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Phytosociological Study of Nyungwe Montane Savannahs

Prof Elias Bizuru[1], Protais Niyigaba[2], Myriam Mujawamariya[3]
1: Head of Biology department, Ag. Director of Post Graduate Studies, Research and publications in the University of Rwanda
2: Park Guide in RDB - Nyungwe National Park and Master's Student in Biodiversity Conservation, University of Rwanda
3: Assistant lecturer and Researcher in the University of Rwanda
Email: ebizuru@gmail.com, protang2002@yahoofr, mmujawamariya@gmail.com

Abstract
It is uncommon to find savannahs encompassed into tropical montane rainforests. The case of Nyungwe savannahs is one of these particularities and until now no explanation on their origin, structure and dynamics was given. This unprecedented research documented special floristic diversity of montane savannahs of Nyungwe, described the structure of their plant communities to provide data for their sustainable conservation. In this paper origin of these savannahs was discussed. The study was conducted in three sites harbouring five savannahs:Karamba, Nyabitimbo and Muzimu. Eight plant communities (4 in savannah-forest contact zone and other 4 in savannah) were identified with 198 species. Vascular species were distributed in 71 families. Phytogeographic distribution analysis of species showed the predominance of afromontane species (Mo) in sampled savannahs (31%), followed by East African montane species (Mo, EA) with 22% of all species. Montane endemism proved the predominance of 'relatively restricted endemic species' identified in 2or3 montane systems (among Kivu-Ruwenzori, ImatongsUsambara, UluguruMlanje, and Ethiopia with 41.1%) followed by 'afromontane endemic wades' identified in 4to7 systems representing 39.9%). 'Local endemic montane species' represented 31% of all species. Thus, these savannahs are favourable to species coming from almost seven African montane systems.
Keywords: Nyungwe, Plant communities, montane savannahs.

Introduction

Nyungwe National Park montane savannahs are high-altitude savannahs, located in a few spots throughout the montane forest. From a general climatic point of view, and according to the terracing pattern of vegetation in tropical mountains as highlighted by Schnell (1977) and cited by Bizuru (2005), these regions should be covered by evergreen montane and submontane forests. The forest cover at some places in Nyungwe National Park changes abruptly to savannah stretches which have long been viewed as anthropogenic artefacts neglected by scientists and of no interest to conservation (Perrier de la Bâthie, 1936; Dalfelt *et al.*, 1996 & Banerjee, 1995 cited in Bond and Parr, 2010).

The neglect of savannahs and grassy habitats by scientists and researchers is noticed by simply considering all researches that, so far, have been carried out on the whole flora of Nyungwe. Although the savannahs are among the five plant habitats recognized by Ewango (2001) following the 1999 Nyungwe plant inventory, there has been no studies devoted exclusively to montane savannahs.

Savannahs, compared to the bigger part of closed forest, are easy targets for clearing for cropping. They are easier to convert to crops and their degradation is not considered as a serious environmental attack compared to the clearing of forests. They constitute a breach that facilitates illegal activities to access the forest; where for example beekeepers prefer these places particularly for laying their hives. Savannahs have been often noticed to be epicentres of different destructive bushfires that, along the history of Nyungwe, decimated large tracts of other habitats such as the closed evergreen primary forest, the secondary forest and bamboo areas.

Nyungwe mosaics of forest and savannah vegetation occur in various corners, and the concern of this study was to understand both ecosystem states in order to provide conservation measures for their floristic diversity sustainability. This study is a good contribution that documents the special floristic diversity of montane savannahs of Nyungwe, describing the structure of their plant communities in order to provide scientific data for sustainable conservation of Nyungwe and particularly montane savannahs. The main ecological drivers that created these savannas in these areas are outlined, and their future is predicted.

Materials and Methods

Study area

The study was carried out in Nyungwe National Park which is located on the edge of Lake Kivu in the South West of Rwanda (2°15' – 2°55' S, 29°00'– 29°30' E). This region is located in the valleys of the Albertine Rift eco-region (Plumptre *et Al*, 2002). Nyungwe National Park is the largest protected area of Rwanda (Appendix 1).

