PLANT DIVERSITY AND VEGETATION PATTERNS IN THE NORTH OF THE KAOKOLAND ENDEMIC CENTRE, IONA NATIONAL PARK

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Declaration

I, *Telmo Ernesto Meneses António*, hereby declare that the work contained in the thesis entitled: *Plant Diversity and Vegetation Patterns in the North of the Kaokoland Endemic Centre, Iona National Park* is my own original work and that I have not previously in its entirety or in part submitted it at any university or higher education institution for the award of a degree.

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List of Acronyms

CBH	Circumference at Breast Height
CV	Cross-validation
DBH	Diameter at Breast Height
DEM	Digital elevation models
DTs	Decision trees
ESA	European Space Agency
GPS	Global Positioning System
ISA	Indicator Species Analysis
IV	Indicator value
LST	Land Surface Temperature
LUBA	Herbarium of Lubango
MODIS	Moderate Resolution Imaging Spectroradiometer
MRPP	Multi Response Permutation Procedure
MSI	Multispectral Instrument
NDVI	Normalized Difference Vegetation Index
NMS	Non-metric multidimensional scaling
NUST	Namibia University of Science and Technology
OOB	Out-of-bag
PC-ORD	Program for multivariate analysis of ecological data
RF	Random forest
SCIONA	Skeleton Coast Iona Transfrontier Park Project
SRTM	Shuttle Radar Topography Mission
T	The test statistic
TPI	Topographic position index

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Dedication

I dedicate this thesis to Dr Fernanda Lages, I want to shout out loud that I am proud of you.

It was a big step in my life to meet you, as a child you were teaching me how to give the first steps in science, I learned a lot with you. It was a great learning experience in my life, I believe it's just the beginning.

Abstract

Angola has high biodiversity, representing the second-largest ecoregional diversity in Africa, with 7 biomes, 15 ecoregions, 22 vegetation types, and 4 regional centres of endemism. The first studies on the distribution, composition and classification of vegetation in Angola at a national level were part of the floristic exploration and scientific missions during the colonial time. The Kaokoveld Desert and Namib Escarpment Woodlands are ecoregions represented in Iona National Park. Few vegetation or ethnobotanical studies were done in the south of Namibe province, where the oldest park of Angola is located: Iona National Park. Himba community are semi-nomadic herders, they move with their herds both on a daily and seasonal basis, according to fodder availability. This is reflected in a long deep traditional ecological knowledge, cultural heritage developed. Information on plant species and the distribution of vegetation types is an essential baseline for conservation management and planning of the natural resources for any country. This research aims to study the spatial patterns of the vegetation, as well as the use of the plants by the communities in Iona National Park, in Namibe province, southern Angola, as well as the potential that plants present for the economy and tourism. Vegetation data were obtained using sample plots and all the species that were seen in the field during the trips were recorded. The field sampling was randomly stratified. Multi-Response Permutation Procedures and Indicator Species Analysis results were used to determine the number of vegetation communities. Environmental variables were selected as predictors for the vegetation analysis based on the correlation with the ordination axes and contribution to Random forest model. Random forest was used to investigate the vegetation patterns and create a vegetation map.

In total 157 different plants species were recorded, of which 120 species were identified that belong to 49 genera. Of the 120 species, 89 are listed in the Checklist of Angola plants, 31 are new species for the Checklist of Angola plants, with 4 are listed as endemic. The vegetation in the area was divided into eight communities, *1- Acacia mellífera, 2- Terminalia prunioides -Colophospermum mopane, 3- Calicorema capitata, 4- Commiphora multijuga - Rhigozum virgatum, 5- Salvadora persica - Combretum imberbe, 6- Grasses, 7- Euphorbia virosa - Commiphora wildii, 8- Welwitschia mirabilis.* Normalized Difference Vegetation Index, slope, bedrock and annual precipitation were the most important variables in the model aiming to map the vegetation.

The analysis demonstrated that the quantity of the plots used and the choices of environmental variables for the model are the main factors to cause the high OOB error for Random Forest modelling.

The interviews made with the local people that are familiar with plants, resulted in the description of 45 native plant uses by communities living in Iona National Park.

Future studies may consider collecting more vegetation data and environmental variables for the model. Comparing the Kaokoveld vegetation between Angola and Namibia, makes more sense to consider plants as endemics to the Kaokoveld region rather than to each country.

Keywords: Iona, vegetation classification, ethnobotany, plant communities, vegetation map.

Chapter 1: General Introduction

1.1 Introduction

The classification and mapping of vegetation are the most used tools in the study of complex ecosystems (Brown *et al.* 2013). Information on plant species and the distribution of vegetation types provide an essential baseline for conservation management and planning of the natural resources for any country (Figueiredo *et al.* 2009) as plant communities form the basis of ecological processes (Viereck *et al.* 1992, Strohbach and Sheuyange 2001). The main purposes of vegetation classification are to identify as well as to delineate vegetation patterns; to explain vegetation patterns using causal links with the environment, and to conclude field observations and measurements of vegetation to a relevant level of geographic or ecological generalization (Mueller-Dombois 1984). Vegetation studies do not only indicate the location, distribution and abundance of the plant communities and rare or endemic species but are also used to monitor changes in cover, structure and composition of the vegetation. Consequently, vegetation classification and mapping allow the identification of important areas for conservation management (Craven 2002, Revermann *et al.* 2016) taking into account that by identifying different plant communities we are essentially identifying different ecosystems.

1.2 Vegetation classification

The first research recognising ecosystems emerged around the nineteenth century (Ellenberg and Mueller-Dombois 1974, Trimer 2009). The natural vegetation types in Africa are diverse and, using physiognomic characters that cover all aspects of the vegetation structure like height, density, thorniness, deciduousness, were classified by White (1981) into seven (7) biogeographical regions, nine (9) biomes, nine (9) regional centres of endemism and sixteen (16) vegetation types: forest, woodland, bushland and thicket, shrub land, grassland, wooded grassland, desert, Afro-alpine vegetation, scrub forest, transition woodland, scrub woodland, mangrove, herbaceous fresh-water swamp and aquatic vegetation, halophytic vegetation, bamboo, and anthropic landscape. These vegetation types are varied, and their formations are very unequal in the size of the area they occupy, with a high degree of physiognomic distinctiveness (White 1981). Olson *et al.* (2001) used digital data and different technical descriptions to characterize each ecoregion combining regional spatial information on fauna, flora and vegetation across the entire planet. According to the classification of Olson *et al.* (2001), the global terrestrial land surface is subdivided into eight (8) biogeographic regions, fourteen (14) biomes and eight hundred sixty-seven (867) ecoregions. Another vegetation study of Africa that produced a vegetation map based on the spectral response and the temporal profile of the vegetation cover using remote sensing, distinguished five main vegetation types with subgroups: forest with eight sub-groups, woodlands and shrublands with three sub-groups, grasslands with five sub-groups, agricultural lands with four sub-groups, bare soil with four sub-groups, and other landcover classes with two sub-groups (Mayaux *et al.* 2003).

Vegetation changes across time and space as a result of ecological processes acting on plant populations and communities at different temporal and spatial scales, hence it is necessary to update information about vegetation patterns over time (Wong *et al.* 2007). These facts show that there is no stability of the classifications, and vegetation classifications are necessary to be continually updated and refined to appropriately integrate and summarize all available information on the spatial variation of the vegetation (Peet and Roberts 2013, Wiser and De Cáceres 2013, De Cáceres *et al.* 2015).

Global biodiversity is declining (O'Connor *et al.* 2015), and Africa shows a continuous loss of species and habitats (Stephenson *et al.* 2017). Records provide evidence that a number of the ecoregions are regarded as critically endangered. 3,148 plants in Africa are threatened with extinction (Pacheco Capella 2016). With the transformations of natural ecosystems, the problems of environmental change become more evident, and conservationists need to intensify their actions on halting the loss of biodiversity (Edwards and Abivardi 1998).

1.3 Vegetation studies in Angola

Angola has high biodiversity, and the second-largest ecoregional diversity in Africa, with 7 biomes, 15 ecoregions, 22 vegetation types, and 4 regional centres of endemism (Huntley 2019). The first studies on the distribution, composition and classification of vegetation in Angola at the national level were directly related to the floristic exploration and scientific missions during the colonial time (Revermann and Finckh 2019). The first vegetation map of Angola was published by Gossweiler & Mendonça in 1939 and presents 19 classes of vegetation. This map was the basis for a more detailed study; the Carta Fitogeográfica de Angola which recognizes 32 vegetation classes (Barbosa 1970). However, due to Barbosa's floristic rather than ecological emphasis, the classification did not contribute much to a better understanding of the ecology of the main vegetation classes. Although not presenting a definition of the vegetation classification scheme, Diniz published a monograph on the physical properties of the agricultural zones of Angola (Revermann and Finckh 2019).

The first local studies on vegetation in Angola were based on missions to assess natural resources and a few of these works are highlighted here. Monteiro's studies (Monteíro 1962, Monteiro 1966, 1967) contributed to knowledge on the species composition in the forests of Maiômbe, Dembos and Bié, implementing new methods in the mapping of vegetation based on quantitative data of vegetation plots and aerial photography. Menezes (1971) realized phytosociological studies and produced vegetation maps in pastoral ecosystems of the Cunene Province. Teixeira *et al.* (1967, Teixeira (1968) developed vegetation maps for the Quiçama and Bicuar national parks. Aguiar and Diniz (1972) mapped the vegetation of the western plateau of Cela. Coelho (1967) proposed a classification of the lower Cubango Basin.

Angola has been ravaged by a prolonged civil war for more than 30 years, which limited the accomplishment of vegetation studies (Craven 2002, Figueiredo *et al.* 2009). Recently, a new era of research on the vegetation of Angola has started, especially with a study on the plants of Angola that estimated 6735 plants species native to the country (Figueiredo 2008). The research in "The flora of Angola" provided the first record of diversity and endemism (Figueiredo *et al.* 2009). Additional studies include work about linking land surface phenology and vegetation-plot databases to model terrestrial plant diversity of the Okavango Basin (Revermann *et al.* 2016). This study showed that plant diversity in two main vegetation units, Miombo woodlands and dwarf shrub grassland, was among 15 to 65 species per 10^3 m^2 with greater diversity in Miombo woodlands followed by Baikiaea-Burkea woodlands. Data indicate that the number of vascular plants species in Angola comprises about 2000 to 3000 per 10000 km^2 and that Angola is the second richest country with regard to endemic plants in continental Africa (Heinze *et al.* 2017). Recent research carried out in the framework of the TFO and SASSCAL projects have revealed species that were not included in the current checklist of vascular plants of Angola (Goyder and Gonçalves 2019). There is still a large gap in our knowledge on the floristic biodiversity of Angola taking into account that Angola covers an area of 1,246,700 km^2.

1.4 Vegetation studies in Namibe

As shown by Goyder & Gonçalves (2019) and Reverman & Finckh (2019) there are few vegetation studies in from the Namib province and in particular from the Iona National Park (Figure 1), the oldest park in

Angola that is located in the south of Namibe province. The following studies can be highlighted; a study on the vegetation communities along the steep altitudinal gradient of the Serra da Leba (Cardoso *et al.* 2006) and an expedition to the Huíla plateau and the Iona National Park in 2009 which collected 2700 botanical specimen (Goyder and Gonçalves 2019). Joaquim (2018) focused on the exploitation of *Colophospermum mopane* (Mutiaty) and the paradigm of conservation of natural ecosystems in the province of Namibe.

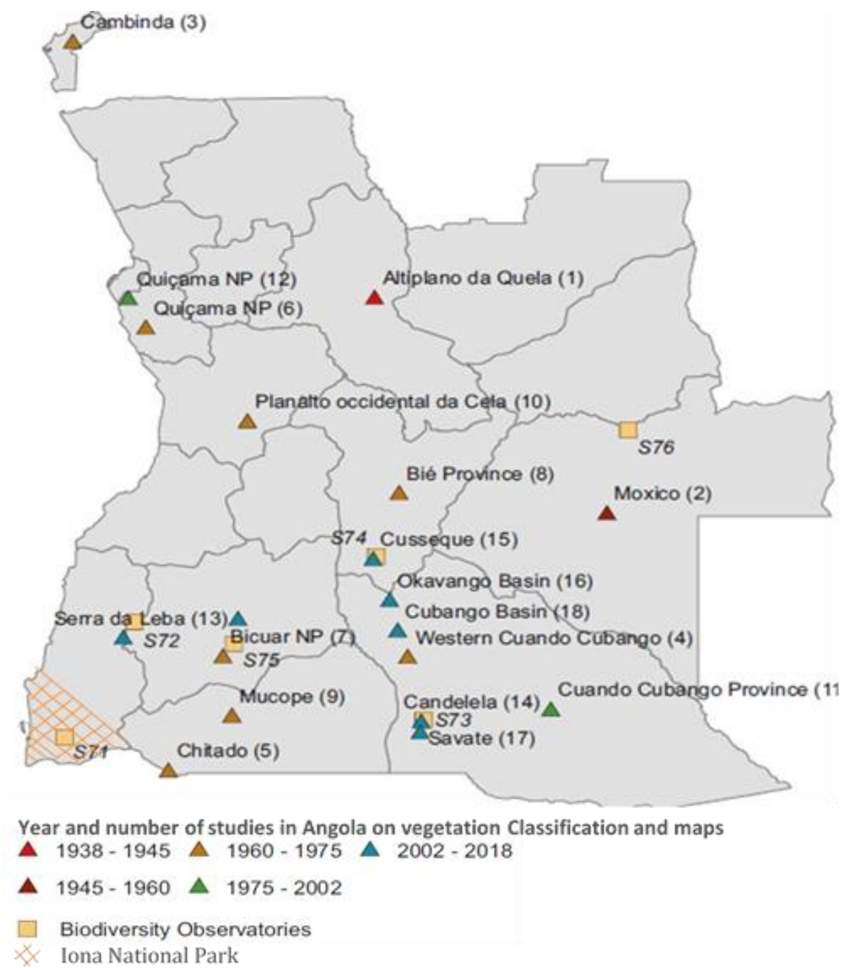

Figure 1. Location of vegetation studies in Angola (Revermann and Finckh 2019).

1.5 Ethnobotany

In Angola, particularly in the southern provinces, agro-pastoral activities are crucial for local economic development (Mendelsohn 2019). The main and often sole possible means of survival and source of income for the people in this area is livestock (Bruschi *et al.* 2017). Most farmers are nomadic pastoralists, they move with their herds both on a daily and seasonal basis, according to fodder availability and in accordance with their social environment. This reflects in a deep traditional ecological knowledge that is part of an ancient cultural heritage developed by local communities (Bruschi *et al.* 2017). Urso *et al.* (2016) show that people living in this area still hold valuable knowledge on food and medicinal plants and that some of these plants are crucial factors in the livelihood strategies of the indigenous communities.

One area of plant research that is particularly important is ethnobotany because it allows us to know the uses and importance of plants for people. Ethnobotany and conservation have three parts, indigenous knowledge and conservation of biodiversity, knowledge and sustainable use of traditional plant resources, and the third, ethical issues in ethnobiology (Brush 2005). The political and ethical dimensions of ethnobotany are of great interest to many people (Van Wyk and Van Staden 2002). Numerous scientific and semi-popular books on the subject have appeared in recent years highlighting the medicinal plant resources, the loss of indigenous cultures and the development of sustainable primary health care products from plants (Malan and Owen-Smith 1974, Sullivan 1998, Heinrich 2001, Van Wyk and Van Staden 2002, Latham and ku Mbuta 2010). There is a growing international interest in ethnobotany, and Southern Africa is one of the regions that provide exciting opportunities for scientific research on the cultural and commercial significance of the plants as well as one of the global hotspots of biological and ethnic diversity (Van Wyk and Van Staden 2002).

1.6 Problem Statement

Previous vegetation classifications of Angola resulted in maps without sufficient biogeographic resolution to accurately reflect the complex distribution of the vegetation communities (Barbosa 1970, Olson et al. 2001). Detailed vegetation maps are necessary to document the distribution of vegetation and analyse its characteristics for correct management of natural resources.

The Kaokoveld Desert and Namib Escarpment Woodlands are ecoregions represented in Iona National Park (Huntley 2019). Iona National Park presents a great floristic diversity and features a high percentage of endemic species (Bombi 2018, Huntley 2019). New species continue to be described in this zone (Van Jaarsveld and Van Wyk 2007, Swanepoel 2008, 2009a, 2009b, 2015) and there still a lack of knowledge about the plants which occur in this area.

Communities living in Iona National Park depend mainly on their livestock for their livelihood and income. Taking into account that vegetation serves as food for cattle and for wild animals, this constitutes a problem considering the need for ecosystem conservation and management in the park. Unsustainable use of plant resources by the community and their livestock, as well as lack of information on the sustainable and ecological management of plants is a problem in this area leading to the degradation and loss of natural habitats, this may ultimately lead to the extinction of (endemic) species.

1.7 Objectives

This research will study the vegetation and endemic plant species, as well as the use of the plants by the communities in Iona National Park, in Namibe province, southern Angola.

This research aims to achieve the following objectives:

1- Identify species within the study area that are endemic to Angola;
2- Identify plant communities and their environmental drivers in Iona National Park;
3- Identify vegetation patterns and create a vegetation map of representative habitats in the Park;
4- Identify plants with a socio-economic and ethnobotanical value that occur in the area.

This study also aims to contribute specimens from Iona National Park to the Herbarium of Lubango (LUBA), updating data about plant species occurrences, and determining the plant species diversity in different habitats in the study area.

1.8 Thesis outline

The introduction (Chapter 1) provides a general overview of the study and presents studies with a similar focus that were done in Angola. Clarification and presentation of the general aims of the study are made in this section.

The methodology (Chapter 2) presents all the detailed information on the procedures that were followed for this research as well as the tools that were used during data collection and analyses. The result chapter (Chapter 3)presents the results obtained in this study for each objective. The discussion (Chapter 4) elaborates on the significance and relation of this research to other studies that have been done in the same area.

Chapter 2: Methods

2.1 Study Area

The study was carried out in Iona National Park (NP), which is located in the south of Angola in Namibe province, municipality of Tômbwa, and 200 km from the city of Mossamedes. Iona NP is the oldest and one of the largest National Park in Angola. It was declared as a game reserve on 2 October 1937, and then, was promoted to the category of National Park on 26 December 1964, with the increase of the area limits (Morais *et al.* 2019). Today the NP covers 15,150 km^2. It has a triangular shape and is delimited in the north by the Curoca River, in the south by the Cunene River (forming the border between Angola and Namibia), in the east between the Curoca and Cunene rivers by the Otchifengo valley, and the Atlantic Ocean to the west (Morais *et al.* 2018, 2019).

The Namib Desert offer the potential to form one of the largest conservations and tourism areas in Africa (Hanks 2003). In May 2018, an agreement was made between the Namibian and Angolan governments that declared Iona NP and Skeleton Coast NP a Transfrontier Park - a special case of the Transfrontier conservation areas (TFCAs). The proclamation and development of Transfrontier Parks (TFP) and Transfrontier Conservation Areas (TFCA) are based on a fundamental re-thinking of protected area concepts and management (Duffy 2001). It is in contrast to the colonial fences-and-fines approach to conservation that alienated society from nature, these current strategies focus on managing entire bioregions based on the sustainable utilisation of biodiversity and involving multiple stakeholders (Mannetti *et al.* 2017). The two countries are currently embarking on the development of an integrated plan based on the acknowledgement of the importance of ecological, physio-geographic and socio-cultural, anthropogenic factors that influence this area.

The elevation of the Park area ranges between 0 and 2050 meters above sea level. Based on Diniz' (1973) classification, the park is composed of two different landscape units, the coastal zone and the escarpment zone. The coastal zone is characterized by mobile dunes with sparse vegetation, typical of the Namib Desert. The Escarpment Zone is a broad transition belt located between the coastal plains and the interior plateaus, formed by complex geology composed of different crystalline types of rocks from the Precambrian era (granites, gneisses, schists, quartzites and amphibolites) (Diniz 1973, Eiselt *et al.* 2017, Morais *et al.* 2018, Huntley 2019).

