. spicatum* was reported to be very rare in the study area and probably in risk of local extinction due to its high value as timber (Barbosa, 1970).

Vegetation classification

The Angolan miombo woodlands cover an extensive area of central Angola, extending into Democratic Republic of Congo (Burgess et al., 2004). Most of this eco-region is found at elevations between 1 000-1 500 m above sea level and includes the highlands of Huíla, Huambo, and Bié (Barbosa, 1970; Huntley, 1974a). Within our study area, miombo woodlands covered large areas, ranging from high rainfall sites in the north, where the woodlands seem to be much denser and almost intact, towards the southeastern and western parts of the region, where the woodlands are generally sparser (Communities **1, 2, 3, 5, 6, 7,** and **8**). Miombo woodlands show variations in terms of density and species composition throughout the region, with differences in species composition being more evident at local scale. Local abiotic conditions and changes from *Brachystegia spiciformis* to *Julbernardia paniculata* communities, together with various other woody species, may also influence the stand structure and composition of the woodlands (Revermann & Finckh, 2013). Signs of tree damage caused by fire, woodcutting, and/or agriculture activity were also documented; this is a stark reminder that fire frequency, together with other human disturbance, plays a major role in miombo woodland dynamics, affecting physical structure, composition of species, and also woodland recovery following disturbance (Chidumayo, 2002; Furley et al., 2008).

Community 4, *Combretum collinum-Pericopsis angolensis* woodlands, was found associated with key miombo and non-miombo species, mainly in the municipalities of Caconda, Caluquembe, and Chicomba. Similar patterns of key miombo species occurring together with other woody species have also been documented in the Tanzanian miombo woodlands (Banda et al., 2008). These findings contrast with the pattern usually considered common for miombo woodlands, suggesting that on a larger spatial scale, the species composition of miombo is very high, and common genera as *Brachystegia*, *Julbernardia,* and *Isoberlinia* are not always dominant at the local scale (Mwakalukwa et al., 2014).

Community 9, *Hexalobus monopetalus-Pteleopsis anisoptera* woodlands, was widely distributed across the region. Stands of *Hexalobus monopetalus* are reported to occur mainly at low altitudes in southern Africa (Coates Palgrave, 2005), but in the study area, these species also appeared to be very common in disturbed woodlands. This community was also found on rocky outcrops and mountainous areas of the Quilengues and Humpata plateau. Small trees of key miombo species such as *Brachystegia spiciformis* and

Julbernardia paniculata were commonly found associated to the community (Gonçalves, 2009).

Community 10, *Baikiaea plurijuga-Baphia massaiensis* subsp. *obovata* woodlands, belongs to the Zambezian *Baikiaea* woodlands eco-region, which forms a mosaic of *Baikiaea plurijuga*-dominated forest, woodlands, thickets, and secondary grassland in Angola, Namibia, Botswana, Zambia, and Zimbabwe (Burgess et al., 2004). These dense woodlands, described in the southeastern parts of Gambos, appear similar to the dense *Baikiaea-Burkea* woodlands first described for the Okavango basin along the Cubango River, characterised by a closed canopy and thicket-like understorey (Revermann & Finckh, 2013; Wallenfang et al., 2015). Further north of Gambos, *Baphia massaiensis* subsp. *obovata* dominates the landscape; this attracts private farmers to these areas, as this species is of high nutritional value for livestock (Maiato & Sweet, 2011). The *Baikiaea* woodlands become more open and constitute one of the dominant vegetation types of Quipungo within the administrative division of Bicuar National Park (BNP). A detailed vegetation account of this area points to about six vegetation communities occurring within the BNP, including woodlands, shrublands, and grasslands with aquatic and semi-aquatic vegetation (Teixeira, 1968). We documented *Baikiaea plurijuga-Baphia massaiensis* subsp. *obovata* woodlands during the field survey as one of the major woody vegetation components in the region, which is not clearly described in this previous study. Barbosa (1970) described these woodlands as occupying large areas of the BNP. The *Baikiaea-Baphia* woodlands here can be considered part of an extensive area of dry tropical woodland in southern Africa; in Angola, it has its southeast limit in deep Kalahari sands along the Angolan-Namibian border. Here the canopy is dominated by tree species such as *Schinziophyton rautanenii*, *Guibourtia coleosperma,* and *Pterocarpus angolensis*; pure stands of *Baikiaea plurijuga* only rarely occur (Gonçalves et al., 2018). The woodlands in the BNP may represent the most intact unit of this vegetation community in Huíla Province, as the surrounding areas of Matala and Quipungo were largely depleted, most likely by timber over-exploitation and clearance of large areas for agriculture purposes in the two municipalities.