The mean annual rainfall of 1.744 mm (Sun *et al*., 1996 cited in Plumptre *et al*., 2002) is typical for an African rainforest. A major dry season occurs between July and August and a minor dry season takes place between December and January.

Specifically, the study was carried out in three chosen sites: Karamba with one savannah located between 1965m and 1997m of elevation, Nyabitimbo with 3 savannahs (Ubunyovu bw'Abasozo with altitude varying between 1728m and 1771m, Ubunyovu bw'Imbaragasa I with altitude varying between 1750m and 1820m, Ubunyovu bw'Imbaragasa II with altitude varying between 1768m and 1908m), and Muzimu with one savannah located between 2770m and 2822m of altitude (Appendix 2).

Karamba is open grassland presenting some scattered trees and shrubs at some points. The soil is made of a very thin layer of humus covering rocks and mainly quartz. At several points of this savannah, wide bare areas of quartz are remarkable. The centre of Karamba savannah is a flat and often inundated place where soaked carpets of species like *Sphagnum sp*. (characteristic of acidic wetlands) are met. This stagnation of water is due to the impermeability of the quartz substrate. More distant areas (towards the periphery) are gentle, dry and more or less bare slopes.

The site of Nyabitimbo has three aligned savannahs. Located from the East of the site is the Ubunyovu bw'Abasozo, in the middle is Ubunyovu bw'Imbaragasa I, and at the eastern side of the site is Ubunyovu bw'Imbaragasa II savannahs. These are familiar and ancient names given to these savannahs by local people; the term 'ubunyovu' is equivalent to 'savannah'.

All the three savannahs are commonly characterized by a thick (around 1m) carpet of old *Eragrostis* that makes the walk too hard in these areas. They are almost mono-specific grasslands dominated by *Eragrostis* on slopes with many areas occupied by protruding rocks. Their average slope is more or less than 45°. The soil is shallow black humus on quartz rock. Some scattered places are dominated by *Erica johnstonii* and others by *Protea welwitschii*.

Muzimu is among the highest mountains (2830m) in NNP after mount Bigugu (2950m). The savannah occupies a big part of the top of mount Muzimu. The soil is shallow black humus which is sandy and/or stony. The eastern part is drier and rockier with some protruding rocks.

Muzimu - among other studied savannahs - has the particularity of harbouring up to five different Ericaceous species (*Blaeria kiwuensis, Erica bequaertii, Erica benguellensis,Vaccinium stanleyi,* and *Agauria salicifolia*). This richness in Ericaceous species can be accounted for by the fuzzy state of the border between savannah and the Ericaceous shrub. The ericaceous shrub is described by Fischer & Killmann(2008). The flora of Muzimu is also characterized by important number of particular species distinguishing it from other savannahs studied such as *Blaeria kiwuensis*, *Isachne mauritiana, Struthiola thomsonii*, *Lobelia holstii* and *Hedythyrsus thamnoideus.* This particular flora of Muzimu can be explained by the difference in elevation and geographical distance. This savannah solely ranges above 2000m of altitude (between 2770m and 2822m) whereas other savannahs are located between altitude of 1728m and 1990m. Frequently, the savannah on top of Muzimu is blown by cold winds, which constitute another important factor that induces particular ecological conditions. Muzimu is geographically distant compared to the other two sites. Contrary to other savannahs, no inundated places were encountered; the species like *Sphagnum* were not recorded.

The vegetation sampling was done according to Braun-Blanquet (1932) method using mixed sampling. Plant species were inventoried in plots of(5mx5m) within the savannah and (5x10) in the savannah-forest contact zone. Detrended Correspondence Analysis (DCA) with MVSP software was used to identify plant communities. In total 174 plots were sampled, with 48% of the total surface located within the savannahs and the remaining 52% in the savannah-forest contact zone.

Biological forms

Biological forms were determined using the methodology proposed by Raunkiaer (1932). According to this methodology, biological forms are determined and distinguished on basis of various mechanisms used by plants to protect their buds or their vegetative organs during unfavourable season.

Phanerophytes (Ph): plants that remain visible in all seasons of the year; their height above the ground is above 0.5 m; their vegetative apparatus holds persistent visible buds at a height of more than 40 m above the ground.