In Iona NP, there are three different soil types; arenosols that cover approximately 60%, the leptosols 30% and calcisols that cover approximately 10% of the area (Huntley 2019). The arenosols and leptosols are part of the main soil groups found in Angola, together cover about 59% of the country. Arenosols form the dominant sandy soil in the dunes of the Namib Desert. Calcisols have a substantial accumulation of secondary lime; they are waterlogged and provide fertile loam soils for crops in drainage lines with high organic content and high water-retaining capacity. Leptosols are shallow soils, the parent rocks are marl or limestone with little structure; these soils occur in mountainous and desert regions (Jones 2013, Quilliam *et al.* 2013, Akça *et al.* 2018, Huntley 2019).

The Park is surrounded by two large rivers belonging to two different categories; The perennial Cunene river is one of the most important rivers in Angola, which is classified as a coastal river, and the intermittent Curoca river which belongs to the category of rivers of the vast interior plateaus (Huntley 2019).

Angola presents diverse climatic and weather conditions, resulting from many atmospheric, oceanic and topographic driving forces. Based on the Köppen system, the southwest and coastal plain of Angola belong to the desert and semi-desert groups (Bsh, Bwh) (Eiselt *et al.* 2017, Huntley 2019). There is a linear relationship between temperature and elevation, the Namib Desert represents the minimum as well as the highest temperatures of the Angolan coast (Huntley 2019).

Iona lies within two major terrestrial biogeographic regions that characterize southwestern Angola; the semi-arid area with *Acacia, Commiphora, Colophospermum* savannas, and the desert of the Karoo-Namib. In this area, three main typical habitat types can be found: ephemeral watercourses, mountainous areas and sandy areas (Barbosa 1970, Goyder and Gonçalves 2019). This area is formed by the biome deserts xeric shrublands that is covered by two ecoregions. 1- The Kaokoveld Desert, characterized mainly by the genera *Welwitschia, Zygophyllum, Stipagrostis, Odyssea*. 2- Namib Escarpment Woodlands characterised mainly by the genera *Acacia, Commiphora, Colophospermum, Sesamothamnus,* and *Rhigozum* (Burgess *et al.* 2004, Bombi 2018).

2.2 Field data collection

2.2.1 Sampling area and field trips

The access in the Park was limited to landmine safe and accessible areas. The study area starts from the North of the Park (Salonjdamba) and extends to the South (Otchinungua), to the border formed by the Cunene River (Figure 2). The area delimitated covers an area of 4,122.7 km² (Figure 2).

The data collection was conducted during the wet and dry seasons. The first field trip in May 2019 was considered as part of the wet season. Data collection in October 2019 was conducted for the dry season and data collection in April 2020 was conducted for the wet season. To achieve objective number 1, all the species that were seen in the field during the trips were recorded, and the ones that were not identified in the field were collected to be identified by experts.

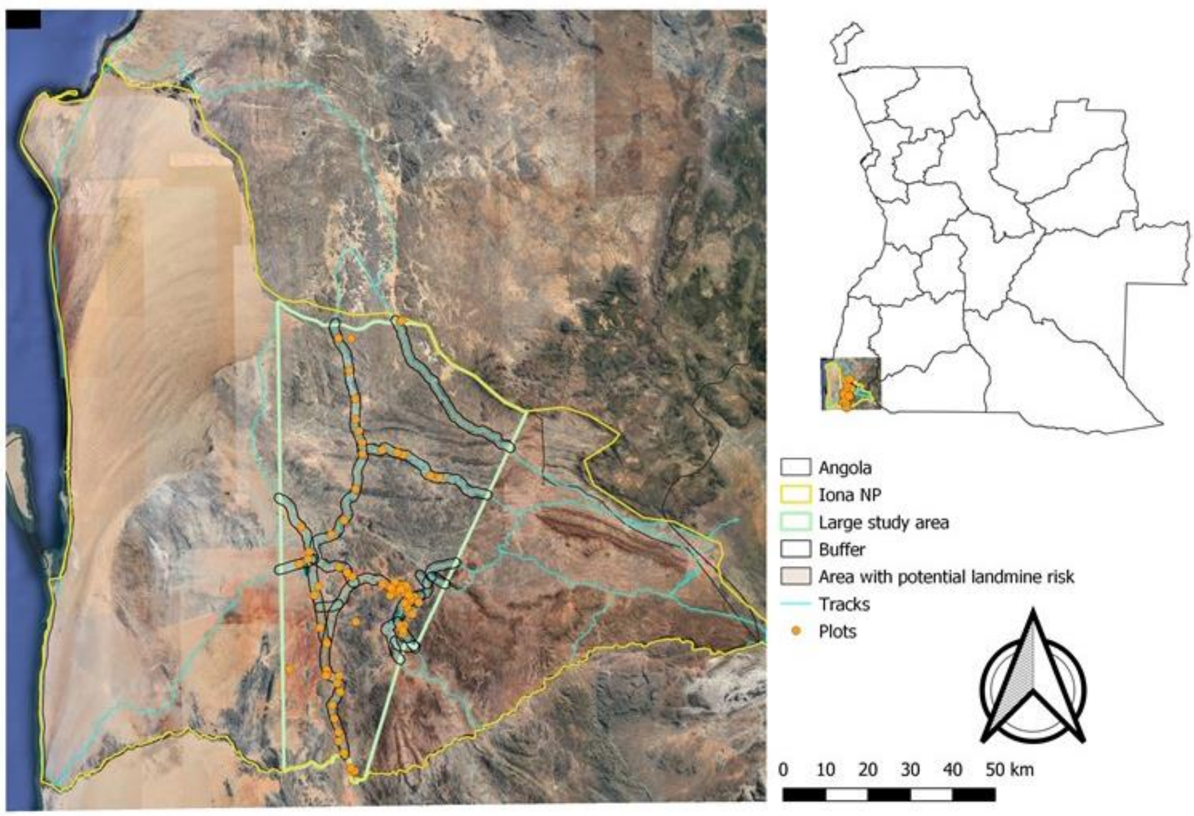

Figure 2. Geographic location of the study area and the sampled areas in Iona National Park

The original intention was to have the study area divided into a large area and a smaller core area. The core area between Iona and Cambeno was used to achieve objectives 2 and 3. The large area was for the achievement of objectives 1 and 4. This resulted in a high concentration of plots in the core area (Figure 2). During the second fieldwork trip, the data collection for objective 2 was extended to the larger study area which presents a higher variation in plant communities and consequently more plant species. The vegetation information collected for the core area that was not used in this study was used by another NUST student, Jackson Hamutenya, for his thesis "Assessment of the feasibility to reintroduce Angolan giraffe (*Giraffa giraffa angolensis*) into Iona National Park, Angola focusing on habitat and social suitability". This data will also be added to the NUST woody vegetation database, which will be used for multiple purposes.

2.2.2 Plot design

Vegetation data obtained from plots allow us to describe in detail the variation in vegetation, species composition of a certain vegetation type or area as well as the species richness and diversity for that particular area (Kapfer *et al.* 2017). The approaches for the classification of vegetation are sensitive to different plot forms and sizes (Kent 2011, Dengler 2016). The plot design consisted of circular plots with 20 m radius and an inner circle with a 5 m radius from the plot centre. The cover was estimated for all species that occur in the plot while all the woody species with the diameter at breast height (DBH) less than 5 cm were counted within the inner circle (Geldenhuys 1977, De Cauwer 2013, 2015, Schelstraete n.d.) (Figure 3).

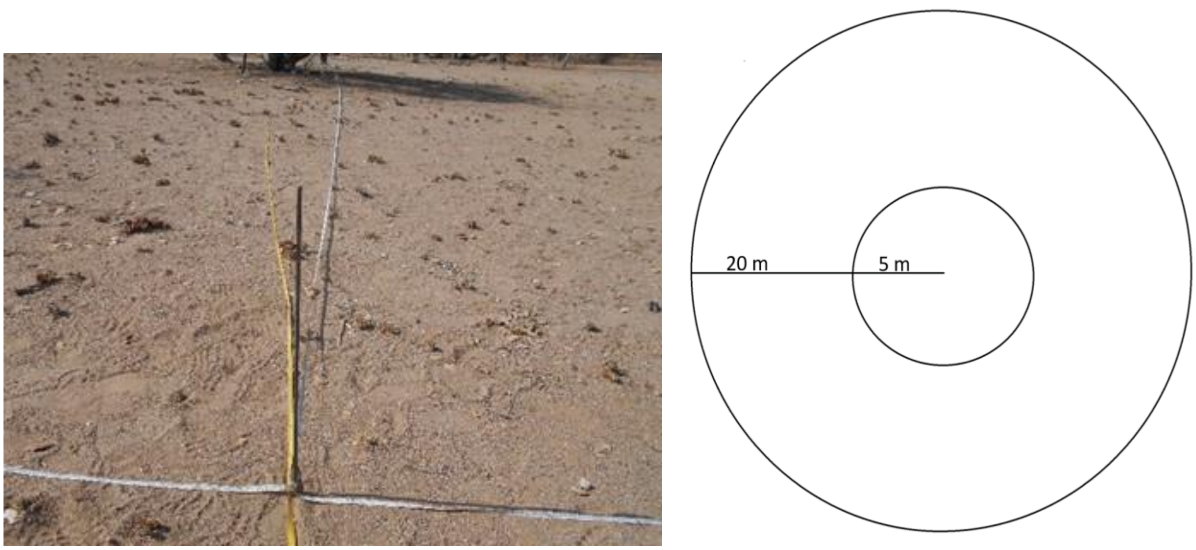

Figure 3. On the left, the measuring tapes for 5 and 20 m radius intersecting at the plot centre. On the right, a circular plot with a radius of 5 and 20 m.

2.2.3 Sampling design

Vegetation types are classified based on the plants' life forms, density, seasonality (evergreen and deciduous) in association with environmental factors such as altitude, climate, soil and vegetation architecture (Matthews 1983). The field sampling was randomly stratified with the samples randomly distributed in the strata (Brown *et al.* 2013). Before the fieldwork, stratification of the study area was done using satellite images (Sentinel-2A taken during the dry season on 2017/08/21), that were freely downloaded from the sentinel hub, which was developed by ESA (https://scihub.copernicus.eu/). Sentinel-2A is equipped with a Multispectral Instruments (MSI) capable of acquiring 13 bands of information at different spatial resolutions (10m, 20m and 60 m). Optical satellite images with a good number of spectral bands are often used to classify diverse land covers or plants under various stresses (Zhang *et al.* 2017). The stratification was made based on the visible light bands red (B04), green (B03) and blue (B02), resulting in a natural colour, which is a good representation of the Earth as humans would see it naturally (Quilliam *et al.* 2013).

A visual/manual stratification was done because the digital clustering did not present a clear distinction of the strata. The large projections of shadows from the mountains, distinguishing other strata difficult. Manual stratification allowed a clear delimitation of the strata. Elevation, land cover and landscapes were taken into account to combine the homogeneous units of the vegetation in the same stratum (Brown *et al.* 2013). The strata were identified to represent different habitats in the study area. The number of plots per stratum was determined according to the size of the strata; the number of plots increased according to the relative size of the stratum.

Data collection focused on the places that are easily accessible (near roads). Using GIS, a buffer zone of 2 km along the main routes inside the study area was created in which the sampling for the area was conducted (Figure 2). The plots were randomly distributed in the in the buffer zone using a GIS program before the field work. The coordinates were transferred to a handheld GPS (Garmin GPSMap 64s) for the location of the plots in the field.
During the time that fieldwork was carried out, a lockdown was decreed in Angola from 18th March to 06th May 2020 by the Ministry of Environment because of the COVID-19 pandemic, halting all activities in the Parks (See appendix 1). That prevented finalising the data collection; 21 plots were not established.

2.2.4 Data collection in vegetation plots

The data were collected according to the data entry sheet that was made for data collection in the relevé (see appendix 2). All plant species present in each plot were recorded. In arid and semi-arid areas, some plant species are not easily identifiable, because often the plants are found without the specific characteristics that help to identify them, such as fruits or flowers (Werger 1973). Plants that could not be identified in the field were given a field number or a field name. If the common name of these plants was known, it was noted, too. All the non-identified plants were photographed and a voucher specimen was collected and later deposited at the LUBA herbarium for subsequent identification. Given the lack of literature on plant identification for the study area (Ferrinho *et al.* 2011, Revermann and Finckh 2019), books from neighbouring regions such as Field Guide to Trees of Southern Africa (2013), Guide to Namibian Trees and Shrubs (2009), were used for plant identification in the field. Additionally, expert botanist Wessel Swanepoel helped with some of the identifications.

The determination of the species' abundance in each plot was made based on an estimate of plant coverage (in %). For woody regeneration, all woody species within a radius of 5 m were counted. All trees in the 20 m radius of the plot were recorded and measured. Trees were considered as woody plants with a diameter at breast height (DBH) greater than 5 cm (corresponding to a circumference at breast height (CBH) of 15.7 cm), including dead trees and trees with multiple stems. Trees that had more than one stem were given the same individual number (Procheş 2011, Van Wyk 2013, Schelstraete n.d.) (Figure 4). Total crown cover of all the trees and shrubs in the plot was determined by the variable-plot or Bitterlich method (Cooper 1957, Lindsey *et al.* 1958, Gomes *et al.* 2011) (Figure 5). Woody plants with DBH less than 5 cm were considered seedlings or shrubs.

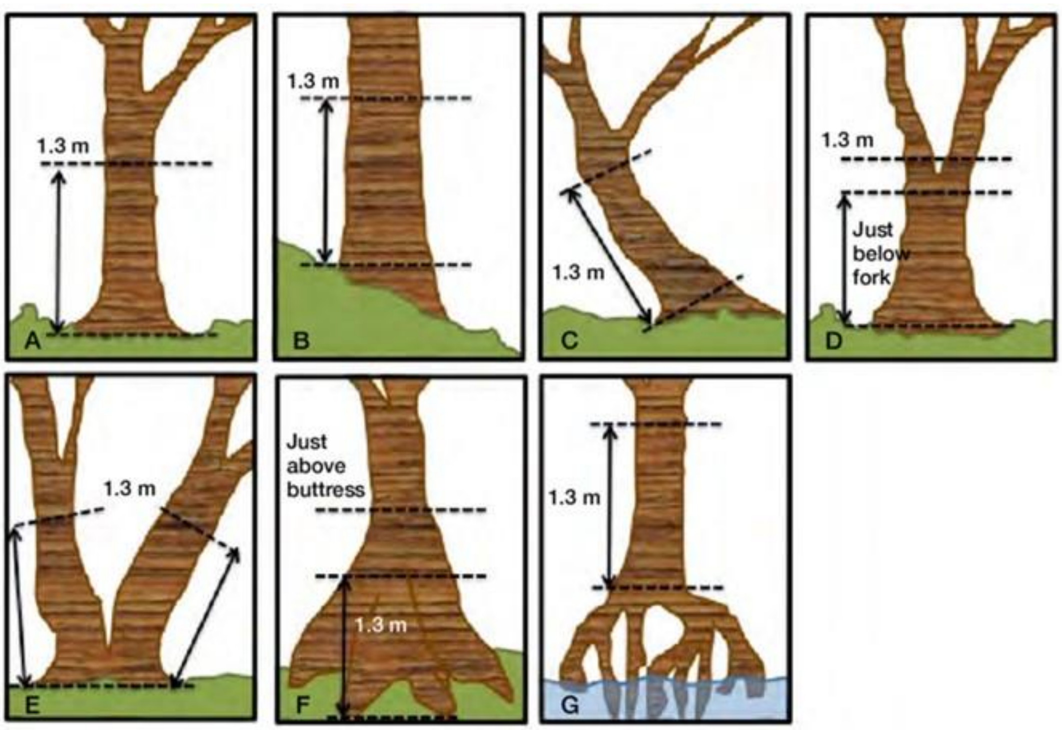

Figure 4. Demonstration of how to measure the Diameter Breast Height (DBH) of trees (Fourqurean et al. 2015).

Figure 5. Demonstration of the Bitterlich used in the field to estimate the total cover of woody plants in the plot.

For each tree in the plot, the distance to the plot centre was measured using a laser inclinometer (Haglöf Vertex Laser VL400) or tape measure, height was measured using a Vertex, and a market pole was used to define the central point of the plot. The advantage of using a Vertex is its precision to determine if the trees are inside the 20 m radius circle. The limitation of the Vertex is that it is only possible to measure the height of the tree if the crown is visible. In cases where the tree was very close to the central plot point, it was necessary to move away until the top of the tree was visible (da Silva *et al.* 2012, 2012, De Cauwer 2013).

Basic information about the environmental information such as soil colour, gravel and rock cover on the ground, elevation above sea level, lithology, topography, slope steepness and position on the slope was collected by observation of each plot, photographs, GPS and vertex. The data were collected to understand the influence of these factors on plant distribution.

2.2.5 Data collected from the communities living in the study area

The information about the ethnobotanical and socio-economic value of the plants was collected in two stages. First, the data was collected during the trip to Iona NP organized by the SCIONA team from 15 to 29 May 2019, of which the objectives included vegetation surveys and ethnobotanical walks. The fieldwork occurred in four villages and settlements in and next to Iona NP; Monte Negro, Cambeno, Otchinungua and Pediva. Botanical walks were performed near the villages and settlements. All the plants encountered were identified and the uses and common names were discussed with local people that are familiar with plants in that area. The para-ecologist Filipa Tchambilo, who has excellent plant knowledge, joined the team in Monte Negro and travelled along to Iona, Cambeno, and Otchinungua (Figure 6).

The second stage occurred from 17th March to 17th April, it included directed interviews using open questions and botanical walks during the data collection in the plots in the villages of Iona, Cambeno, Ochinungua, Pediva, Marinde and other areas around the park. Semi-structured open interviews are carried out mainly in cases of life stories or explanations of a certain phenomenon. As is the case in this study, taking into account the fact this type of interview is informal, and provoke more or less free speech, which significantly meets the research objectives in the investigated context (Duarte 2004). Interviews were made with different people who are familiar with plants in that area, especially traditional authorities, farmers, community members with livestock and community members who are involved in harvesting natural products from local plants (Karanth *et al.* 2012). Four main questions were made to obtain information related to the use of plants. What is the name of the plant, what is it used for, how to prepare it to use, when to use these plants?

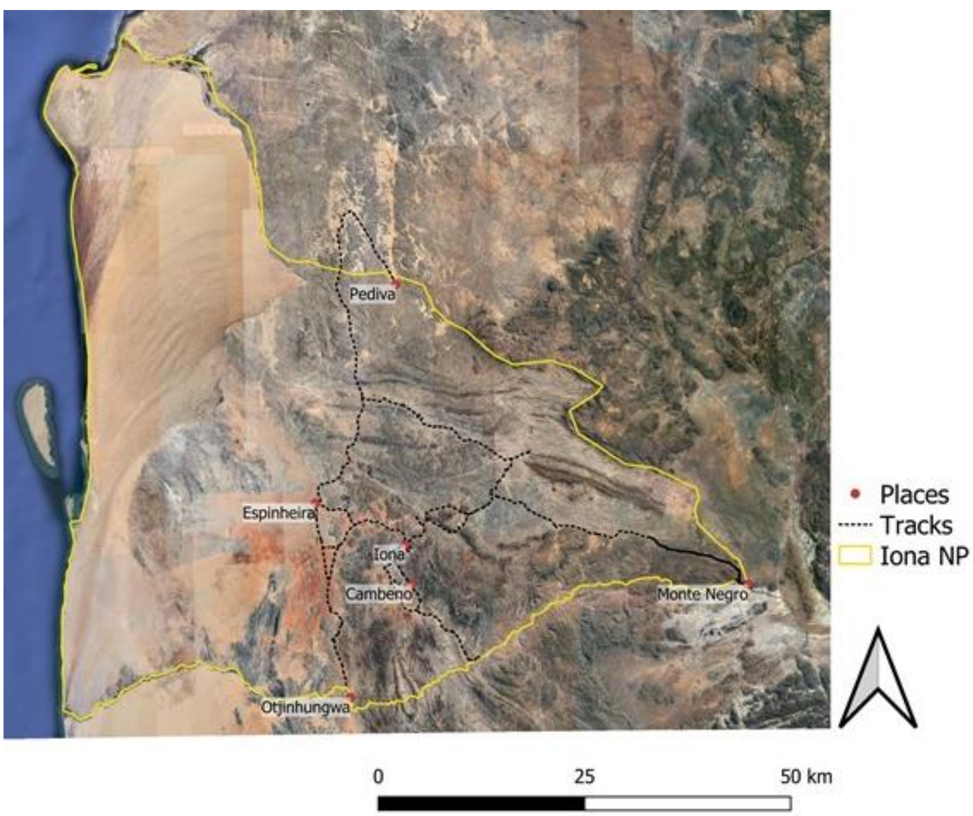

Figure 6. Route in Iona National Park along which ethnobotanical data collection was done.