To the south, moving towards Mulondo in the municipality of Matala, we were able to characterise woodland as *Baphia massaiensis-Terminalia sericea* woodlands (Community 11). This community also covers large areas of Bicuar National Park. Shrubby species within the community were generally very few, and included *Vitex mombassae and Grewia* spp. The previous vegetation studies refer to this community as *Terminalia sericea, Acacia nilotica, A. tristis,* or *Hippocratea-Baphia-Croton-Combretum* spp. shrublands, where *Baikiaea* may or may not occur (Teixeira, 1968; Barbosa, 1970). In fact, *T. sericea* may also appear associated to these species in our study area; however, we were not able to assess these shrublands, as they generally form dense and almost impenetrable thicket, and standing trees rarely occur.

Mopane woodlands cover an estimated area of 55 000 km^2 in southern Africa (Makhado et al., 2014). The woodlands stretch between Angola and Namibia in the southwest, from the marginal mountain chain at the base of Serra da Chela to more open and sub-desert habitats (Barbosa, 1970; Menezes, 1971). The Mopane woodlands in Angola grow over vast areas, and are typically associated with ferralitic and black clay soils. Within these areas, *C. mopane* appears associated with tree species, which mirrors the much drier climate previously documented between the municipalities of Caraculo and Virei in the Namibe Province (Maiato & Sweet, 2011). In our study, two communities (Communities 12 and 13) with *C. mopane* as a character species were identified with only slightly differing species composition. Community 13, *Colophospermum mopane-Pterocarpus lucens* subsp. *antunesii* woodlands was mostly characteristic of the drier areas of Huíla Province. This community may represent a vegetation of contact between medium open miombo woodlands of *Julbernardia paniculata*, *Brachystegia spicifomis* and *B. boehmii* of Chibia and typical Mopane woodlands further south (Barbosa, 1970). Further indicator species of the community were *Commiphora* species, and shrubs of *Croton mubango,* common in the understorey.

Conclusion

Information on Angolan vegetation is scarce, as most studies conducted in the country date back to the colonial era. This study, carried out in Huíla Province, represents the first plot-based vegetation survey in this province and provides the first vegetation classification for this region. A high sampling effort guaranteed that most tree species expected to occur in the Huíla were recorded and that representative tree communities were identified. As such, this survey constitutes the basis for the first detailed vegetation map of the province. Additionally, a deeper analysis of environmental drivers of vegetation patterns will be needed in order to explain the distribution and variation of species composition and diversity in the woodlands of Huíla Province.

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Table 2: Vegetation classification of the woody vegetation of Huíla province based on 1 000 m^2 vegetation plots. The 465 table displays the indicator species of 466 every vegetation community identified in the analysis. Species are ordered according to Pearson's phi coefficient of association p <= 0.05. The phi value 467 ranges from 0 to 100, where phi > 30 is regarded as diagnostic of tree species. Species can be associated with more than one group or group combinations. 468 Only species with p ≤ 0.05 are shown in the table.