Chamaephytes (Ch): plants with a dwarf vegetative apparatus (less than 40 cm of height). **Hemicryptophytes (Hc)** are characterized by an aerial vegetative apparatus which dries out during the unfavourable season.

Geophytes (Ge): plants with underground reserve organs from which they quickly propagate at the beginning of the favourable season.

Therophytes (Th): annual plants that pass the unfavourable season in the form of seeds.

Phytogeographic distribution

Species were classified into Phytogeographic types according to their distribution. They include Cosmopolitans (Cosm), Sub-cosmopolitans (Subcosm), Pantropicals (Pantr), Paleotropicals (Paleo), Montane paleotropicals [Paleo (Mo)], Afro-Americans (Af-Am), Afro-Malagasy (Afro-Mal), Montane Afro-Malagasy [Afr-Mal (Mo)], Multiregional africans (Pluri af), Afro tropical (Afr trop), Spieces with Sudano-zambezian distribution (S-Z), Species of Afro montane region (Mo) , East African (EA), Endemic species (End).

Vegetation analysis

The presence index was attributed to species according to Vander Bergen (1982) and the plant communities were individualized using multivariate analysis of all the study sites data. A data matrix with two inputs was treated using Correspondence Factorial Analysis for the identification of the existing plant communities.

The floristic diversity of different communities and sites was calculated according to Simpson's diversity index formula which takes into account both the species number and their cover-abundance dominance:

$$D^{'} = 1 - \sum_{i=1}^{s}(pi)2$$

Where D' = Simpson floristic diversity index

Pi = proportion of species in a community

1= Simpson's ideal diversity index

The montane endemism was expressed by the distribution and representativeness of species in the seven regional montane systems. These latter include: West African, Ethiopian, Kivu-Ruwenzori, Imatongs-Usambara, Uluguru-Mlanje, Chimanimani and Drakensberg regional montane systems. Floristic similarity between savannah areas was calculated using Sorensen's coefficient. Similarity between communities and zones was estimated according to the species number and their abundance using cluster analysis. Linkages were determined using the method of unweighted pair-group (UPGMA), which uses arithmetic averages to evaluate the distances between clusters.

Results

Plant species composition, diversity, and floristic similarity

A total of 174 plots were sampled, with 48% of the total surface located within the savannahs and the remaining 52% in the savannah-forest contact zone. A total number of 198 plant species in all the three sites were identified. Also listed are 147 genera and 71 families only among vascular species.

Sixty one (61) plots were selected in the savannah-forest contact zone and 133 plots in the savannah zone. One hundred sixty (160) species in the savannah-forest contact zone distributed in 129 genera and in 67 families were identified. The inventory in the savannah zone was composed of 109 plant species, 95 genera and 43 families (Appendix 3). The numbers above represent tracheophytes only. During fieldwork both tracheophytes and non tracheophytes (lichens and bryophytes such as *Sphagnum planifolium* and mosses) were observed as whole floristic diversity and ecology of NNP's savannahs. However, due to the lack of enough equipment (identification keys, reference herbarium specimens and other documents) for their identification, most of non tracheophytes species were not fully identified.

The Comparison of floristic diversity between the savannahs and the savannah-forest contact zone (Appendix 3) showed that according to species relative frequency**,** the most frequent species (appearing in most of the 174 sampled plots) were: *Pycnostachys erici-rosenii* (present in 62.6% of all the plots), *Eragrostis olivacea* (55.1%), *Virectaria major* (48.2%)*, Scleria distans* (47.7%)*, Panicum adenophorum (41.9%), Bothriocline nyungwensis (38.5%), Microglossa pyrifolia (* 38.5%), *Melinis tenuinervis (36.7%), Polygala ruwenzoriensis* (34.4%), *and Anisopappus africanus (33.3%)*. It should be noted that the first and third species are generally characteristic to disturbed areas.