2.3 Data Analysis

2.3.1 Identification of endemic plants to Angola

A list of the plants observed around the Iona NP identified during the field trip was made. The identification of plants endemic to Angola was based on the Plant List of Angola (Figueiredo 2008) that registers 997 endemic species.

2.3.2 Vegetation classification

Classification is the placement of species and/or sample units into groups (Palmer 2004). First, all the site and vegetation data from the plots were entered in an Excel spreadsheet. The vegetation data analysis and transformations were conducted in PC-ORD 7.02 software (Kindt and Coe 2005, McCune and Mefford 2006). The data used is composed of 83 vegetation plots recorded in the wet season. Species with less than two occurrences were excluded to remove noise in the data. Deleting rare species is widely considered a useful way to reduce noise and to enhance the detection of relationships between community composition and environmental factors (Etzold *et al.* 2016).

The species-area curve shows the cumulative number of species found in the study area, it was calculated to evaluate if the number of sampling plots in the study area were enough (Brown *et al.* 2013, Gebremedhin 2013).

One complex scientific undertaking is the study of the plant cover and its relationships with the environment, finding patterns in a fuzzy target like plant species composition is a persistent challenge in vegetation science (Schmidtlein *et al.* 2010). Vegetation classification aims to assign sample units, the plots, to groups based on the similarity of the redundant patterns of their components and form groups of sample units that are similar in composition. It allows the creation of the dendrogram to visualize the linkages of the plots that form the groups (Ward Jr 1963, Kent 2011). Hierarchical Cluster Analysis was performed for up to six different vegetation associations for classification of the relevés. Flexible Beta was used to describe the group linkage with a beta set to -0.25 (Juergens *et al.* 2013). Because of the heterogeneity of the data, Sørensen was used as a distance measure.

Data analysis involved techniques of multivariate analysis. Numerical classification in studies of analysing species data and non-parametric analysis using similarity analysis are becoming more widely used (Kent

2011). To determine the optimal cutting level of the cluster dendrogram, to identify which species have been found most constant and abundant, to distinguish the compositions between the groups and also to determine the number of vegetation classes (groups) that best represent the plant communities, Multi-Response Permutation Procedures (MRRP) and Indicator Species Analysis (ISA) results were used.
MRPP evaluates the differences between and within groups (McCune *et al.* 2002, Mielke and Berry 2007). The test statistic (T) of MRPP evaluates the statistical significance of the observed, weighted within-group average distances. A larger T indicates a greater separation of groups. The A value of MRPP indicates how similar the sample units within a group are to one another. If the variation among sample units within groups is just as high as expected by chance, then A=0; as the similarity of sample units within groups increases, A increases (to 1, when all sample units in a group are identical) (McCune and Mefford 1999).

At first, ISA was performed to determine the optimal number of vegetation classes taking into account the result of the indicator species value, mean *p*-value and the mean indicator value (*IV)* for each group. Also, it was used to identify characteristic species for each group. The *IV* of the ISA gives an indication of relative abundance and constancy within each group and the *p*-value indicates the probability of having observed such a large *IV*. The species was only considered as a good indicator species to define ecological groups (vegetation classes or plant communities) if it presented an *IV* above 20 and a *p*-value below 0.05 (Kindt and Coe 2005).

2.3.3 Naming the plant communities

The most basic system in classification is a taxonomic classification that is independent of place (Bailey *et al.* 1978). Plant communities or vegetation classes generally are named for diagnostic species (species with high indicator value) (Viereck *et al.* 1992, Schmidtlein *et al.* 2010). According to Weber *et al.* (2000), names are labels to assist in the classification of plant communities and they will never be wholly adequate; the most important is to understand the meaning of the name then find one characteristic name in every respect. Therefore, to avoid confusion and to enable consistency, plant communities were named following the guidelines presented in the International Code of Phytosociological Nomenclature (Weber *et al.* 2000). For maximum usefulness, the classification was based on all the plants at the plots and the relative abundance of the individual plant species, with the class groups based on the similarity of the species composition.

2.3.4 Vegetation ordination

The distribution of the plant species in a large area is controlled by environmental factors as well as by the history of evolution and ecology (Juergens *et al.* 2013). To describe the composition of the community, habitat factors must be taken into account (Viereck *et al.* 1992). Ordination is a multivariate method of gradient analysis and data reduction in which the distribution of samples is arranged in a few dimensions based on the similarity (Anderson 1971, Palmer 2004). It allows identifying the impact of environmental drivers for vegetation patterns, ordering the sample units along a synthetic axis, based on the redundant pattern in composition and relative abundance in the response matrix.

NMS is an ordination technique that is often used for information visualization and exploring similarities or dissimilarities in ecological data (Kruskal 1964, Shafii *et al.* 2013). Holland (2008) present the following advantages of NMS compared to other analysis techniques.

1- NMS calculates only a limited number of axes that are explicitly chosen before the analysis
2- Unlike other techniques whereby the axes are difficult to interpret such that axis 1 explains the greatest amount of variance, axis 2 explains the next greatest amount of variance, and so on, the NMS results can be rotated, inverted, or centred to any desired configuration.
3- NMS allows the use of any distance measure.

An NMS analysis was done to calculate the axes values that represent the gradients in the vegetation patterns. The analysis was performed using Sørensen distances as a distance measure, on random starting configurations for 200 runs. The number of axes was determined based on the suggestion from the autopilot mode analysis that was made (McCune *et al.* 2002).

The Iona NP vegetation classes were ordained in the space using 27 environmental variables (Table 1) and the axes resulted from non-metric multidimensional scaling (NMS) in PC-ORD (McCune *et al.* 2002). Ordination was done using R program to understand the correlation between the axes and all environmental variables. it allowed to select the most important variables for others analysis of the vegetation.

2.3.5 Environmental drivers of plant communities

Environmental variables were related to the NMS axes to determine the most important environmental gradients. The environmental data used were both from field data collection and extracted from global datasets (Table 1). NDVI was determined with Sentinel bands of an image taken during the dry season for not show clouds (4 red and 8 near-infrared, 10 m of resolution) according to the formula:

$$\text{Normalized Difference Vegetation Index (NDVI)} = \frac{\text{Band 8} - \text{Band 4}}{\text{Band 8} + \text{Band 4}}$$

Healthy and well-nourished vegetation will absorb most of the visible wavelengths that it receives and will reflect a large proportion of the near-infra-red light, whereas vegetation in poor condition or sparse vegetation, will reflect more visible wavelength light and less near-infrared light (Ashcroft and Wentz 2000). The variables were clipped to the study area, converted to ASCII raster file format and resampled to 10 m spatial resolution to have all the alignment and spatial extent consistent across all the layers (Elith and Leathwick 2009, De Cauwer *et al.* 2014).

Table 1. A summary of the environmental variables and sources.

Variable abbreviation	**Meaning**	**Data source**
BIO1	annual mean temperature	Global climate and weather dataset website: WorldClim version 2 website: https://www.worldclim.org/.
BIO2	mean diurnal range	
BIO3	Isothermality	
BIO4	temperature seasonality	
BIO5	max temperature of warmest month	
BIO6	min temperature of coldest month	
BIO7	temperature annual range	
BIO8	mean temperature of wettest quarter	
BIO9	mean temperature of driest quarter	
BIO10	mean temperature of warmest quarter	
BIO11	mean temperature of coldest quarter	
BIO12	annual precipitation	
BIO13	precipitation of wettest month	
BIO14	precipitation of driest month	
BIO15	precipitation seasonality	
BIO16	precipitation of wettest quarter	

BIO17	precipitation of driest quarter	
BIO18	precipitation of warmest quarter	
BIO19	precipitation of coldest quarter	
TPI	Topographic position índex	Shuttle Radar Topography Mission (SRTM) website: https://srtm.csi.cgiar.org/.
DEM	digital elevation model	
	Slope	DEM in QGIS.
	Aspect	
BDRICM	The depth to bedrock (R horizon)	International Soil Reference and Information Centre (ISRIC) website: http://www.data.isric.org/.
LST Day and Night	Land Surface Temperature Product, annual time values for October, spatial resolution 1km	Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data website: (https://zenodo.org/).
NDVI	Normalized Difference Vegetation Index Not multitemporal, Image taken on: 2021/05/17.	Derived from Sentinel data from the Copernicus Open Access Hub website: (https://scihub.copernicus.eu/.

Using the R program (R i386 3.4.0), the Spearman's rank correlation coefficient was calculated between the scores of the ordination axes and all environmental variables to determine the variables that most affect the distribution of the vegetation (Hearn *et al.* 2011, Dormann *et al.* 2013, Etzold *et al.* 2016).

A one-way analysis of variance (ANOVA) using Tukey's test HSD (honestly significant difference) as a multiple comparison test, was used to test for differences in the communities by different environemtnal variables. ANOVA is the simplest form, that can be used to compare any number of groups or treatments (Bewick et al. 2004). The interpretation of the p-value was used to interpret the differences between classes, if the p-value is less than 0.05 (5%), it is concluded that there is a significant difference between groups.

2.3.6 Vegetation patterns and map

A vegetation map provides an in-depth look at plant communities on a large scale (Küchler and Zonneveld 2012). Analysis of the correlation between vegetation and environment requires a detailed understanding of the environmental processes that influence vegetation (Austin 2005).

Random forests (RF henceforth) was used to investigate the vegetation patterns and create the vegetation map. The data used for the RF model is composed of the plots grouped in the community to which it belongs as a factor and environmental variables obtained from satellite and other data as predictors (Lu and Weng 2007). Relevant variables used in the RF model were selected according to the result of the NMS axes and the correlation analyses that was made between the nvironmental variablesthat characterise the vegetation.

RF is a new, efficient, powerful, and popular statistical classifier introduced by Breiman (2001), based on model aggregation ideas for both classification and regression problems. RF can be used for either a categorical response variable, referred to as "classification," or a continuous response referred to as "regression". The principle of RF is to combine many binary decision trees built using several bootstrap samples coming from the learning sample and choosing randomly at each node a subset of explanatory variables (Cutler *et al.* 2012, Genuer *et al.* 2015). The advantages of RF compared to other statistical classifiers include (1) very high classification accuracy; (2) a novel method of determining variable importance; (3) an ability to model complex interactions among predictor variables; (4) flexibility to perform several types of statistical data analysis, including regression, classification, survival analysis, and unsupervised learning; and (5) an algorithm for imputing missing values (Cutler *et al.* 2007).

The out-of-bag (OOB) error and the associated classification errors for each class were used to evaluate the classification results. The out-of-bag (OOB) error, also called out-of-bag estimate, is a frequently used method for measuring the prediction error of random forests and also is one of the rules to estimate the importance of the variables in RF (Genuer *et al.* 2010). The OOB score is computed on data that was not necessarily used in the analysis of the model, but on a subset of decision trees (DTs) not containing the OOB sample in their bootstrap training dataset (James *et al.* 2013, Janitza *et al* 2018). The two parameters that have the most influence on the OOB error are the number of trees grown (ntree) per forest and the number of predictors to randomly sample at each node (mtry; Goldstein et al. 2010). Increasing the values of ntree and mtry will usually improve the accuracy of Random Forest until the OOB reaches a plateau (Goldstein et al. 2010). Once a plateau is reached, increasing values of ntree and mtry do not improve predictive power but instead become computationally costly (Brieuc *et al.* 2018, González *et al.* 2020).

Ten-fold Cross-validation (CV) was used to confirm the result obtained with the RF model (Tibshirani and Efron 1993, Hayes *et al.* 2014). It is a data resampling method to assess the generalization ability of predictive models and to prevent overfitting (Duda *et al.* 2001, Friedman *et al.* 2001). Cross-validation is similar to the repeated random subsampling method, but the sampling is done in such a way that no two test sets overlap. In k-fold cross-validation, the available learning set is partitioned into k disjoint subsets of approximately equal size (Berrar 2019).

Kappa was used to evaluate the CV results. The Out-of-bag error (RF) and Kappa (CV) are different validation methods for estimating the model error of a machine learning model (Friedman *et al.* 2008). The Kappa statistic (or value) is a metric that compares an observed accuracy with an expected accuracy (random chance). The validation score was calculated using all the DTs of the ensemble analysed (Brieuc *et al.* 2018). There is not a standardized interpretation of the Kappa statistic (Gwet 2010). Landis *et al* (1977) and Ramasubramanian *et al* (2017) consider 0-0.20 as slight, 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as substantial, and 0.81-1 as almost perfect. Fleiss *et al.* (2013) consider Kappa > 0.75 as excellent, 0.40-0.75 as fair to good, and < 0.40 as poor.

Variable selection is very important for interpretation and prediction (Han *et al.* 2016). The advantage of variable importance as determined by the random forest model is that they cover the impact of each predictor variable individually as well as in multivariate interactions with other predictor variables (Strobl *et al.* 2008). The contributions of the environmental variables on the classification were analysed using the Mean Decrease Accuracy (MDA) (Han *et al.* 2016). The index MDA utilizes permuting OOB samples to compute the importance of the variable. The larger the MDA value, the more important the variable (Han *et al.* 2016).

The model was executed in the R program with the package randomForest in addition to the packages that are required to classify landcover, maptools (Bivand and Lewin-Koh 2013) and raster (Hayes *et al.* 2014). The RF analysis wasmade with 80% of training data, 1000 ntrees and mtry 10, CV was done with out splitting in training and testing data to evaluate all the factors.

Ethnobotanical data collected through the interviews with local informants were organized according to the scientific name and the native name of each plant. The plants that were not identified were described using the native name. The information collected during the interviews was presented to the plant paraecologists (Filipa and Tchafene) together with plant photos to validate the information obtained. The information was translated from Portuguese to English and during the translation, the book of Procheş (2011) Trees & Shrubs of Namibia and the study of Malan *et al.* (1974) The Ethnobotany of Kaokoland, were used to help with specific words and to organise the description of the categories on the plant uses for the plants.

Chapter 3: Results

3.1 Summary of vegetation data

Vegetation data were collected with a vegetation survey for objectives 1 to 3, resulting in a total of 83 sample plots that were sampled during the wet season, of which 11 plots were sampled in May 2019 and 72 plots in March – April 2020. Of these 72 plots surveyed in 2020, 26 were revisited plots that were established during the dry season of 2019. Three plots were excluded from the RF model because they were situated a few kilometres outside the park (Pediva reserve) and the shapefile of the park does not cover that area. The sample plots were distributed in the previously identified strata; desert sand or desert (9 plots), hilly (6 plots), mountain (29 plots), riverbed (13 plots), Kaokoveld sand or sand areas (13 plots), as illustrated in (Figure 7). During the fieldwork, it was observed that most of the sample plots in the stratum sandy areas have soil covered by rocks, hence the strata of 13 plots were redefined as stony ground stratum (Figures 8 and 9).

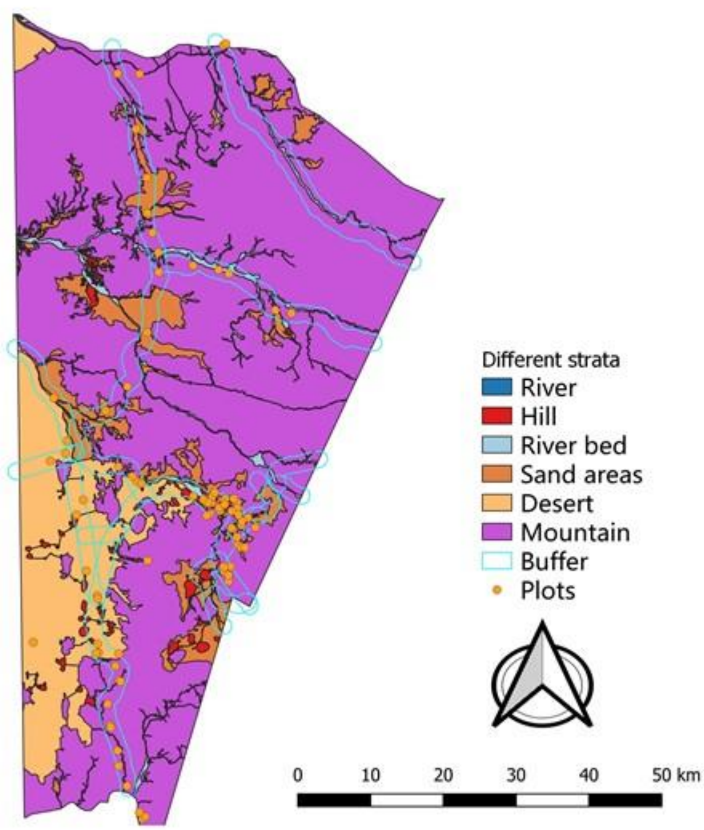

Figure 7. Stratified sampling design of the study area

R98L R25R

Figure 9. Plot R98L in stony ground stratum

Figure 8. Plot R25S in stony ground stratum

The species-area curve was constructed using all the species observed within the sites. It describes the relationship between the number of plots sampled and the number of species found within these plots, estimating the number of species of the study area. The species accumulation curve shows that the area has been sufficiently sampled (Figure 10).

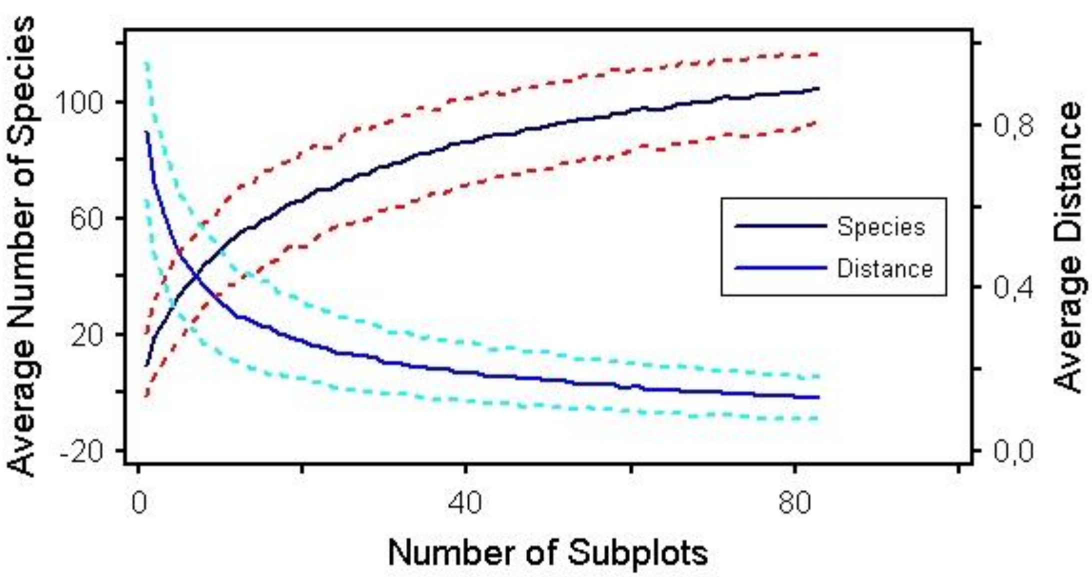

Figure 10. Species-area curve with 83 plots from the wet season. The distance line represents the abundance of the plots. This line will eventually go to zero when the number of plots is sufficient.

3.2 Identification of species within the study area that are endemic to Angola

In total of the plants observed in Iona NP, 157 different plant species were recorded in the study area, of which 120 were identified (See appendix 3). The remaining 37 specimens could not be identified as their development was directly affected by the drought that has been occurring since 2016, preventing many plants from presenting the main characteristics that facilitate their identification (De Cauwer: Field trip report Serra Cafema Camp, October 2020). The 120 identified species belong to 73 genera and 39 families (Figure 11), with 89 listed in the Checklist of plants of Angola and according to Figueiredo (2008), four are endemics to Angola (*Cerraria carrissoana, Commiphora mossamedensis, Euphorbia congestiflora, Euphorbia gariepina*) (Figueiredo 2008). But, two of them are registered as occurring in Namibia (*Cerraria carrissoana, Euphorbia congestiflora*). The most common genera were *Commiphora* (12 species), *Euphorbia* (9 species), *Acacia* (6 species), and *Combretum* (4 species), (See appendix 3).