Vegetation Communities	1	2	3	4	5	6	7	8	9	10	11	12	13	1+2	1+4	2+3	2+5	2+6+7	12+13	*p-value*
Community 1: *Brachystegia spiciformis - Parinari curatellifolia* woodlands																				
Brachystegia boehmii	90														71					0.001
Parinari curatellifolia	86													69						0.001
Brachystegia spiciformis	83													82				100		0.001
Uapaca kirkiana	76													44						0.001
Brachystegia floribunda	72																			0.001
Brachystegia longifolia	72																			0.001
Syzygium guineense	69													51						0.001
Anisophyllea boehmii	62													41						0.001
Faurea rochetiana	62													36						0.001
Bobgunnia madagascariensis	62													49						0.001
Albizia antunesiana	55																			0.001
Uapaca nitida var. *nitida*	55																			0.001
Burkea africana	55																			0.001
Monotes africanus	41																			0.001
Bridelia mollis	41																			0.01
Pterocarpus angolensis	31																			0.01
Community 2: *Julbernardia paniculata-Brachystegia spiciformis* woodlands																				
Julbernardia paniculata		92														100	97	92		0.001
Brachystegia spiciformis		82																		0.001
Bobgunnia madagascariensis		49																		0.01
Uapaca kirkiana		44																		0.001
Syzygium guineense		51																		0.001
Faurea rochetiana		36																		0.001
Combretum collinum		36																36		0.01
Community 3: *Brachystegia longifolia-Diospyros kirkii* woodlands																				
Brachystegia longifolia			100																	0.001
Diospyros kirkii			66																	0.001
Pseudolachnostylis maprouneifolia subsp. *dekindtii*			62																	0.001
Dombeya rotundifolia			59																	0.001
Ekebergia benguellensis			45																	0.001
Bridelia micrantha var. *micrantha*			38																	0.001
Cussonia angolensis			31																	0.001
Vitex madiensis subsp. *madiensis*			31																	0.001
Bobgunnia madagascariensis			72																	0.001
Community 4: *Combretum collinum-Pericopsis angolensis* woodlands																				
Combretum collinum				86																0.001
Pericopsis angolensis				69																0.001
Diplorhynchus condylocarpon				63																0.001
Baphia bequaertii				55																0.001
Bridelia mollis				51																0.001
Combretum zeyheri				47																0.001
Phyllanthus reticulatus				47																0.001
Rothmannia engleriana var. *engleriana*				41																0.001
Community 5: *Julbernardia paniculata-Diplorhynchus condylocarpon* woodlands																				
Julbernardia paniculata					97															0.001
Diplorhynchus condylocarpon					83															0.001
Pseudolachnostylis maprouneifolia subsp. *dekindtii*					57															0.01
Brachystegia boehmii					51															0.01
Diospyros kirkii					49															0.001
Community 6: *Julbernardia paniculata-Combretum collinum* woodlands																				
Julbernardia paniculata						92														0.001
Combretum collinum						36														0.001
Community 7: *Brachystegia spiciformis-Pteleopsis anisoptera* woodlands																				
Brachystegia spiciformis							100													0.001
Pteleopsis anisoptera							58													0.01
Julbernardia paniculata							31													0.001

Vegetation Communities	1	2	3	4	5	6	7	8	9	10	11	12	13	1+2	1+4	2+3	2+5	2+6+7	12+13	*p-value*
Community 8: *Julbernardia paniculata-Burkea africana* woodlands																				
Burkea africana								50												0.001
Julbernardia paniculata								30												0.001
***Community 9: Hexalobus monopetalus-Pteleopsis anisoptera* woodlands**																				
Hexalobus monopetalus									42											0.001
Pteleopsis anisoptera									33											0.01
Commiphora mollis									31											0.001
Community 10: *Baikiaea plurijuga-Baphia massaiensis* woodlands																				
Baikiaea plurijuga										100										0.001
Baphia massaiensis subsp. *obovata*										63										0.001
Community 11: *Baphia massaiensis-Terminalia sericea* woodlands																				
Baphia massaiensis subsp. *obovata*											80									0.001
Terminalia sericea											70									0.001
Community 12: *Colophospermum mopane-Spirostachys africana* woodlands																				
Colophospermum mopane												90							84	0.001
Spirostachys africana												62								0.001
Terminalia prunioides												62							42	0.001
Acacia nilotica												45								0.001
Community 13: *Colophospermum mopane-Pterocarpus lucens* subsp. *antunesii* woodlands																				
Colophospermum mopane													84							0.001
Acacia nilotica													58							0.001
Commiphora mollis													53							0.001
Kirkia acuminata													53							0.001
Pterocarpus lucens subsp. *antunesii*													42							0.001
Commiphora angolensis													37							0.001
Croton mubango													32							0.01

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