In terms of cover-abundance, the most dominant species in the whole studied areas were *Eragrostis olivacea* (22.4% of the total surface area) and *Eragrostis boehmii* (11%). The most represented families were Orchidaceae (represented by 17 species, which is equivalent to 9.1% of the tracheophytes), Asteraceae (16 species i.e. 8.6%), Poaceae (15 species i.e. 8.1%), Rubiaceae (15 species i.e. 8.1%), Cyperaceae (8 species i.e. 4.3%), Euphorbiaceae (7 species i.e. 3.7%), Melastomataceae (7 species i.e. 3.7%) and Ericaceae (6 species i.e. 3.2%). However, in terms of cover-abundance, the most abundant families are Poaceae (covering 42.5%), Asteraceae (covering 7.8%), Dennstaedtiaceae (covering7.4% though represented by one species "*Pteridium aquilinum*") and Ericaceae (covering6.8%). Other families were Lamiaceae(6.6%) and Rubiaceae(4.7%).

In terms of frequency, Poaceae are found in 18% of all the plots, followed by Asteraceae (15%), Rubiaceae and Lamiaceae(8%), Cyperaceae(5.7%), and Melastomataceae(4.1%). Phytogeographic distribution of species showed the predominance of afromontane species (Mo) (31%), in all the sampled savannahs followed by the East African montane species (Mo (EA)) with 22% of all species. Sclerochores or light non fleshy diaspores were the most abundant and the most represented covering 59% of NNP montane savannahs. At the second position were Ballochores covering 22% of the NNP montane savannas.

The cluster analysis of the three study sites showed the similarity between Karamba and Nyabitimbo rather than with Muzimu(Appendix 4). In fact, the savannah on top of Muzimu is located between 2770m and 2822m of altitude whereas the other two sites are located between 1728m and 1990 m of altitude. This difference in elevation gives to Muzimu a particular high altitude flora that distinguishes it from the two other lower sites.

Given Karamba's highest species number, only 50% of its species are shared with Muzimu whereas 68.6% are common between Karamba and Nyabitimbo.

Floristic similarity among the three study sites is presented in Appendix 4.Tthe distribution and representativeness of species according to White (1978)'s seven regional montane systems show that 31 species(i.e.19%) are local endemics, thus belonging exclusively to Kivu-Ruwenzori. Other 67 species(i.e.41.1%) are 'relatively restricted endemic species' and are distributed in two or three regional montane systems. This study also showed that 65 'Afromontane endemic wides'(i.e. 39.9%) are distributed at least in four of the seven montane systems, thus corresponding to the largely distributed species. Among all the recorded species, 59.5% are also found in Imatongs-Usambara, 52.14% in Uluguru–Mlanje, 41.71% in Ethiopian System, 35.58% in West African System, 32.51% in Chimanimani, and 15% in Drakensberg montane System.

In general a big number is common between Kivu-Ruwenzori and East African montane Systems (Imatongs-Usambara, Uluguru–Mlanje, and Ethiopian) (Appendix 7).

The cluster analysis shows affinity between Kivu-Ruwenzori and the East African montane systems (Imatongs-Usambara, Ulugulu-Mlanje and the Ethiopian System) (Fig. 1). West African species are more represented than species from Southern Africa (Fig. 1). Therefore, the West African System is closer to Kivu-Ruwenzori than Southern Africa systems (Drakensberg and Chimanimani).