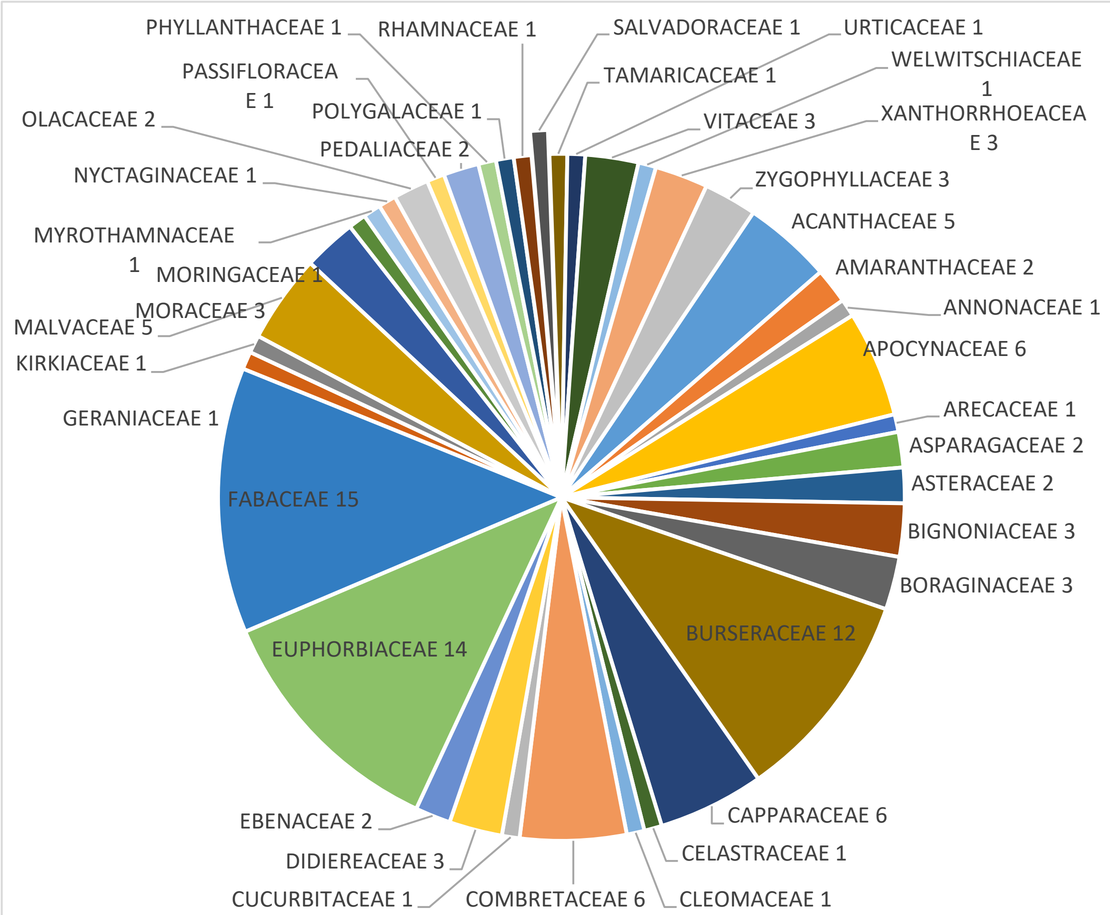

Figure 11. Diagram grouping the plants identified in Iona National Park in family and number of genera.

We are aware of the taxonomic change of the genera *Acacia* (Kyalangalilwa *et al.* 2013, Dyer 2014), however, we still use the term *Acacia* as it is still accepted in the plant list website (www.theplantlist.org), the updated checklist of Namibian plants (Klaassen and Kwembeya 2013), and the checklist of Angola plants (Figueiredo 2008).

3.3 Identify plant communities and their environmental drivers in Iona National Park

Major plant communities of large areas are classified into component communities based on physiognomy. Component communities are classified into small communities, recognized after identifying the dominant species.

3.3.1 Identification of plant communities

The vegetation classification based on the mean dissimilarity of the plots per vegetation unit resulted in a cluster dendrogram that presents the optimal cutting level at eight classes (Figure 12). The optimal cutting level of the dendrogram is based on the best results of the MRPP (T and A) and ISA (Indicator species, mean *IV*) for the analysis of 6 communities groups with 3 to 8 classes(Table 2). The best result is for group number 6 with 8 communities (Gr6-C8). It is characterised by 32 indicator species with a significant *p*-value and IV (Table 2). The plant community number 6 is formed by a group of unidentified species of grasses because the vegetation was affected by the abnormal drought occurring since 2016. Shannon diversity index, species abundance and species richness are provided for each community to understand the distribution of the plants and plant diversity (Figure 13 and Table 5).

Table 2. MRPP (T and A) Result for different groups (Gr), with the number of communities (C) for each group.

MRPP Wet season all	**Gr1-C3**	**Gr-C4**	**Gr-C5**	**Gr-C6**	**Gr-C7**	**Gr-C8**
T	-34.337	-33.844	-35.707	-36.099	-35.247	-33.738
A	0.137	0.166	0.204	0.233	0.250	0.264

Table 3. ISA (Indicator species, mean *IV*) result for different groups (Gr), with the number of communities (C) for each group.

ISA wet season all	**Gr1-C3**	**Gr-C4**	**Gr-C5**	**Gr-C6**	**Gr-C7**	**Gr-C8**
Indicator species	20	22	22	20	26	33
mean p	0.490	0.452	0.415	0.409	0.413	0.415
mean IV	11.213	12.161	13.592	15.079	15.988	18.860

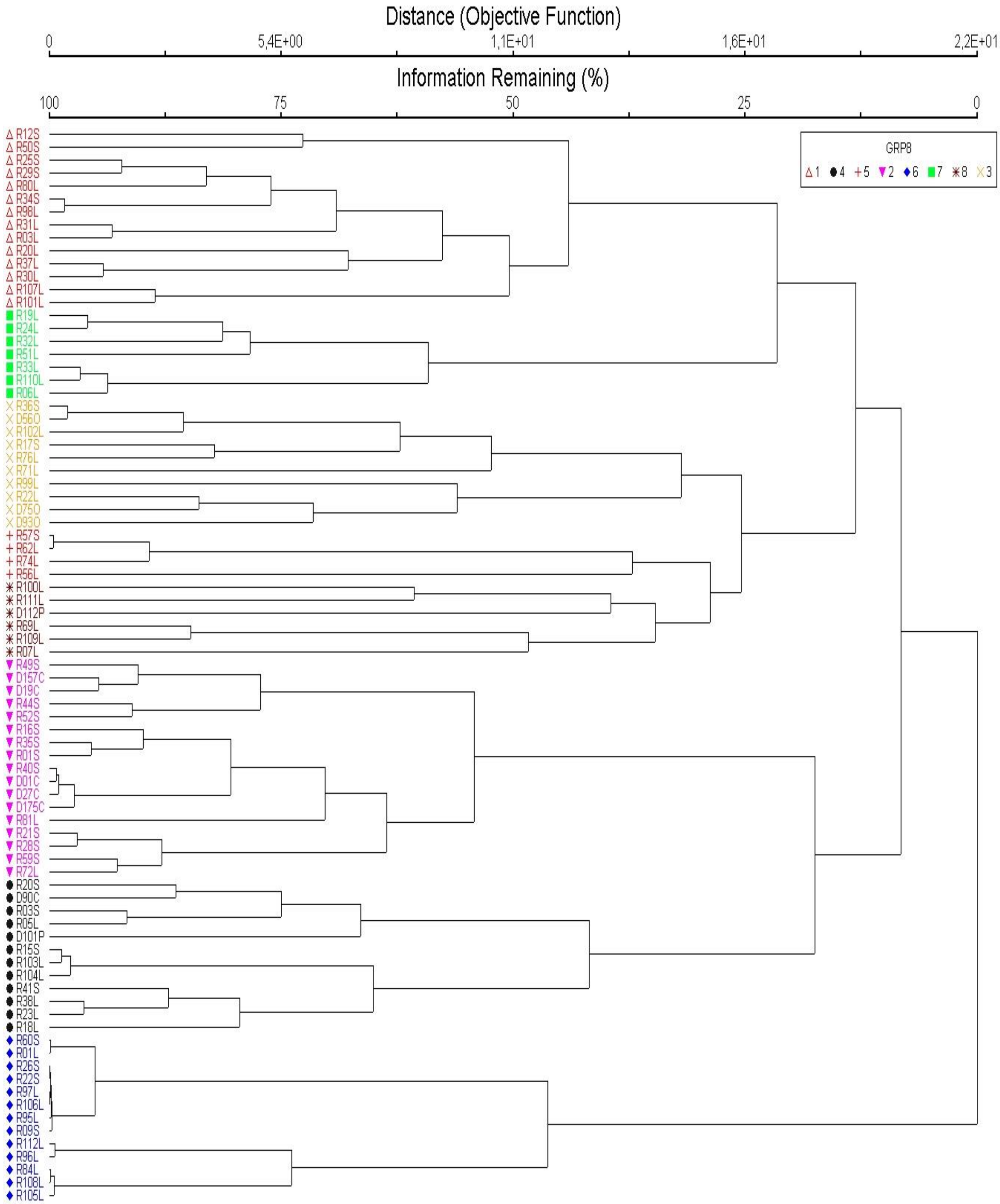

Figure 12. Cluster dendogram of 83 relevés. Cass *1- Acacia mellífera, 2- Terminalia prunioides - Colophospermum mopane, 3- Calicorema capitata, 4- Commiphora multijuga - Rhigozum virgatum, 5- Cordia sinensis - Combretum imberbe, 6-* Grasses, *7- Euphorbia virosa - Commiphora wildii, 8- Welwitschia mirabillis.*

Table 4. Plant communities in the study area.

Groups	Plant community	Number of species with a significant Indicator Value	Total number of the species that form the community	Number of plots
1	*Acacia mellífera*	1	27	14
2	*Terminalia prunioides - Colophospermum mopane*	4	17	17
3	*Calicorema capitata*	1	8	10
4	*Commiphora multijuga - Rhigozum virgatum*	5	12	12
5	*Salvadora persica - Combretum imberbe community*	4	10	4
6	Grasses	1	3	13
7	*Euphorbia virosa - Commiphora wildii* community	5	7	7
8	*Welwitschia mirabilis*	1	7	6

Table 5. Species richness per community.

Groups	Groups	Richness
Class1	*Acacia mellífera*	73
Class2	*Terminalia prunioides - Colophospermum mopane*	133
Class3	*Calicorema capitata*	41
Class4	*Commiphora multijuga - Rhigozum virgatum*	85
Class5	*Salvadora persica - Combretum imberbe community*	29
Class7	*Euphorbia virosa - Commiphora wildii* community	44
Class8	*Welwitschia mirabilis*	11

Table 6. Significant indicator species for classification with 8 classes.

Communities	**Column**	**Indicator Value**	**p* value**
1- *Acacia mellífera*	*Acacia mellifera*	72.2	0.02
2- *Terminalia prunioides - Colophospermum mopane*	*Colophospermum mopane*	64.2	0.02
	Terminalia prunioides	55.8	0.04
	Catophractes alexandri	44.6	0.04
	Hoodia parviflora	23.7	0.04
3- *Calicorema capitata*	*Calicorema capitata*	30	0.01
4-*Commiphora multijuga - Rhigozum virgatum*	*Rhigozum virgatum*	64.4	0.02
	Commiphora multijuga	39.3	0.04
	Commiphora mossamedensis	31.4	0.02
	Boscia tomentosa	27.2	0.02
	Commiphora tenuipetiolata	27	0.02
5- *Salvadora persica - Combretum imberbe*	*Combretum imberbe*	73.1	0.02
	Salvadora persica	72.9	0.02
	Cordia sinensis	69.4	0.02
	Tamarix usneoides	50	0.02
	Gossypium anomalum	40.3	0.06
	Balanites angolensis	27.6	0.02
	Commiphora glandulosa	25	0.04
	Dichrostachys cinerea	25	0.02
	Sutherlandia frutescens	25	0.04
	Gymnosporia senegalensis	23.2	0.02
7- *Euphorbia virosa - Commiphora wildii*	*Commiphora wildii*	67.5	0.02
	Petalidium sp.	60.2	0.02
	Euphorbia virosa	46.7	0.01
	Commiphora virgata	37.3	0.05
	Commiphora glaucescens	33.8	0.01
8- *Welwitschia mirabilis*	*Welwitschia mirabilis*	33.5	0.01

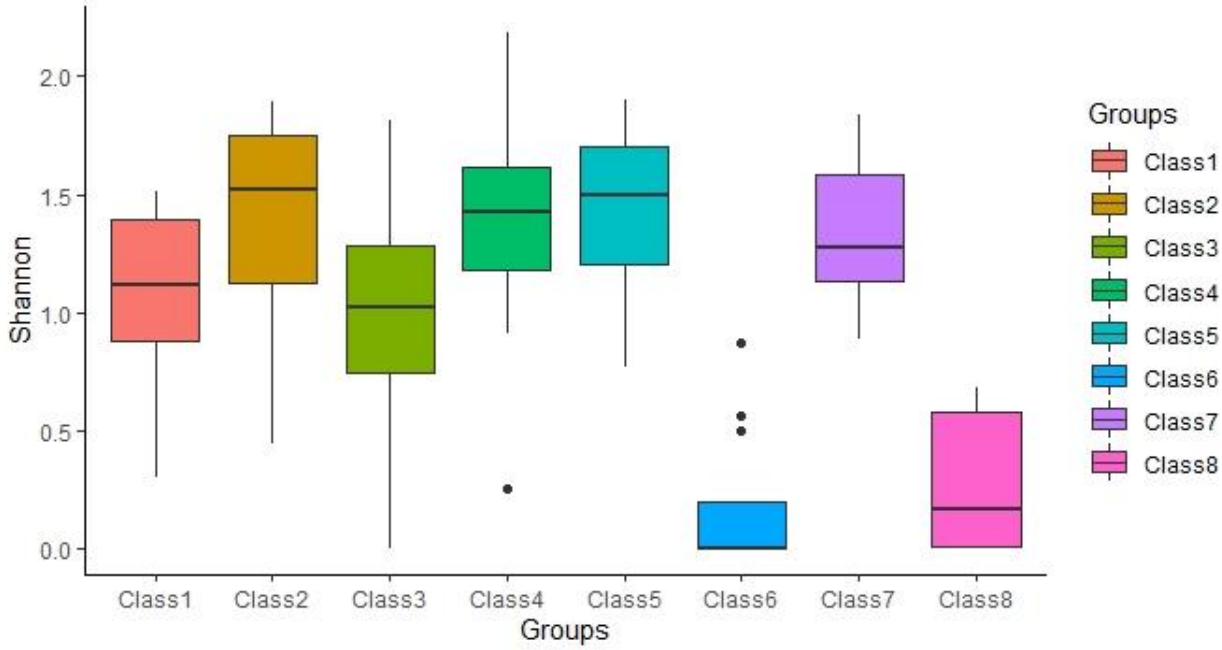

Figure 13. Shannon diversity indices of the communities. Class 1- *Acacia mellífera, 2- Terminalia prunioides -Colophospermum mopane,* 3- *Calicorema capitata,* 4- *Commiphora multijuga - Rhigozum virgatum,* 5- *Cordia sinensis - Combretum imberbe, 6-* Grasses*, 7- Euphorbia virosa - Commiphora wildii,* 8- *Welwitschia mirabilis.*

3.3.2 Plant communities and their environmental drivers

The figures 14, 15, and 16 show the distribution of the communities along the ordination diagram for the three NMS axes. The patterns show that the vegetation classes, in general, are closely related to each other. Observing each axis, it is noted that several vegetation communities do overlap, but the community 4-*Commiphora multijuga - Rhigozum virgatum,* 6- Grasses, and 5- *Salvadora persica - Combretum imberbe* are separated from others and well defined. In general, axis 1, shows that the communities 4- *Commiphora multijuga - Rhigozum virgatum*, 5- *Salvadora persica - Combretum imberbe* and 6- Grasses are more distinct from others. Axis 2 shows that communities 4- *Commiphora multijuga – Rhigozum virgatum* and 6- Grasses are distinct from others and for axis 3, the community 5- *Salvadora persica - Combretum imberbe*, is very distinct from other communities again.

The correlation between the environmental variables and NMS axes is weak for most of the cases, and thus not much information can be obtained about the impact of environmental variables on the vegetation composition (See table 7).

Table 7. Correlation of the environmental variables and NMS ordination axes, underlined and bold the strongest correlations for each axies.

	Axis.1	Axis.2	Axis.3
Axis.1	1	0.172	-0.017
Axis.2	0.172	1	0.011
Axis.3	-0.017	0.011	1
Slop	-0.191	-0.287	0.255
Elev	0.057	-0.020	-0.281
Boulders	**-0.521**	**-0.378**	0.134
Cobbles	**-0.525**	**-0.318**	0.053
Pebbles	**-0.516**	**-0.386**	0.027
TPI	-0.042	-0.045	0.224
Aspect	-0.139	0.103	0.173
Distan	0.186	-0.236	0.257
B.Rock	**0.434**	0.192	0.219
BIO1	-0.030	0.039	0.262
BIO5	0.042	0.133	**0.345**
LST.Day	0.215	0.108	**0.506**
LST.Night	-0.275	-0.187	0.166

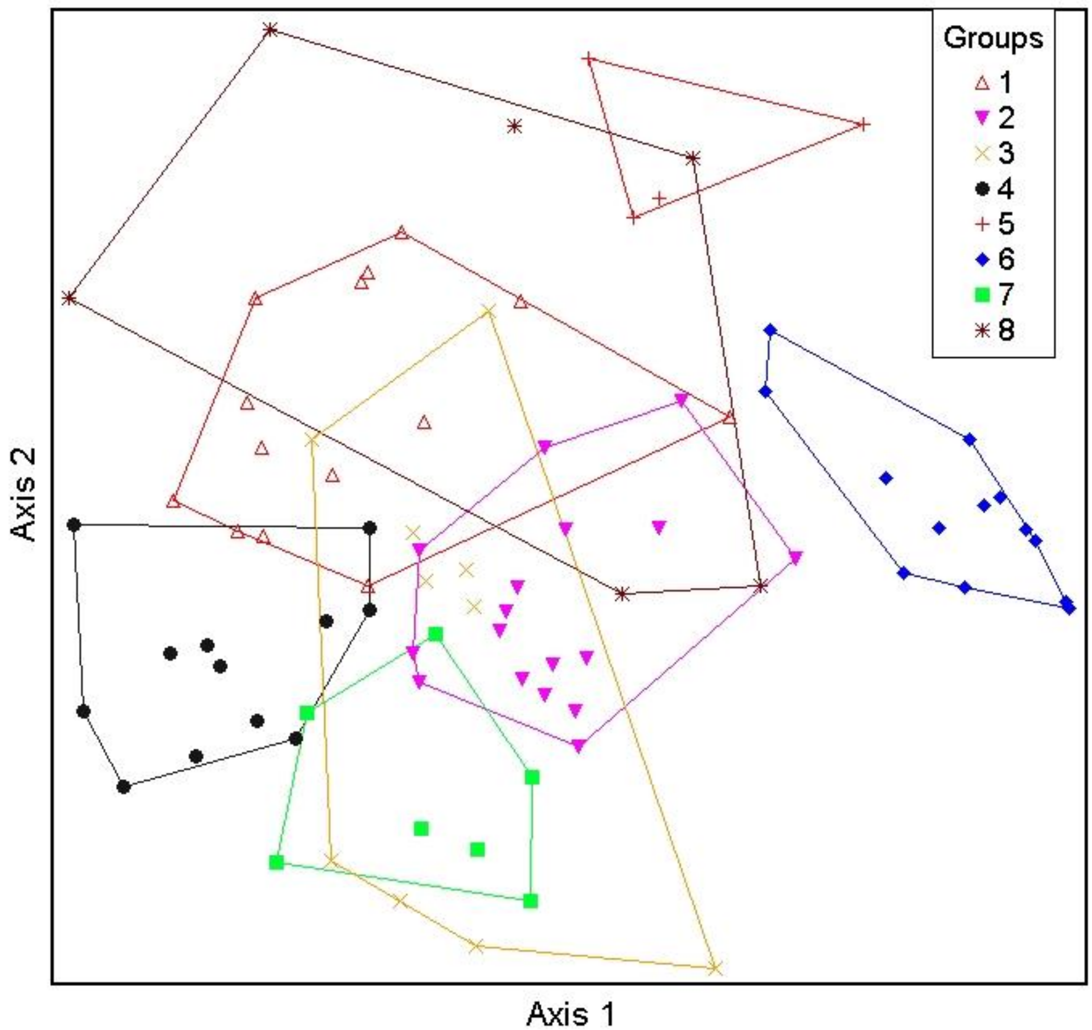

Figure 14. NMS Ordination along axes 1 and 2. 1- *Acacia mellífera*, 2- *Terminalia prunioides - Colophospermum mopane*, 3- *Calicorema capitata*, 4- *Commiphora multijuga - Rhigozum virgatum*, 5- *Salvadora persica - Combretum imberbe*, 6- Grasses, 7- *Euphorbia virosa - Commiphora wildii*, 8- *Welwitschia mirabilis*.