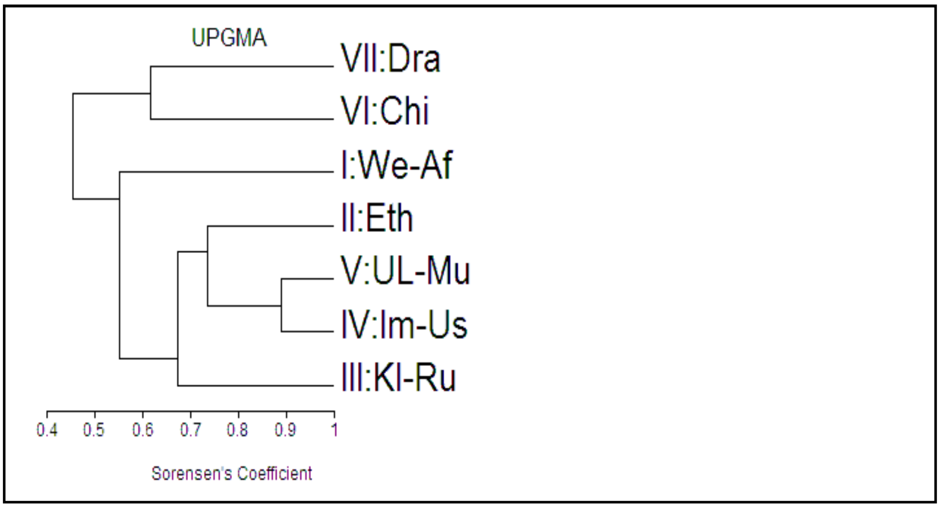

Fig.1: Floristic similarity among the seven montane systems. I: We-Af : West African System. II: Eth: Ethiopian System. III: Ki-Ru : Kivu-Ruwenzori System. IV: Im-Us : Imatongs-Usambara System. V: Ul-Mu: Uluguru–Mlanje System. VI: Chi : Chimanimani System. VII: Dra : Drakensberg System.

The Factorial Correspondence Analysis enabled the identification of the following eight plant communities: individualization of plant communities in the savannah zone(Appendix 5) and individualization of plant communities in the savannah-forest contact zone(Appendix 6)

The study of the plant communities' proper values enabled the individualization of plant communities(Appendices 5&6) by highlighting the statistical differences. The cumulative variances on the two forth axes are more than 15% (i.e. 21.765% in the savannah-forest contact zone and 18.477% in the savannah) and thus these values are high enough to enable the distinction and separation between plant communities in both the savannah and ecotone zones. Savannah communities' indices varied between 0.542 and 0.847 whereas the savannah-forest contact zone indices vary between 0.840 and 0.941. In fact, savannahs comprise very few species and thus appear as monospecific areas occupied mainly by *Eragrostis* and other few Poaceae species. The savannah-forest contact zone, by contrast, is inhabited by both forest and savannah species, which makes its flora even and diversified.

Discussion

For all the studied savannahs, the predominance of Poaceae as the most abundant family covering 42.5% of the savannahs was noticed. Poaceae were followed by Asteraceae(7.8%), Dennstaedtiaceae(7.4% though represented by one fern species *Pteridium aquilinum*), Ericaceae (6.8%), Lamiaceae(6.6%) and Rubiaceae(4.7%).

In general, the savannah–forest contact zone possesses a higher specific richness compared to the savannah zone(Appendix 3). The former encompasses ecological conditions of both habitats (forest and savannah) and thus allows, at the same time, the installation of savannah species and forest ones. As for the savannah zone, the poor floristic diversity is due to stress undergone by species inhabiting these areas. Most of the savannah covered areas in NNP are dry rocky slopes covered with a very shallow soil, which allows only the installation of drought and poor soil tolerant species.

Though Karamba is the smallest site, its varied ecological sub habitats allow the presence of various species. The dry rocky slopes; the inundated flat areas, valleys, the presence of a trail that passes in the middle of the savannah and the presence of a temporary stream are various ecological conditions that explain the highest diversity index. As for Nyabitimbo, its three savannahs make it the widest site among the three study sites. However, its poverty in species is visible even with simple observation. Its savannahs are old and almost monospecifically dominated by *Eragrostis* which makes a thick carpet of grass matter and dead boles.

Throughout the studied savannahs, afromontane species were the most represented Phytogeographic types with 30.5% of all the species, covering 11.3% of the sampled area and present in 18.4% of the sampled plots. East African montane species were also the most abundant, covering 12.5%, of the sampled area, representing 20.3% of all the species and present in 9% of all the sampled plots. Afro-tropic species were in the third position, followed by Afro-Malagasy species.

As far as diaspores are concerned, and according to their classification by Dansereau & Lems(1957) cited in Habiyaremye(1995), Sclerochores or light non fleshy diaspores are the most abundant in NNP montane savannahs. Sclerochores, due to their lightness are more likely to be dispersed by wind. The south-easterly trade winds that blow in the Albertine Rift originating from the Indian Ocean play a big part in this long distance dispersal which emphasises once more, the high representativeness of East African montane systems in NNP montane savannas.

The cluster analysis of the three study sites showed the similarity between Karamba and Nyabitimbo rather than with Muzimu.