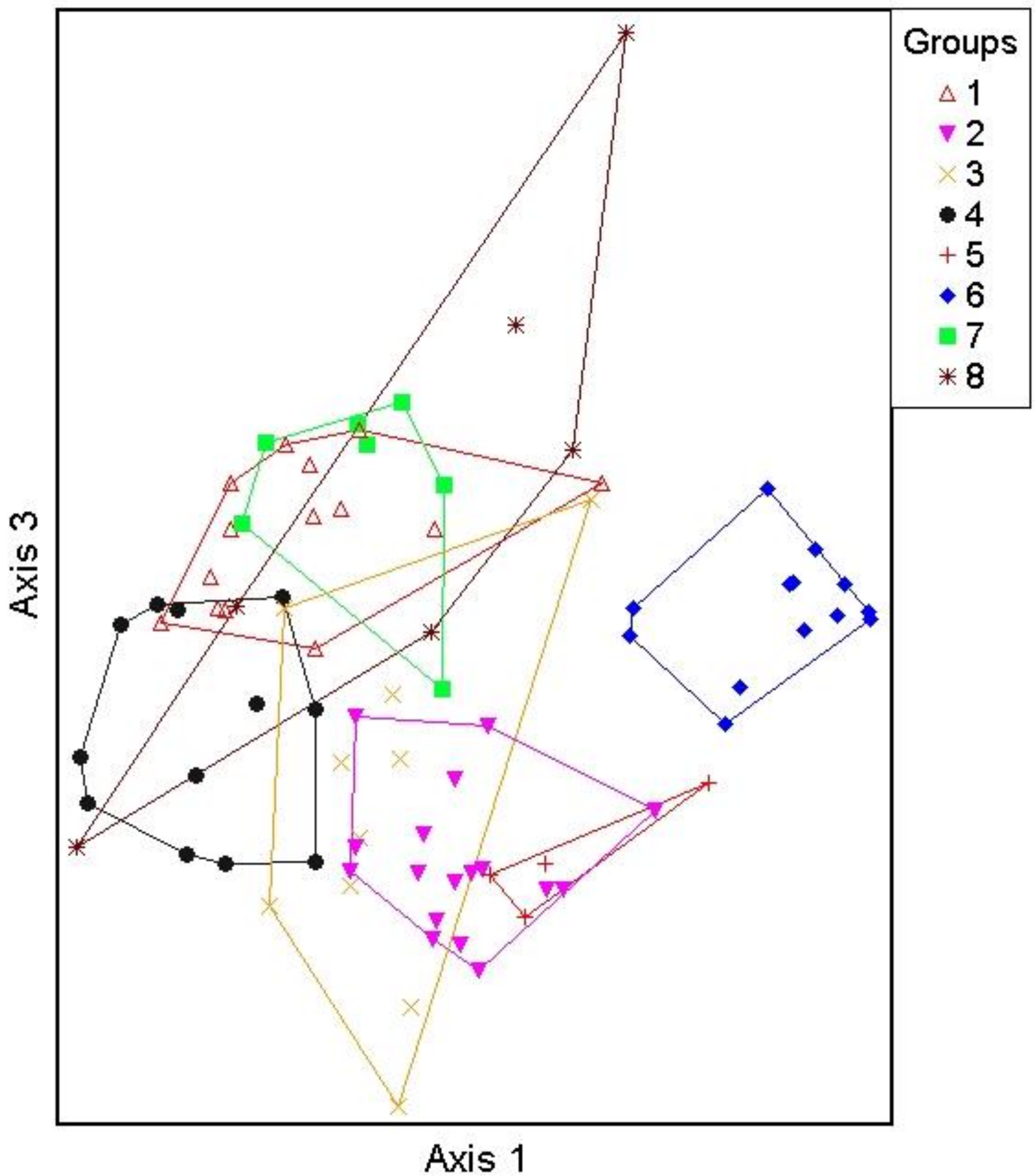

Figure 15. NMS Ordination along Axis 3 and Axis 1. 1- *Acacia mellífera*, 2- *Terminalia prunioides - Colophospermum mopane,* 3- *Calicorema capitata*, 4-*Commiphora multijuga - Rhigozum virgatum*, 5- *Salvadora persica - Combretum imberbe*, 6- Grasses, 7- *Euphorbia virosa - Commiphora wildii*, 8- *Welwitschia mirabillis.*

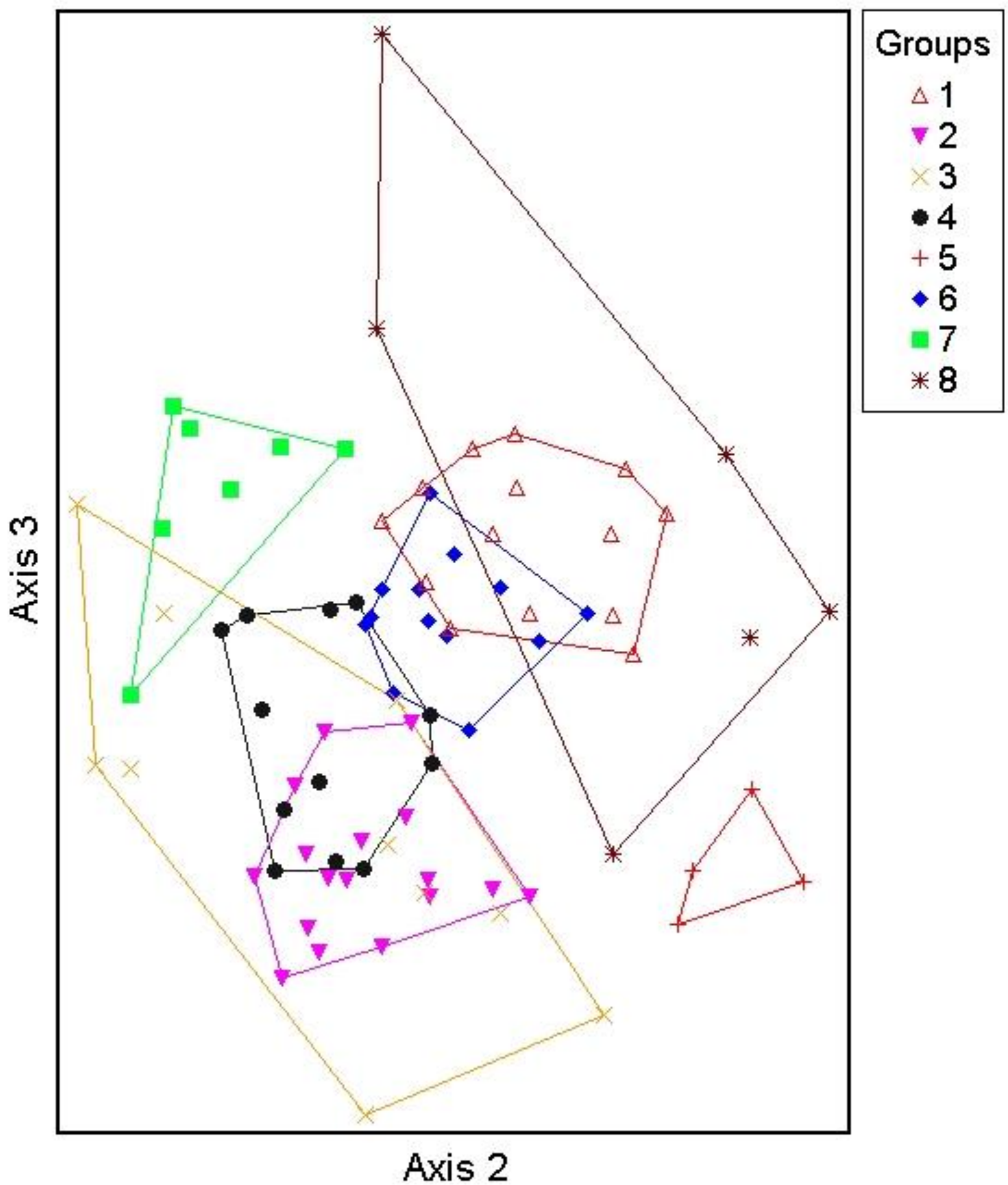

Figure 16. NMS Ordination along Axis 3 and Axis 2. 1- *Acacia mellífera*, 2- *Terminalia prunioides - Colophospermum mopane*, 3- *Calicorema capitata*, 4- *Commiphora multijuga - Rhigozum virgatum*, 5- *Salvadora persica -Combretum imberbe*, 6- Grasses, 7- *Euphorbia virosa - Commiphora wildii*, 8- *Welwitschia mirabillis.*

The ANOVA with the Tukey post hoc test presents the differences and similarities of each community related to each variable (Figure 17 to 20). The boxplot was coloured blue according to the result of the medium value for each class; the larger the medium value, the darker the colour. Compact letter displays were used to visually help discern the significant differences between communities related to the variable.

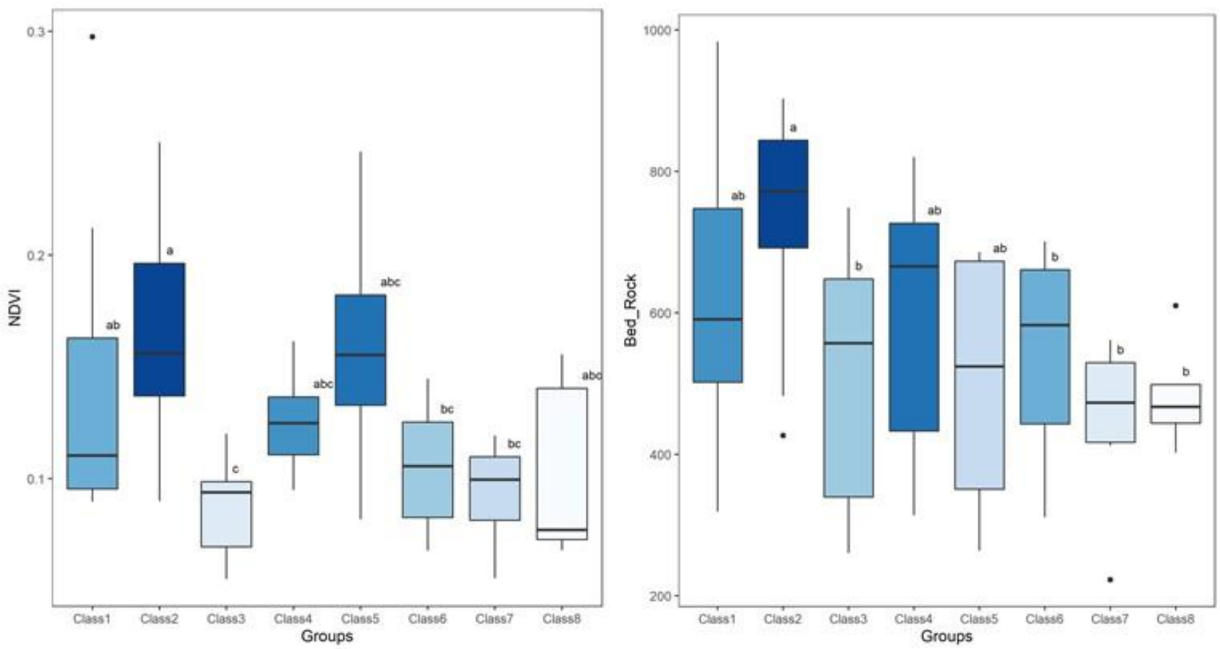

Figure 17. Boxplots of Difference of the Normalised Difference Vegetation Index and Bedrock between communities. The boxes represent the median and the interquartile range with the vertical lines showing the range. Class *1- Acacia mellífera,* Classe *2- Terminalia prunioides -Colophospermum mopane,* Classe *3- Calicorema capitata,* Classe *4- Commiphora multijuga - Rhigozum virgatum,* Classe *5- Salvadora persica - Combretum imberbe,* Classe *6- Grasses,* Classe *7- Euphorbia virosa - Commiphora wildii,* Classe *8- Welwitschia mirabillis.*

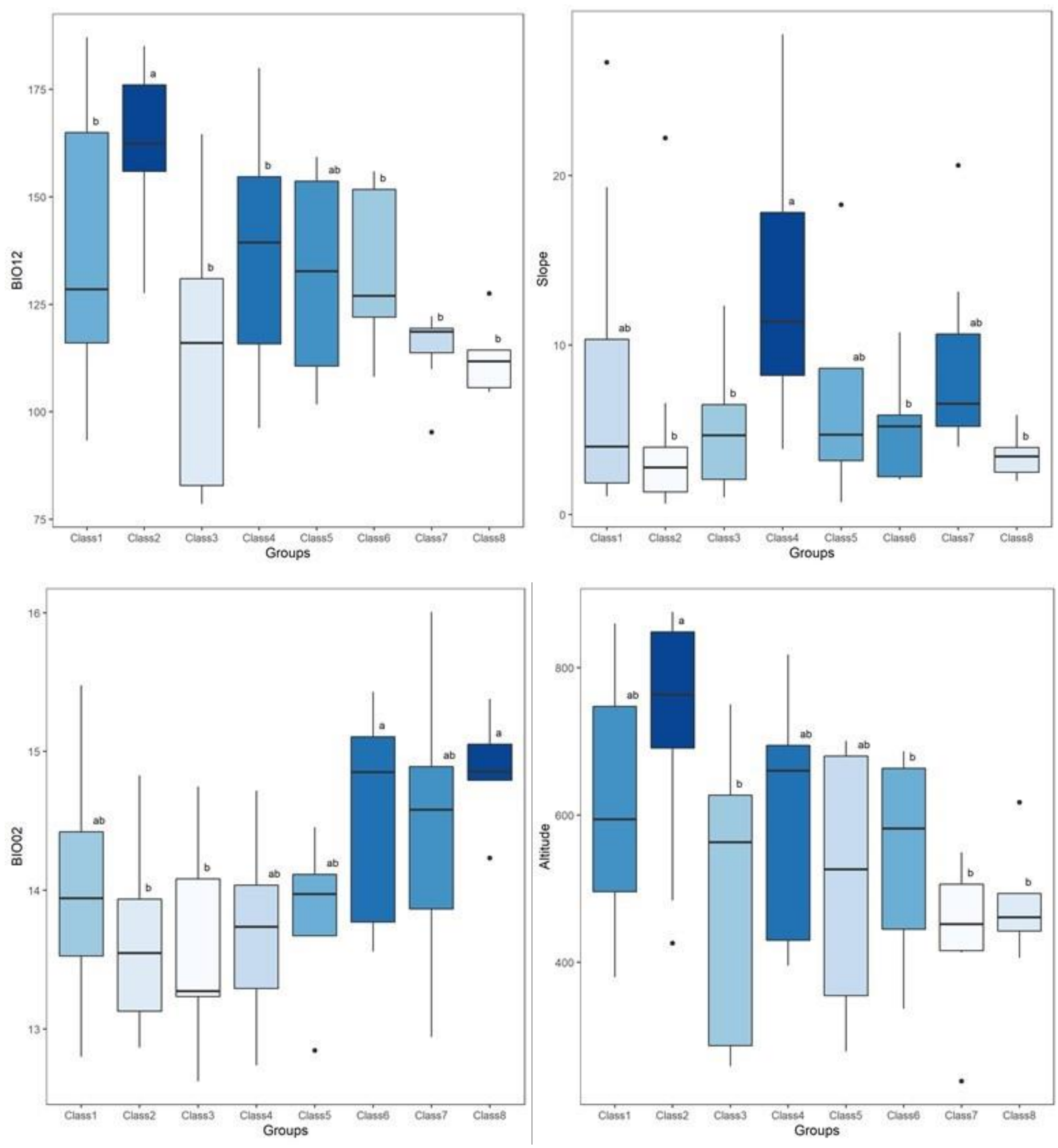

Figure 18. Boxplots of Difference of the Annual precipitation (BIO12), Slope, Mean diurnal range(BIO2) and Altitude. The boxes represent the median and the interquartile range with the vertical lines showing the range. Class 1- *Acacia mellífera*, Classe 2- *Terminalia prunioides -Colophospermum mopane*, Classe 3- *Calicorema capitata*, Classe 4- *Commiphora multijuga - Rhigozum virgatum*, Classe 5- *Salvadora persica - Combretum imberbe,* Classe 6- Grasses, Classe 7- *Euphorbia virosa - Commiphora wildii*, Classe 8- *Welwitschia mirabillis.*

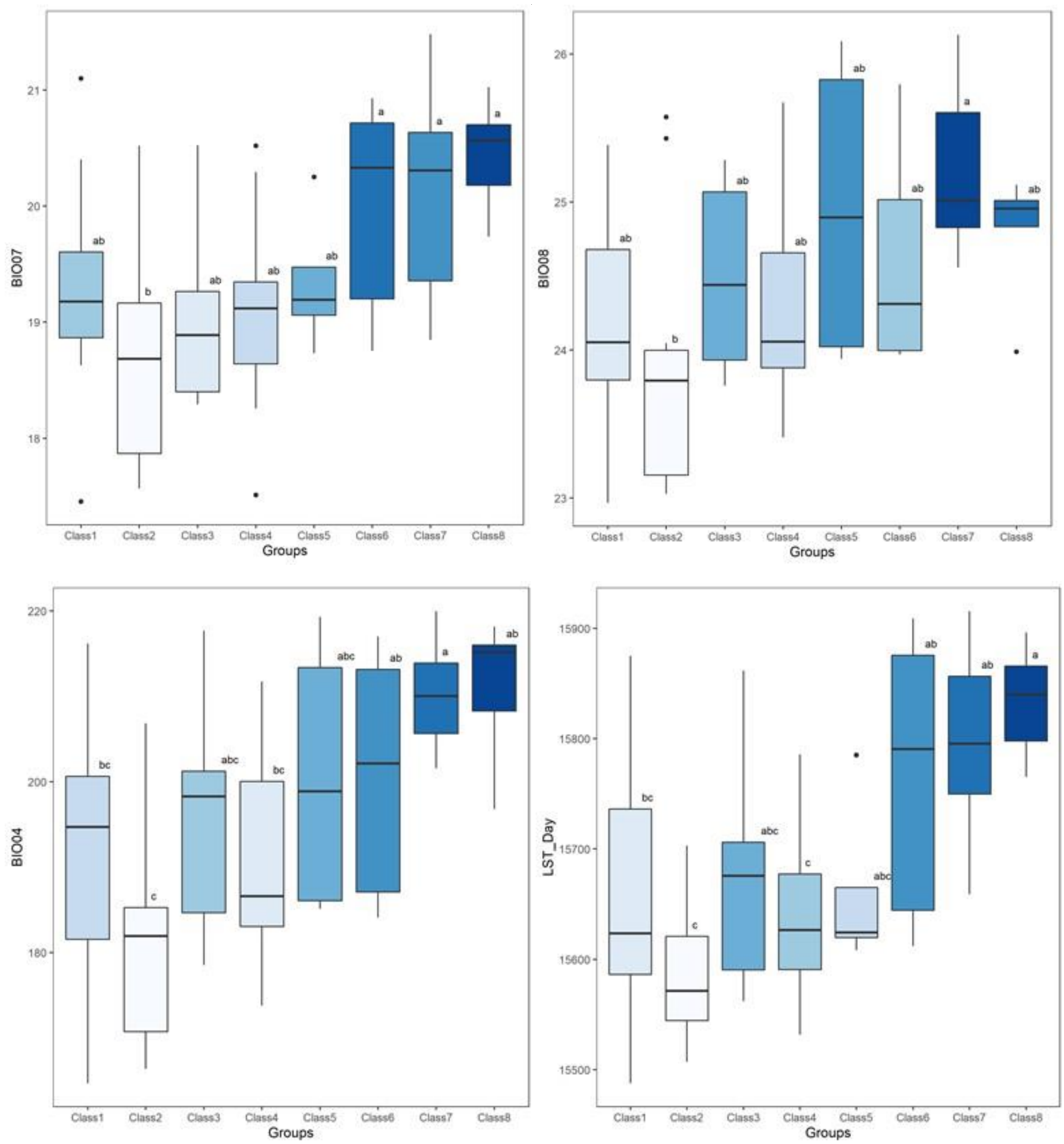

Figure 19. Boxplots of Difference of the Temperature annual range (BIO7), Mean temperature of wettest quarter (BIO8), temperature seasonality (BIO4) and Land Surface Temperature Day (LST_Day). The boxes represent the median and the interquartile range with the vertical lines showing the range. Class *1- Acacia mellífera,* Classe *2- Terminalia prunioides -Colophospermum mopane,* Classe *3- Calicorema capitata,* Classe *4- Commiphora multijuga - Rhigozum virgatum,* Classe *5- Salvadora persica - Combretum imberbe,* Classe *6- Grasses,* Classe *7- Euphorbia virosa - Commiphora wildii,* Classe *8- Welwitschia mirabillis.*

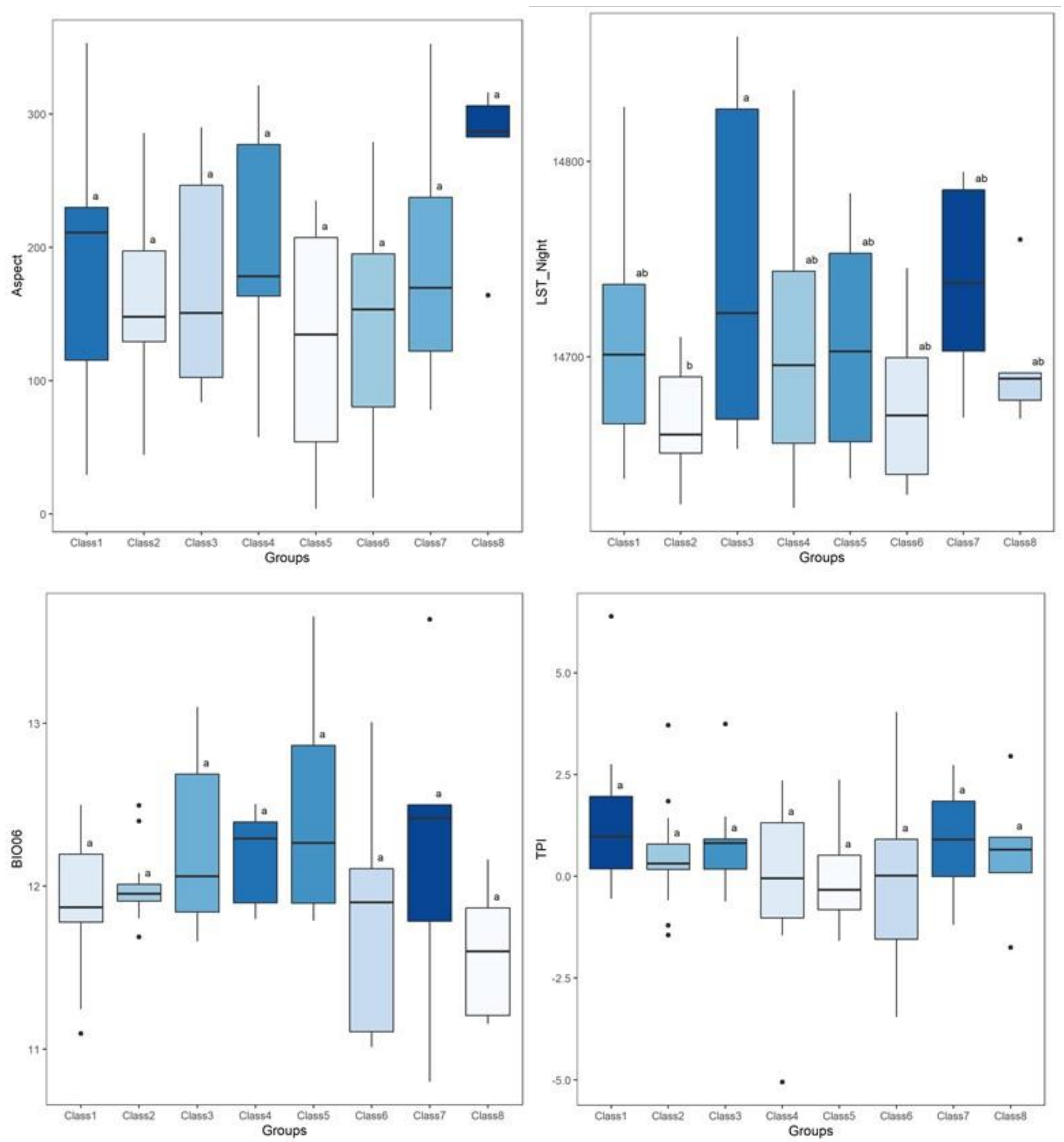

Figure 20. Boxplots of Difference of the Aspect, Land Surface Temperature Night (LST_Night), min temperature of coldest month (BIO6), and Topographic position índex (TPI). The boxes represent the median and the interquartile range with the vertical lines showing the range. Class *1- Acacia mellífera,* Classe *2- Terminalia prunioides -Colophospermum mopane,* Classe *3- Calicorema capitata,* Classe *4- Commiphora multijuga - Rhigozum virgatum,* Classe *5- Salvadora persica - Combretum imberbe,* Classe *6- Grasses,* Classe *7- Euphorbia virosa - Commiphora wildii,* Classe *8- Welwitschia mirabillis.*

3.3.3 Description of identified plant communities

Detailed characterization of the eight different plant communities resulting from the analyses described before is provided. It was carried out according to data collected on-site and the interpretation of the results of the impact of environmental variables on this community.

1- *Acacia mellífera* community

The first group is the second biggest group in terms of the number of species but is characterized by only one species with a significant indicator value, which represents the community: *Acacia mellifera.* The vegetation of this community is abundant in the Park and common in several strata (Figure 21 and 22, Table 8).

Habitat: This vegetation usually occurs in areas with stony soil or on the hill, and and it is distributed in areas close to the bedrock. It is not affected by terrain slopes, with random values of Land Surface Temperature day and night and can be found at different altitude levels. It has a temperature annual range and mean temperature of wettest quarter randomly equal to all other communities.

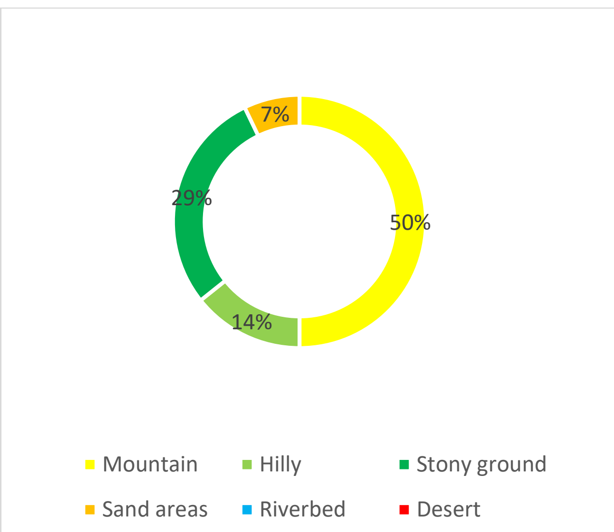

Figure 21.Distribution of the strata for the plots that form the community *Acacia mellífera.*

Table 8. Summary of environmental variables for the plots that form the *Acacia mellífera* community.

Position on slope	**Plots**	**Soil texture**	**Plots**
Bottom	10	Sandy loamy	7
Lower middle	3	Sand	3
Top	1	Clay loamy	4
Upper middle	0	Loam	0

Figure 22. Appearance of *Acacia mellifera* community, Relevé 20L, 29 March 2020.

2- ***Terminalia prunioides - Colophospermum mopane* community**

This community has the highest number of plots sampled. It is a community that is commonly observed in the Park, and it is characterized by tall shrubs and trees. *Colophospermum mopane* and *Terminalia prunioides* are the dominant species in this plant community*. Catophractes alexandri* and *Hoodia parviflora* also belong to this community (Figure 23 and 24, Table 9).

Habitat: This plant community is very close to the first one in terms of habitat as it is characterized by stony soil with a moderate amount of boulders, cobbles and pebbles cover situated on the lower to middle mountain slopes. It presents the values for vegetation index and hence, highest plant biomass. The distribution of this community is well affected by the distance of the bedrock layer. It presents the lowest value of Land Surface Temperature day and night, It is found at the highest places with the low value of the slope. Occurs in areas with the highest level of annual precipitation and with the lowest temperature annual range and mean temperature of wettest quarter compared to other communities.

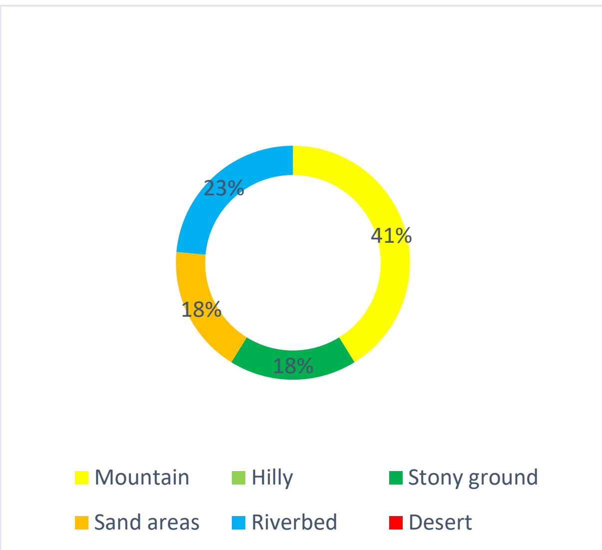

Figure 23. Distribution of the strata for the plots that form the community *Terminalia prunioides - Colophospermum mopane*.

Table 9. Summary of environmental variables for the plots that form the *Terminalia prunioides* - *Colophospermum mopane* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	9	Sandy loamy	14
Lower middle	4	Sand	3
Top	2	Clay loamy	0
Upper middle	2	Loam	0

Figure 24. Vegetation of *Terminalia prunioides* - *Colophospermum mopane* community, Relevé 81L, 29 March 2020.

3- *Calicorema capitata* community

This community varies from low to tall open shrubland. The vegetation is as variable as the habitat is, and it has only one indicator species, *Calicorema capitata,* that represents the community. *C. capitata* is a shrub that is quite abundant in the study area and common in several strata (Figures 25 and 26, Table 10). Habitat: This vegetation occurs usually on stony soil. has a low vegetation index and is distributed in areas with low cover of the bedrock layer. It had the lowest values of land surface temperature during the day but the highest at night. It is found at places with low altitude and rather flat terrain. Occurs in areas with relatively lower annual precipitation.

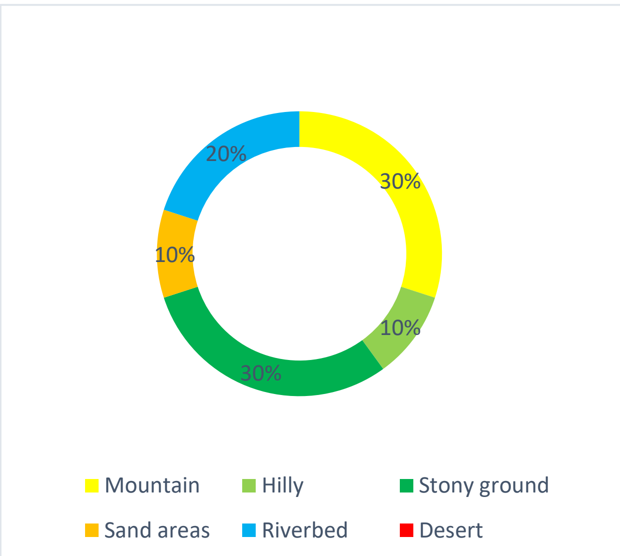

Figure 25. Distribution of the strata for the plots that form the community *Calicorema capitata*.

Table 10. Summary of environmental variables for the plots that form the *Calicorema capitata* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	3	Sandy loamy	9
Lower middle	5	Sand	1
Top	0	Clay loamy	0
Upper middle	2	Loam	0

Figure 26. Vegetation of *Calicorema capitata* community, Relevé 22L, 26 March 2020.

4- *Commiphora multijuga* - *Rhigozum virgatum* community

This community consists of shrubs and trees. *Rhigozum virgatum* and *Commiphora multijuga* are the characteristic and dominant plant species in this plant community. *Boscia tomentosa, Commiphora tenuipetiolata,* and *Commiphora mossamedensis* also belong to this community (Figure 27, 28 Table 11).

Habitat: This community is found on stony soil, mainly in mountains. It presents a low value of Land Surface Temperature during the day. ., It is found at places with the steepest slopes. Occurs in areas with a low level of annual precipitation.

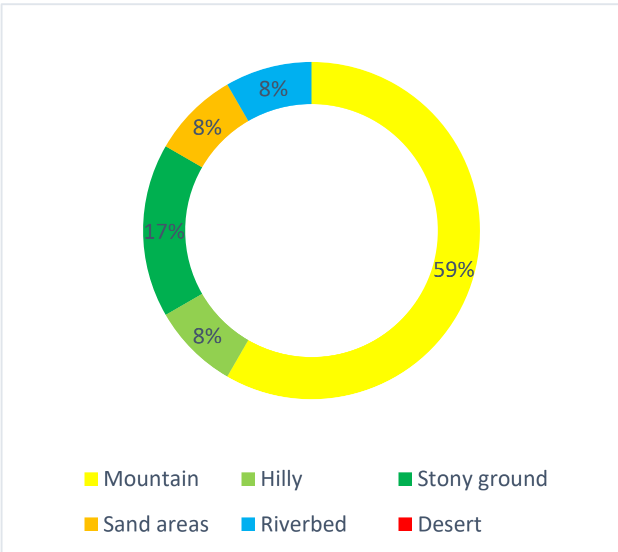

Figure 27. Distribution in the strata of the plots that form the community *Commiphora multijuga - Rhigozum virgatum*.

Table 11. Summary of environmental variables for the plots that form the *Commiphora multijuga - Rhigozum virgatum* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	5	Sandy loamy	9
Lower middle	3	Sand	1
Top	1	Clay loamy	1
Upper middle	3	Loam	1

Figure 28. Vegetation of *Commiphora multijuga - Rhigozum virgatum* community, Relevé 18L, 30 March 2020.

5- *Salvadora persica - Combretum imberbe* community

This community has the largest number of species with a significant indicator value. The dominant species are *Combretum imberbe* and *Salvadora persica*. Other plants that characterize this community are *Balanites angolensis, Commiphora glandulosa, Cordia sinensis, Dichrostachys cinerea, Gossypium anomalum, Gymnosporia senegalensis, Tamarix usneoides,* and *Sutherlandia frutescens* (Figure 29, 30 Table 12).

Habitat: this community is only found near rivers in areas where the soils are more sandy.

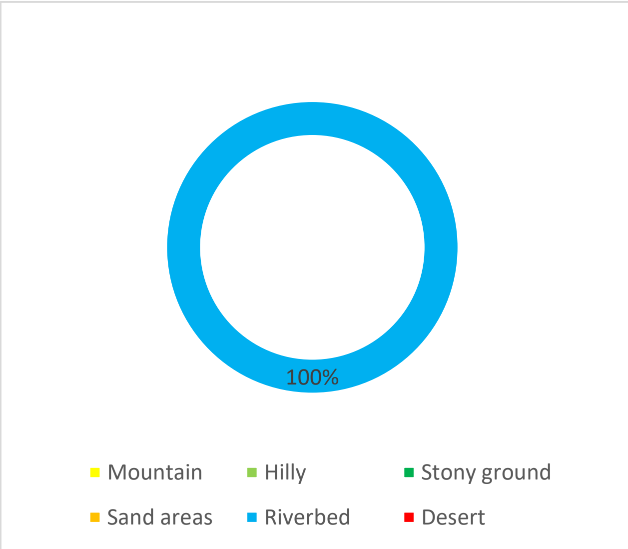

Figure 29. Distribution in the strata of the plots that form the community *Cordia sinensis - Combretum imberbe*.

Table 12. Summary of environmental variables for the plots that form the *Salvadora persica - Combretum imberbe* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	5	Sandy loamy	1
Lower middle	0	Sand	2
Top	0	Clay loamy	1
Upper middle	0	Loam	0

Figure 30. Vegetation of *Salvadora persica - Combretum imberbe* community, Relevé 57L, 07 April 2020.

6- Grasses community

This community is characterized by grasses. The plants belonging to this community were completely dry during data collection. It was possible to observe that they are grasses but it was not possible to identify them. Amongst the predominant species from this area are various *Stipagrostis* species (Figure 31, 32, Table 13).

Habitat: This plant community belongs to open sandy areas of the semi-desert. It is found at places with low values of altitude and slope. Occurs in areas with a low level of annual precipitation.

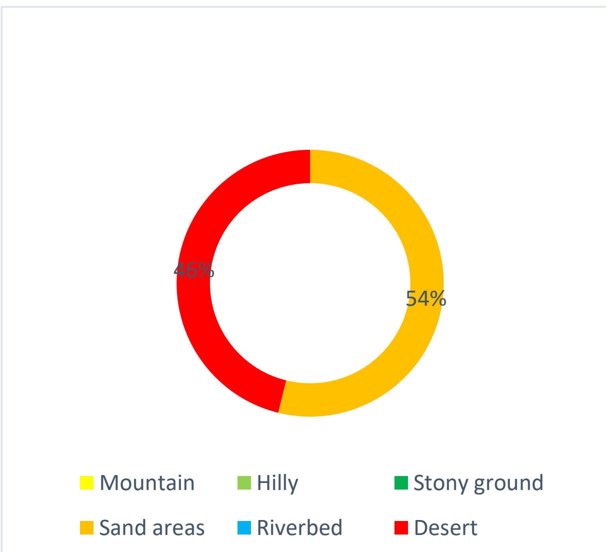

Figure 31. Distribution in the strata of the plots that form the community Grasses.

Table 13. Summary of environmental variables for the plots that form the Grasses community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	13	Sandy loamy	7
Lower middle	0	Sand	7
Top	0	Clay loamy	0
Upper middle	0	Loam	0

Figure 32. Grasses community, Relevé R96L, 07 March 2020.

7- *Euphorbia virosa - Commiphora wildii* community

This community forms open shrubland and is characterized by species that are found in mountains (Procheş 2011). The most common species are *Commiphora wildii* and *Petalidium spp*. Other species that belong to this community are *Commiphora dinteri, Commiphora virgata,* and *Euphorbia virosa* (Figure 33, 34, Table 14).

Habitat: the vegetation from this community is mainly found on mountains and hills with very rocky soil. It is found at places with lower altitude. Occurs in areas with a low level of annual precipitation, with a high value of temperature annual range and the higher temperature of wettest quarter compared to other communities.

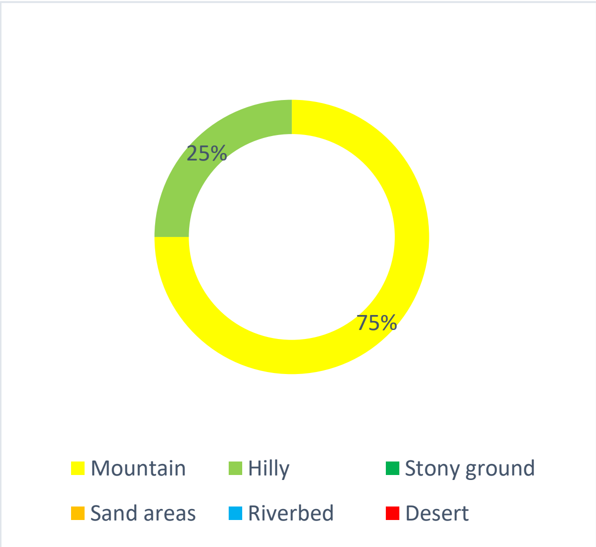

Figure 33. Distribution in the strata of the plots that form the community *Euphorbia virosa - Commiphora wildii.*

Table 14. Summary of site information of the plots that form the *Euphorbia virosa - Commiphora wildii* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	2	Sandy loamy	4
Lower middle	1	Sand	1
Top	2	Clay loamy	2
Upper middle	2	Loam	0

Figure 34. Vegetation of the community *Euphorbia virosa - Commiphora wildii* , Relevé 32L, 30 March 2020.

8- *Welwitschia mirabillis* community

In this community, the vegetation is generally low open shrubland, while it is characterized by only one species that is endemic to the Namib desert; *Welwitschia mirabilis* (Van Zinderen Bakker 1975, Van Damme 1991). See figure 35, 36 Table 15.

Habitat: This plant characterizes the Namib Desert, it is found on sandy to medium stony ground areas. has the lowest value of the impact of bedrock layer. It is found at places with lower elevation and flatter terrain. Occurs in areas with a low level of annual precipitation, with a high value of temperature annual range and general random value of the temperature of wettest quarter compared to other communities.

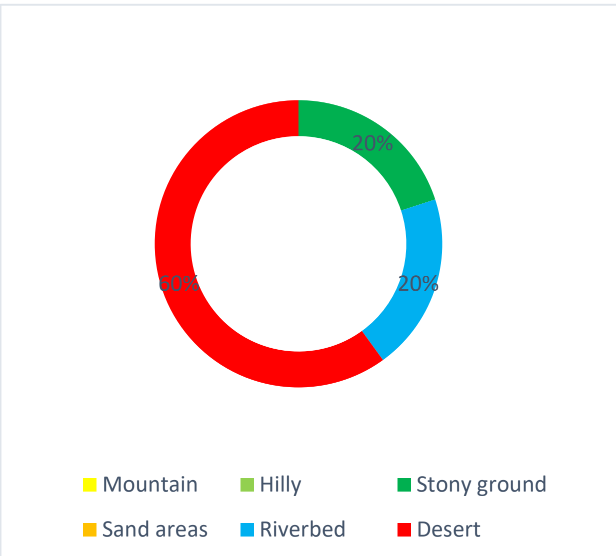

Figure 35. Distribution in the strata of the plots that form the community *Welwitschia mirabillis.*

Table 15. Summary of site information of the plots that form the *Welwitschia mirabilis* community.

Position slope	**Plots**	**Soil texture**	**Plots**
Bottom	6	Sandy loamy	4
Lower middle	0	Sand	2
Top	0	Clay loamy	0
Upper middle	0	Loam	0

Figure 36. *Welwitschia mirabilis* community, Relevé 100L, 28 March 2020.

3.4 Identify vegetation patterns and create a vegetation map of representative habitats in the Park

To avoid in the model redundant, noisy or unreliable variables that may impair the performance of the final prediction of the model, the selection of the variables was based on the result of variable importance of RF model. 14 variables were selected to be used as predictors for de finale model. The RF model presents 69.12% as OOB estimate of error. The OOB error for each class results showed that the best result of the classification is for class 2 *Terminalia prunioides - Colophospermum mopane,* and the poorest for classes number 1- *Acacia mellífera*, 5- *Salvadora persica - Combretum imberbe and* 7- *Euphorbia virosa - Commiphora wildii* (Table 16).

For cross-validation, the data were partitioned into a fixed number (83 plots), in order to estimate how the RF model is expected to perform in general when used to make predictions on data not used during the training of the model. This resulted in a Kappa coefficient of 0.19, which indicates that the prediction of the model is poor. Because of the poor results obtained with the RF model, the map was not created to avoid the risk of presenting a map with low accuracy in the distribution of communities.

Table 16. OOB error per plant community in Random Forest analysis.

Communities	**Class error**	**Number of plots**
1- *Acacia melífera*	0.91%	14
2- *Terminalia prunioides -Colophospermum mopane*	0.21%	17
3- *Calicorema capitata*	0.62%	10
4-*Commiphora multijuga - Rhigozum virgatum*	0.77%	12
5- *Salvadora persica - Combretum imberbe*	1%	4
6- *Grasses*	0.45%	13
7- *Euphorbia virosa - Commiphora wildii*	1%	7
8- *Welwitschia mirabillis*	0.75%	6

The indices, a default output of the RF model, allow to measure variable importance, the Normalized Difference Vegetation Index, slope, bedrock and annual precipitation are the most important variables in the model (Figure 37).

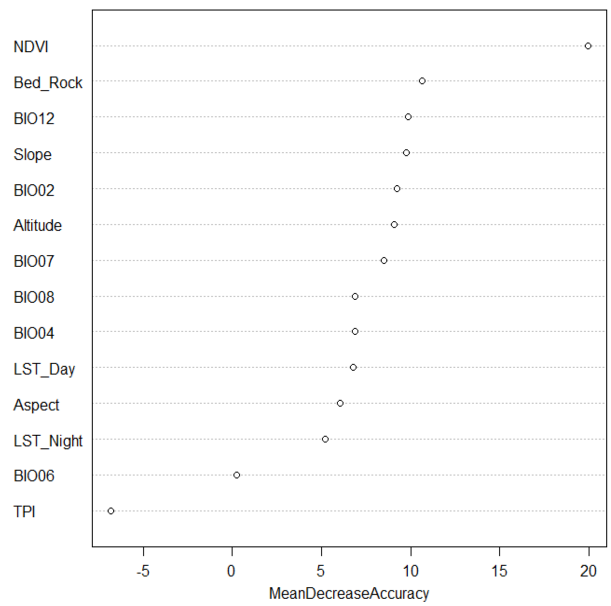

Figure 37. Variables importance in the random forest model, with abbreviated variables Normalized Difference Vegetation Index (NDVI), depth to bedrock (Bed_Rock), Mean diurnal range (bio2), Temperature seasonality (bio4), Minimum temperature of coldest month (bio6), Temperature annual range (bio7), Mean temperature of the wettest quarter (bio8), Annual precipitation (bio12), Land Surface Temperature for the day (LST), and the topographic position index (TPI).

3.5 Identify plants with socio-economic and ethnobotanical value that occur in the area

The interviews were made with the local people that are familiar with plants in that area (herbalists, herders, community chief). A total of 11 individuals, 9 males and 3 females, with ages between 22 and 65 years old, belonging to 5 different villages (Monte Negro, Pediva, Cambeno, Iona and Marinde) were interviewed. From the interviewed 10 people belong to Himba (Ovahimba) that is the most dominant tribe in the area, and 1 belonged to the Curoca, the second dominant tribe in Iona.

The interviews resulted in the description of 45 native plants used by communities living in Iona National Park (Table 7). The uses were divided into 8 categories (livestock fodder, human food, medicinal, traditional uses, wildlife fodder, construction material). The use category with the most cited species is for medicinal purposes and the second most cited use category was for plants that are edible by animals with 10 species.

Table 17. Native plant use by communities living in Iona National Park.

Species	Himba	Curoca	Categories	Uses
Acacia tortilis	Omutondola	Omunkuatampumba	Construction material Medicinal	Used to make hedges around the kraals and vegetable gardens. Women mix it with Chingumuna and use the branches and leaves to steam themself after giving birth to help with recovery.
Aerva leucura		Omkenda	Medicinal Traditional uses	It is used to cure traditional diseases. It is, therefore, their sacred plant that cleanses curses.
Albuca sp	Onhanga	Onhanga	Livestock fodder	It's porcupine and goat food.
Balanites angolensis	Omuumbamenye			The birds eat the fruits, game likes the shade (emphasizing the common name that means "where springboks rest").
Boscia tomentosa	Omupembate	Mupembate	Livestock fodder Traditional uses	Bark eaten by donkeys. In case of fever they inhale the steam. They use the bark to repel evil spirits (crush the bark and rub it on the skin).
Ceraria longipedunculata	Otchinova	Otchimponto	Medicinal Others	The sticky inside bark fibres are dried, crushed, mixed with water then applied on burn wounds. It is also used to heal the circumcision wound. The bark can be used as a cane or whistle for shepherds to play.
Cleome suffruticosa	Ondumba	Ontumba	Medicinal	It is used to heal the circumcision wound (crush the root and put the powder on the wound).
Colophospermum mopane		Omutwati	Medicinal Human food Others	The leaves when chewed cure stomach ache and are also used to make tea. The fruits (seeds) are used as mosquito repellents (crush and rub on the body).
Commiphora dinteri	Omuonga	Omundomba	Human food	People chew the stem when they are thirsty.
Commiphora glandulosa	Omukangue	Onkangue	Human food	The root is eaten.
Commiphora mossamedensis	Omukorui		Human food	Chew a piece of the stem to aid thirst.

Commiphora multijuga	Omuzumba	Omuluimba	Livestock fodder Others	The dry wood is used to create fire sparks and ignite a fire. The goats eat the leaves
Commiphora tenuipetiolata	Omungorwa	Omuthilati	Construction material Others	The wood is used to carve saddles and milking pots (omahoro). The gum from the bark is used to make a substance they use for washing their clothes.
Commiphora virgata	Omumbalá	Omumbala	Livestock fodder Human food Medicinal	Goats eat the leaves. Shepherds chew the stem to prevent thirst. Chewing the stem-bark help bloating.
Cordia sinensis	Omufepa	Omukoyo	Human food Others	The fruits are edible. The stem is used to produce fire.
Elephantorrhiza suffruticosa		Omundjoze	Human food Wildlife fodder	The Porcupine eat the root's bark, also treats swelling.
Euclea pseudebenus	Omuzema		Medicinal Others	The branches are used as toothbrushes, the root is used to cure toothache.
Euphorbia ohiva	Omupitamuhihi	Omupitamahini	Livestock fodder	Browsed by goats, the common name emphasizes that it extrudes a milky sap.
Euphorbia subsalsa		Ohahi	Medicinal	It is used to heal back pain for old people (make small cuts along the spine and insert the latex).
Euphorbia virosa	Otchingando	Eyanga	Wildlife fodder	The latex is poisonous, however baboons and kudu eat the fruits.
Ficus capreifolia			Livestock fodder Wildlife fodder	The monkeys eat the fruits and cattle the leaves.
Ficus sycomorus			Human food Livestock fodder	The figs (makuyu) are eaten by people, goats, donkeys and cattle.
Geigeria sp			Cosmetic	It is used to make cosmetics for Himba women (dry flowers).
Hyphaene petersiana			Human food Livestock fodder	The fruit is edible but generally, people do not eat, it serves as food for the monkeys.

Maerua schinzii	Omutengú	Omutunduwia	Medicinal Livestock fodder	It is used to cure tummy ache and eye pain (boil the leaves drink the tea or wash the face), also It is used to cure gonorrhea (Boil the root and drink tea) or cure measles and scabies (crush fresh leaves and rub on the skin). Donkeys eat the bark and the leaves.
Stapelia schinzii	Okandombo		Medicinal	Used to improve eye sight.
Parkinsonia africana			Human food	Used to sour the milk (cut pieces of the stem put in the fresh milk to sour).
Pechuel-Loeschea leubnitziae			Medicinal	Used to cure flu and intestinal worms (crush the leaves and put in the anus).
Petalidium coccineum		Otjihango	Livestock fodder	It is food for the goats and the donkeys.
Phaeoptilum spinosum	Otchinguahua	Otchihanampala		Cures diarrhoea (boiling the root, drinking a teaspoon in the morning and in the afternoon).
Rhigozum brevispinosum			Medicinal	For turning sticks used to make fire. Eaten by livestock.
Rhigozum virgatum	Omunditi	Omuchuiti	Livestock fodder	It is goat food.
Salvadora persica	Omungambo	Omukambi	Peaplo food	Fruits are boiled to remove the sour taste before they eat it. The root is used to kill lice (crush the root mix with water and rub on the head).
Sesamothamnus benguellensis	Ohuanga	Onkumbati	Medicinal	The bark is crushed and mixed with water to make a cough syrup to cure sore throats and cough.
Sp INP01	Omutchatchala	Omutchatchala	Medicinal	It is used to kill lice (crush the leaves and the branches and use the powder to rub on the head. It burns, don't get too much you can go crazy).
Sp INP02	Otchiteteangala	Otchitete	Cosmetic	It is used as a perfume: crush the flowers and rub the powder on the neck.
Sp INP03	Olutanga	Olutanga	Medicinal	It is used to cure bladder pain (boil the root and drinking the tea).

Sp INP04	Tchichingumuna	Otchichingulula	Medicinal	It is used to cure bloating in case they eat too much meat. (use leaves and twigs to make tea) In case of fever or flu, they use it for steaming.
Sp INP05	Onano	Opondotuei	Medicinal	It cures Mbumbi, furuncle and inflammations (rub cooking oil or vaseline on the wood, put it on fire and steam the affected area. For Mbumbi, cover yourself with a towel from the waist down during steaming.
Sp INP06	Omuliafino	Otchimbuangongo	Medicinal	Cures chest pain and coughing (drink tea from boiled leaves and inhale the steam).
Sp INP07	Oluhona	Ombenga	Human food	The leaves are edible.
Sutherlandia frutescens	Omuhandua	Omuhandua	Others	Used as a toothbrush.
Tamarix usneoides	Omungwati	Omungwati	Medicinal	The leaves are used to heal burn wounds.
Ximenia americana			Medicinal	The root is used to cure tummy ache (peel the root, boil and drink as tea).

Chapter 4: Discussion

4.1 Endemic species recorded in the study area

Even with the difficulties of accessibility and logistics, the fieldwork was successful, allowing the collection of plant data in this remote area that had not been done in a similar study before. This local vegetation classification study is the first step to understanding the dynamics of the vegetation of the Angolan Kaokoveld, especially as the vegetation data collected will be available for other studies.

During the fieldwork, many plants had already lost their leaves or were found with grazed or dried out leaves which made species identification difficult. The grasses were among the most affected because they are completely dependent on the rain and most of them are annual (Baruch 1994, Wigley-Coetsee and Staver 2020). Taking into account that the area is open for research, in future when Iona NP receives good rain, data collection should be done in the plots that are part of the Grasses community to identify the species that form this community.Figueiredo (2008) created a checklist of Angolan plants based on the three main herbaria in Angola: LUBA (Instituto Superior de Ciências da Educação, Lubango), LUA (Instituto de Investigação Agronómica, Huambo), and LUAI (ex-Centro Nacional de Investigação Científica, Luanda). The checklist consists of 6 735 indigenous species with 997 endemics. New research has demonstrated that it is necessary to update this checklist of Angolan plants because many plants are not listed in the checklist (Revermann and Finckh 2019). From the 4 endemic species for Angola that were identified in the study area, two (*Ceraria carrissoana, Euphorbia gariepina*) are registered as occurring in Namibia by Klaassen and Kwembeya (2013).

The distribution of vegetation is directly related to the environmental factors and is not affected by the administrative division of the countries (Craven and Vorster 2006, Mannetti *et al.* 2017), hence most of the species that occur on the Angolan side also occur on the Namibian side (SCIONA: Iona field trip report 2019; Epupa community engagement workshop report 2019). It is observed that endemic species are restricted to a specific geographic region and not found anywhere else in the world (Burke 2012, Huang *et al.* 2012). It is more important to determine plants as endemics to the Kaokoveld region rather than to each country. Bearing in mind that this habitat is unique for the two countries (Angola and Namibia) this will allow for more research in terms of comparative studies for the two countries, sharing resources and lessons learned from their respective conservation programmes to strengthen their combined effort for better conservation of this area. Identification of plant communities and their environmental drivers in Iona National Park

4.2 Identification of plant communities and their environmental drivers in Iona National Park;

Huntley (1974) presented the Namibe province as part of the southwest arid biome, it is mainly characterized by the presence of grass species of the genera *Aristida* and *Stipagrostis,* and woody species of the genera *Acacia and Commiphora,* as well as *Welwitschia mirabilis*. Barbosa (1970) and Huntley (1974) also presented the first identification of plants communities in Iona National Park. Three main plant communities were described that characterize the vegetation of the park: perennial grasslands, *Acacia - Commiphora* in arid savanna, and *Colophospermum* savanna woodland. The genera that characterized the southwest arid biome according to Huntley (1974) also are identified as dominant plants in some plant communities identified in this study: the *Acacia mellífera*, *Terminalia prunioides -Colophospermum mopane*, Grasses and *Euphorbia virosa - Commiphora wildii*.

Barbosa (1970) identified Iona National Park as part of the Deserts and Xeric Shrublands Biome, while Burgess *et al.* (2004) identified two Ecoregions for Iona National Park: A) The Ecoregion Kaokoveld Desert which is characterized by *Welwitschia, Zygophyllum*, *Stipagrostis, and Odyssea* as characteristic genera; b) the Ecoregion Namib Escarpment Woodlands is characterized by the genera *Acacia, Commiphora, Colophospermum, Sesamothamnus, Rhigozum*. Five of the genera identified by Burgess *et al.* (2004) that characterize the ecoregions in Iona National Park, were identified as characterizing a plant community, 2- *Terminalia prunioides -Colophospermum mopane, 4- Commiphora multijuga - Rhigozum virgatum, 7- Euphorbia virosa - Commiphora wildii, 8- Welwitschia mirabillis.*

Zygophyllum stapffii and *Sesamothamnus benguellensis* were also identified by Burgess *et al.* (2004) as characteristic species for the ecoregions in the Park. These species were identified in the Park during this study, however, did not present a good indicator value to characterize a community. *Odyssea* and *Stipagrostis* belong to the Poaceae family and, because of the reasons presented earlier, it was not possible to identify the grasses, resulting in one community characterized by unidentified Poaceae species.

Cardoso (2015) identified three plant communities in Namibe province making phytosociological inventories based on the list of dominant species and estimation of the plant cover by visual estimation: *Welwitschietea Mirabilis* community in the Namibe Desert, the Terminalio Prunioidis-Colophospermetea Mopanes community in the Southwest of Angola and the Sarcocornietea Pillansiae community in salty soils that are occasionally flooded along the Angolan coasts. In this study, the data collection was done using plots and the identification of plants communities was made using the result of MRPP and ISA. Using this approach, the first two communities identified by Cardoso (2015), which occurred in Namibe province, were also identified in Iona National Park.

4.3 Identify vegetation patterns and create a vegetation map of representative habitats in the Park

Kulkarni *et al.* (2016) made a comparison of different classification methods using satellite images with different bands used as variables. The study has proved that finding the optimal number of predictors will yield the highest accuracy because as the number of predictors increases accuracy also increases until a certain point at which it drops off. It was concluded that RF works well when having large homogeneous training data. The result of MRPP demonstrated that average distances within-group (T -33.738) present a poor separation of groups. A value, that indicates how similar the sample units within a group are to one another resulted in 0.264 showing that variation among sample units within groups is quite high. It can be related to the number of training data, demonstrating that it would be necessary to increase the number of plots to obtain a greater homogeneity between the plots that form the communities and consequently it would increase the occurrence value for the classes.

Hüttich *et al.* (2009) created a vegetation map for a dry savanna in the Kalahari of northeast Namibia with an RF model and satellite time series and vegetation indices (NDVI) as predictor variables. The study results in 12 main vegetation types with the genera *Acacia* and *Terminalia* as the dominant species for 2 classes.

This study was also realized in semi-arid areas, the genera *Acacia* and *Terminalia* were also identified in Iona NP as part of the species with good *IV* value that characterize the communities. Compared with the results of Hüttich *et al.* (2009), the Iona NP vegetation classification presents a higher OOB error for the RF model.

Patterns in vegetation green-up are partly associated with soil properties and vegetation types (Zhang *et al.* 2005). It can be concluded that vegetation types with a similar level of vegetation index values in the growing season are one of the reasons for decreased classification accuracies, because, a similar level of vegetation in the dry rainy seasons affected the vegetation reflectance characteristics using remotely sensed data.On the other hand, the dry rainy seasons caused a significant increased in reflectance of the underlying soil (Hüttich et al. 2009).
To distinguish the vegetation patterns, it is important to take into account the soil characteristics of the area. The existing studies of the geology in the Iona area are poor, potential soil map information could be used in the model to improve the results. Iona NP is a region that receives mainly summer rainfall that ranges from an average of less than 50 mm up to 300 mm and there was a drought duringthese last years. It can cause the disappearance of grasses and shrubs, making non-vegetated areas very difficult to distinguish from areas that were dominated by grasses and shrubs before.

Juergens *et al.* (2013) studied the combination of plant species within vegetation units in the Central Namib in Namibia using 1574 relevés for vegetation classification. The classification of the vegetation resulted in 21 large-scale vegetation units, with the accuracy of the vegetation map calculated based on predicted and observed vegetation units, which resulted in a Kappa value of 0.45. This study was divided into 4 zones where the plant's communities are distributed. All the zones identified by Juergens *et al.* (2013) can be observed in Iona NA (Coastal zone, Grassland zones, Shrubland and savanna zones,). The genera that form the communities in the zones Shrubland and savannah (*Calicorema-Commiphora* rocky Shrublands; *Euphorbia-Stipagrostis* northeastern dune grasslands succulent shrublands; *Acacia-Colophospermum* eastern desert plains and hills savanna transition) are also identified in this study as characterizing the communities with same habitat characteristics, therefore we can confirm that some vegetation communities identified in Iona NP are known from the Namibian side. The same method as Juergens *et al.* (2013) was applied in this study for the vegetation map. The big difference is that Juergens *et al.* (2013) used the data of a comprehensive databases, with 2000 relevé data sets for the classification, compared to this study that was based 80 plots. Taking into account this difference in data used for classification we can conclude that the number of plots used in this study was not high enough to cover sufficiently the study area in a representative way for the vegetation map.

Hayes *et al.* (2014) did a study at Pole Mountain Unit in south-eastern Wyoming using high-resolution NAIP imagery (1m) and RF as a model. The purpose of the research was to produce a high-resolution land cover classification. The model presents a good result for most of the classes but with low accuracy for some classes. This was partially explained because, at the time of the image acquisition, the species that characterize the class were fully leafed out, which limits spectral separation of classes. For the Iona NP study, the satellite images of the environmental variables NDVI, LST day and night were collected during the dry season in drought years. Meaning that these data do not represent the vegetation information, well enough, taking into account that most of the plants were affected by the drought causing leaf loss for many plants which could affect the spectral separation of the different communities causing a poor result of the RF model (Hayes *et al.* 2014).

The ANOVA results showed the different impacts of each variable to distinguish the communities. Aspect, BIO06, TPI have high similarities for all the communities, which makes them less important for the model causing difficulty to distinguish the communities leading to a high OOB error result.

4.4 Identify plants with socio-economic and ethnobotanical value that occur in the area

Numerous scientific and semipopular books about ethnobotany have been published in recent years (e.g. Van Wyk and Van Staden 2002). For Angola, most studies about uses of plants have been done in the northern provinces, such as Heinze *et al.* (2017), Lautenschläger *et al.* (2018), Monizi *et al.* (2019) and Göhre *et al.* (2016). The municipality of Bibala is part of two ecoregions (Miombo Woodland and Namib Escarpment Woodlands) that are also present in Iona NP (Huntley 2019). Urso *et al.* (2016) identified 116 species in the north of Namibe province (Bibala) with 20 different uses for medicinal purposes; and 33 species and 8 different uses for food purposes. Medicinal plants are especially used to treat disorders of the gastrointestinal tract, obstetric gynaecological troubles and respiratory tract diseases. A high similarity in terms of the number of plant use categories is observed. Most uses of the plants in this study are also for medicinal purposes and the second most common is also for fodder. Urso *et al.* (2016) identified four species *(Colophospermum mopane, Euphorbia subsalsa subsp. subsalsa (herb), Ficus sycomorus, Ximenia americana)* that were identified in this search*. Myrothamnus flabellifolia and Terminalia prunioides* were the most mentioned used plants for treatment. Although these plants occur in Iona NP, they have not been mentioned as being used during the interviews of this study. The reason that *Myrothamnus* *flabellifolia* was not mentioned was because the species was not observed during the botanical walk, or perhaps the use is already well known and it was not relevant to mention.

Procheş (2011) in the book Trees & Shrubs of Namibia reports the uses of the plants by the communities. From the 45 plants described in this search, 14 species (*Acacia tortilis, Colophospermum mopane, Commiphora virgata, Cordia sinensis, Euclea pseudebenus, Euphorbia virosa, Ficus capreifolia, Ficus sycomorus, Hyphaene petersiana, Maerua schinzii, Rhigozum brevispinosum, Rhigozum virgatum, Salvadora pérsica, Ximenia americana.*) were reported with similar uses as described by (Moll 2010). Malan and Owen-Smith (1974) reported similar plant uses recorded in this study for 10 species (*Rhigozum brevispinosum, Rhigozum virgatum, Commiphora virgata, Colophospermum mopane, Maerua schinzii, Euclea pseudebenus, Acacia tortilis, Ficus sycomorus, Ficus capreifolia, Salvadora persica).* Comparing with the study of Malan and Owen-Smith (1974) and the Trees & Shrubs of Namibia (Moll 2010) book which present a large number of descriptions about plant uses that occur in Kaokoveld, it is observed that many species uses are not described in this research. The principal reason for that is that there was not enough interaction with the community to enable direct and more detailed observation of the relationship between people and plants.

Boscia tomentosa, Ceraria longipedunculata, Commiphora tenuipetiolata occur in Namibia and in Angola, but for Namibia there is no description of the uses by Procheş (2011). *Colophospermum mopane, Commiphora multijuga, Cordia sinensis, Ficus sycomorus* and *Pechuel-Loeschea leubnitziae* are well described by Procheş (2011) but the community Iona mentioned few uses. Understanding the utility of the plants for the communities is a very important tool for the managers to understand the use of resources that man obtains from the flora and how significant is the vegetation for the everyday life of those rural communities.

Chapter 5: Conclusion and Recommendations

This study demonstrated that some vegetation communities in Iona are well distinct and others are very related. The study showed that the classification of vegetation is a good tool to understand the impact of the environmental variables in vegetation communities.

The vegetation classes present distinct habitat requirements such as the vegetation belonging to *Salvadora persica - Combretum imberbe* community is only found on the riverbed, which represent the only class that was very well set apart from the others. Many classes had a lot of environmental factors and spectral characteristics in common that can cause difficulties to distinguish them. Some of the vegetation communities identified in the Angolan Kaokoland side also occur on the Namibia, with a large number of species occurring on both sides.

The extended drought prevented the identification of many plants, especially grasses and herbs and created empty spaces in areas that were previously occupied by plants.

Correlation showed a weak impact of the environmental variables on plant community patterns. The RF model used in this study proved not robust in terms of classification error. However, classifying remotely sensed data into a thematic map remains a challenge because many factors, such as the complexity of the landscape in a study area, selected remotely sensed data, and image processing and classification approaches may have affected the success of classification.

Therefore this study presents the following recommendation that should be considered in the future:
There is a large number of species to be described as occurring in this area, more fieldwork should be done in Iona NP that aims to collect vegetation data during the wet season, taking advantage of the years with good rainfalls. Knowing that most of the species that occur in Angola have been identified in Namibia, it makes more sense to consider describing endemics for the Kaokoveld region instead of endemics for Angola or Namibia.

Future studies may consider comparing the Kaokoveld vegetation between Angola and Namibia. More attention to the potential impact of environmental variables on vegetation should be given during the selection of these variables for the model. For example, other variables from satellite images can be used, as well as geology data to better understand their impact on the vegetation. Considering that it is a desert and semi-desert area in which vegetation is active only during the rainy season, it is important to use the data that represents the information of vegetation during the wet season when the vegetation is well alive.

Information about the plant uses should be continuous collected to allow the creation of a book on the uses of Kakoveld plants.

The findings of this study may also be used to update the checklist of Angola plants and create a field guide of the common plants in Iona NP.

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Appendices

Appendix 1 **Circular from the Ministry of Environment that prohibited all the activities in the park during the lockdown**

REPÚBLICA DE ANGOLA
MINISTÉRIO DO AMBIENTE
INSTITUTO NACIONAL DA BIODIVERSIDADE E ÁREAS DE CONSERVAÇÃO

CIRCULAR N.º 005 /2020

Tendo em consideração o Decreto Legislativo Presidencial Provisório n.º 1/20 de 18 de Março, no âmbito do reforço das prevenções para se evitar a importação de casos e salvaguardar a vida e a saúde da população em geral da pandemia causada pelo vírus COVID -19, somos a determinar o seguinte:

1. São suspensas a partir do dia 19 de Março de 2020 todas as actividades humanas, que não sejam as de gestão, nos Parques Nacionais, Parque Regional e Reservas assim como a entrada de pessoas que não façam parte da equipa de Gestão das Áreas de Conservação por um período de 15 dias, prorrogáveis por igual período de tempo em função do comportamneto global da pandemia do COVID 1-9.

2. É proibida a realização de eventos públicos como actividades de laser, recreativas, desportivas, associativas, privadas e de qualquer outra índole com algumerações de pessoas.

3. São convocados todos os Fiscais em folga para se apresentarem à serviço para reforçar a Fiscalização visto ser considerado um período de emergência operativa.

A presente Circular entra imediatamente em vigor.

Cumpra-se!

INSTITUTO NACIONAL DA BIODIVERSIDADE E ÁREAS DE CONSERVAÇÃO em Luanda aos, 19 de Março de 2020.

O DIRECTOR GERAL
ARISTÓFANES DA CUNHA

Ministério do Ambiente. Instituto Nacional da Biodiversidade e Áreas de Conservação/Lunada Cidade do Kilamba, Rua 26 de Janeiro, Quarteirão Nini Yaluquene, Edifício Q11, Segundo e terceiro andar. NºTelef: 222-71-96-68 Email: inbac2011@gmail.com/inbac2011@hotmail.com

Cuide da natureza para que ela cuide de si e das futuras …

Appendix 2 **Field Sheet for Data Collection**

SCIONA field inventory sheet

SAMPLE PLOT INFORMATION

Collected within radius of 20 m from plot centre. Take pictures of vegetation in plot.

Plot no	
Area	
Stratum (if stratification was done before inventory)	
Date	
Time	
Team	
Lat	
Long	
Accuracy (m)	
Elevation (m)	
Slope steepness (°) (use Vertex)	
Position on slope (slopes>5 °): top, upper middle, lower middle, bottom	
Soil texture (sand, sandy loam, loam, clay loam, clay - use finger test)	
Rock parent material (schist, granite, basalt, limestone, …) + picture	
Boulders (rocks > 25.6 cm): absent, few, abundant (> 10% cover)	
Cobbles (gravel 6.4 - 25.6 cm): absent, few, abundant (> 10% cover)	
Pebbles (gravel 0.4 - 6.4 cm): absent, few, abundant (> 10% cover)	
Soil colour (+ take 2 pictures of soil: one north and one south of centre)	
Distance on Bitterlich (cm)	
Crown coverage trees (use Bitterlich)	
Crown coverage shrubs (use Bitterlich)	
Bare soil coverage (estimate)	
Damage class: Human influence	
Damage class: Livestock - Domestic mammals	
Damage class: Fire	
Other damage: cause	
Other damage: class	
Main cause damage plot	
Basal area of tree stems (with Dendrometer II)	
Number of pictures taken (general appearance plot)	

limited time: complete pages 1 and 3 of survey first. If time allows, then proceed to 2 and 4.

Damage classes

0 = No damage/influence

1 = Mild damages, not affecting the trees

2 = Moderate damages, decreasing vitality of trees

3 = Serious damages, seriously affecting several trees

4 = Fatal damages, several trees are dying or dead

0 Unknown

1 Fire

2 Wild mammals

3 Domestic mammals

4 Insects

5 Human (cutting, debarking, dumping, ...)

6 Frost

7 Drought

8 Erosion

9 Storm 10 Fungi

Vera De Cauwer and Rasmus Revermann, 2019, NUSTIf

Plot no

For all woody species with CBH < 15.7 cm (DBH < 5 cm) within radius of 5 m from plot centre

Species (*)	**Count**	**Voucher number (*)**

(*) if species not identified: use a field name in the species column (e.g. smelly grey green grass), collect a sample, and enter voucher number in last column

COVER of all vascular plant species present

Plot no ☐

Collected within radius of 20 m from plot centre

Outer: check if species only occurs outside a circle with radius 17.8 m (= outside plot with size 10000 m^2)

Species (*)	**Cover (%)**	**Outer**	**Voucher number (*)**

(*) if species not identified: use a field name in the species column (e.g. smelly grey green grass), collect a sample, and enter voucher number in last column

TREES

Plot no ☐

Record for all stems with CBH < 15.7 cm (DBH>= 5 cm) within radius of 20 m from plot centre, including dead trees

For trees with multiple stems at DBH: measure each stem but give it the same number in "Nr individual"

Nr stem	Species (*)	Nr individual	cbh (cm)	Alive	Dist (m)	Azimuth (°)	Phenology	Height (m)	Damage	Cause_dam	Voucher

(*) if species not identified: use field name in species column (e.g. smelly grey green grass), collect a sample, and enter voucher number

Alive Indicate if tree is alive (Y) or not (N)

Dist = Distance from plot centre

Phen = Phenology: Fruits (FR), Flowers (FL), Leaves (L)

Damage and cause damage: see classes on stand sheet

Vera De Cauwer and Rasmus Revermann, 2019, NUST

Appendix 3 **List of plants identified in Iona National park (The plants that were identified in the sample plots are marked with an asterix *)**

Species name	**Angola Checklist**	**Endemic of Angola**	**Life form**
*Acacia ataxacantha**	Existent	No	shrub or small tree
Acacia erioloba	Existent	No	Medium to large spreading tree
*Acacia mellifera**	Existent	No	Shrub or tree
Acacia montis-usti	Not existent	No	shrub or small tree
*Acacia nilotica**	Existent	No	Small to medium-sized tree
*Acacia tortilis**	Existent	No	Small to medium-sized tree
Acanthosicyos horridus	Existent	No	shrub
Adansonia digitata	Existent	No	Deciduous woodland tree (munga, mopane).
*Adenia repanda**	Existent	No	Suberect herb or woody climber
*Adenium boehmianum**	Existent	No	Small tree
*Adenolobus garipensis**	Existent	No	shrub or small tree
Albizia brevifolia	Existent	No	Deciduous shrub or small to medium-sized tree
Aloe esculenta	Existent	No	Succulent with stem to 40 cm long
Aloe littoralis	Existent	No	Succulent with long single stem
Aloe mocamedensis	Not existent	No	Succulent herb
Antiphiona fragrans	Not existent	No	Sub-shrub
*Balanites angolensis**	Existent	No	shrub or small tree
Berchemia discolor	Existent	No	Medium to large spreading tree

*Boscia microphylla**	Existent	No	Small to Medium tree
*Boscia tomentosa**	Not existent	No	Small to Medium tree
Bridelia tenuifolia	Existent	No	shrub or small tree
*Cadaba schroeppelii**	Existent	No	Shrub or small tree
*Calicorema capitata**	Not existent	No	Shrub
*Catophractes alexandri**	Existent	No	Shrub
*Ceraria carrissoana**	Existent	Endemic	Shrub or small tree
Ceraria kaokoensis	Not existent	No	Shrub or small tree
*Ceraria longipedunculata**	Not existent	No	Shrub or small tree
Cissus quadrangularis	Existent	No	Succulent climbing herb with tendrils
*Cleome suffruticosa**	Not existent	No	Herb
*Colophospermum mopane**	Existent	No	Small to medium-sized deciduous tree
*Combretum apiculatum**	Existent	No	Small to medium-sized deciduous tree
*Combretum imberbe**	Existent	No	Medium to large deciduous tree
*Combretum wattii**	Existent	No	Shrub
Combretum zeyheri	Existent	No	Small to medium-sized tree
*Commiphora anacardiifolia**	Existent	No	Shrub or small tree
*Commiphora crenato-serrata**	Not existent	No	Shrub or small tree
*Commiphora giensii**	Not existent	No	Shrub or small tree
*Commiphora glandulosa**	Existent	No	Shrub or small tree
Commiphora glaucescens	Not existent	NO	Shrub or small tree
Commiphora mollis	Existent	No	Small to medium-sized unarmed tree
*Commiphora mossamedensis**	Existent	Endemic	Shrub or small tree
*Commiphora multijuga**	Not existent	No	Medium to large tree
Commiphora oblanceolata	Not existent	No	Shrub or small tree
*Commiphora tenuipetiolata**	Not existent	No	Medium to large tree
*Commiphora virgata**	Existent	No	Shrub or small tree

*Commiphora wildii**	Existent	No	Shrub or small tree
*Cordia sinensis**	Existent	No	Shrub or small tree
*Croton gratissimus**	Existent	No	Shrub or small tree
*Croton megalobotrys**	Not existent	No	Shrub or small to medium-sized tree
Croton menyharthii	Existent	No	Shrub or small tree
Cryptolepis decidua	Existent	No	Shrub or small tree
Cyphostemma currorii	Existent	No	Shrub or small tree
Cyphostemma uter	Existent	No	Shrub or small tree
*Dichrostachys cinerea**	Existent	No	Shrub or small tree
Ecbolium clarkei	Existent	No	Shrub
Ehretia namibiensis subsp. kaokoensis	Not existent	No	Shrub
*Elephantorrhiza suffruticosa**	Existent	No	Shrub or small tree
Euclea divinorum	Existent	No	Shrub or small tree
Euclea pseudebenus	Existent	No	Shrub or small tree
Euphorbia congestiflora	Existent	Endemic	Succulent plant
Euphorbia gariepina	Existent	Endemic	Succulent plant
Euphorbia eduardoi	Existent	No	Succulent plant
*Euphorbia guerichiana**	Existent	No	Succulent plant
Euphorbia monteiroi	Existent	No	Succulent plant
*Euphorbia ohiva**	Not existent	No	Shrub or small tree
Euphorbia subsalsa subsp. fluvialis (herb)	Existent	No	Succulent plant
Euphorbia subsalsa subsp. subsalsa (herb)	Existent	No	Succulent plant
*Euphorbia virosa**	Existent	No	Succulent plant
Ficus capreifolia	Not existent	No	Shrub or small evergreen tree
Ficus ilicina	Existent	No	Shrub or small tree
Ficus sycomorus	Existent	No	Tree up to 15 m tall, terrestrial
*Gossypium anomalum**	Existent	No	Erect or lax shrub

*Grewia tenax**	Not existent	No	Shrub or small tree
*Grewia villosa**	Existent	No	Much-branched shrub
*Gymnosporia senegalensis**	Existent	No	Shrub or small multi-stemmed tree
Helioyropium ciliatum	Not existent	No	Shrub
Hexalobus monopetalus	Existent	No	Shrub or small tree
*Hoodia parviflora**	Existent	No	Succulent plant
Hyphaene petersiana	Existent	No	Tree up to 10 m tall
*Kirkia acuminate**	Existent	No	Medium deciduous tree
*Maerua kaokoensis**	Not existent	No	Small tree
*Maerua parvifolia**	Existent	No	Shrub or small tree
*Maerua schinzii**	Not existent	No	Shrub or small tree
Mimosa pigra	Existent	No	Shrub or small tree
*Moringa ovalifolia**	Existent	No	Medium deciduous tree
*Myrothamnus flabellifolius**	Existent	No	Shrub
Obetia carruthersiana	Existent	No	Many-stemmed shrub
Orthanthera albida	Existent	No	Herb
*Pachypodium lealii**	Existent	No	Sparsely branched tree
*Parkinsonia Africana**	Existent	No	Many-stemmed shrub
*Pechuel-Loeschea leubnitziae**	Existent	No	Shrub
Petalidium coccineum	Existent	No	Shrub
Petalidium halimoides	Existent	No	Shrub
Petalidium welwitschii	Existent	No	Shrub
Phaeoptilum spinosum	Existent	No	Many-stemmed shrub
Pupalia lappacea	Existent	No	Herb
*Rhigozum brevispinosum**	Existent	No	Shrub or multi-stemmed small tree
*Rhigozum virgatum**	Existent	No	Shrub or multi-stemmed small tree
Ricinus communis	Existent	No	Herb

Rogeria armeniaca	Not existent	No	Herb
Ruellia marlothii	Not existent	No	Herb
*Salvadora persica**	Existent	No	Shrub or small tree
Sansevieria pearsonii	Existent	No	Succulent plant
Sarcocaulon mossamedense	Existent	No	Shrub or small tree
Senna italic	Existent	No	Shrub
*Sesamothamnus benguellensis**	Existent	No	Shrub or small tree
Stapelia schinzii	Existent	No	Herb
Spirostachys Africana	Existent	No	Shrub or small tree
*Sterculia Africana**	Not existent	No	Deciduous tree
*Sutherlandia frutescens**	Not existent	No	Shrub or small tree
*Tamarix usneoides**	Existent	No	Much-branched shrub or tree
*Terminalia prunioides**	Existent	No	Deciduous many-stemmed shrub
Terminalia sericea	Existent	No	Deciduous tree
*Welwitschia mirabilis**	Existent	No	Woody plant
Ximenia Americana	Existent	No	Shrub or small tree
Ximenia caffra	Existent	No	Shrub or small tree
*Zygophyllum simplex**	Not existent	No	Herb
Albuca sp heroriensis	Not existent	No	Herb
Polygala cf guerichiana	Existent	No	Herb
Zygophyllum stapffii	Not existent	No	Herb