As far as the distribution in the seven regional montane systems is concerned, an uneven representativeness of species was noticed. Among the recorded species, 59.5% are also found in Imatongs-Usambara, 52.14% in Ulugulu-Mlanje; 41.71% in Ethiopian System, 35.58% in West African; 32.51% in Chimanimani and 15% in Drakensberg system. The cluster analysis shows a high similarity between the East African montane Systems (UL-Mu, Im-Us, and then Ethiopian System) which, at the same time, exhibits an explicit affinity with Kivu-Ruwenzori system (Fig. 1).

Hedberg(1966) cited in Bizuru(2005), indicated that the floristic affinity noticed among East African systems can be explained by direct and indirect contacts among afromontane vegetation facilitated by geographic distance. The author further emphasized that direct contacts including the lowering of the afromontane region, a phenomenon that brought about mixture and breeding among the flora of East African Mountains during the Quaternary glaciations. The low similarity between Kivu-Ruwenzori and the South African montane Systems (Chi. and Dra.) on one hand, and its higher affinity with Ethiopian System on the other hand, show that the data are in accordance with Moreau's north corridor theory.

Moreau(1966) cited in Bizuru(2005) believes the existence of a certain 'north corridor' that connects Mt. Cameroon to Ethiopia, passing at Mt. Jebel Marra in Sudan which is halfway between Cameroon and Ethiopia. However, White(1981) cited in Bizuru(2005), on basis of 40 tree and smaller plant species, stated that the connection between Mt. Cameroon and East African mountains passes though the 'south corridor'.

Using Simpson's diversity index, it was noticed that savannah communities are less floristically diversified than savannah-forest contact zone ones. The most diversified of all was the community comprised of *Clerodendrum johnstonii* and *Virectaria major* (Simpson's index equals to 0.941) which constitute some spots contouring Karamba and Nyabitimbo. This followed by the community of *Pteridium aquilinum* and *Pycnostachys erici-rosenii* (0.941) also constituting the contour of Karamba and Nyabitimbo.

The general abundance of Therophytes in the savannah zone communities are a sign or a trace marking the after-effects of ancient disturbance. Savannahs are epicentres of devastating bushfires that cleared large tracts of Nyungwe forest along its history. The abundance of Phanerophytes in the savannah-forest contact zone communities is an indicator of woody species predominance which proves the encroachment of the forest on savannahs. Moreover, the prevalence of species like *Pteridium aquilinum* is a sign of the forest invasion at the expense of savannahs.

Climate change, conservation, origin and the future of NNP montane savannahs

Maley(1991) showed that Quaternary glaciations corresponded to the global scale coldest periods as well as the maximum fragmentation of tropical forests. Pollen analyses carried out on upper Quaternary deposits from African lakes showed that during the last world glacial maximum (which peaked 18 000 years before present) the climate was dry and cold and forest much reduced and fragmented. The extent of forest must have oscillated greatly. These glacial periods characterized by extreme colds and rare precipitations correspond to the maximum extension of savannas replacing tropical forests. As it happened to other tropical rain forests, some tracts of Nyungwe forest must have been converted into savannas during the Quaternary glaciations period. When the climate was normalized again, some savannah parts were restored to their former rainforest state and others were maintained as savannas by various parameters namely natural and human induced bushfires and dry and/or poor substrate (soil). Nyungwe montane savannas are characterized by shallow humus that covers quartz substrate and by a common presence of protruding rocks visible on most of the slopes.

The abundance of Therophytes in the savannas is an after-effect of ancient disturbance especially bushfires. With the current forest protection measures, these savannas are unlikely to undergo frequent fires as it used to be; which means that the only remaining maintaining factor of Nyungwe montane savannas is the substrate nature. The progressive accumulation of litter falling from the neighbouring forest and the progressive decomposition of grass matter will - step by step- favour the installation of forest species at the expense of savannah ones.
Bond & Parr (2010) suggested that forest expansion in forest/grassland mosaics is likely to be a major threat in protected areas where different mechanisms are put in place in order to thwart fire spread. Fire exclusion experiments in Africa and the USA showed that high rainfall savannas can be replaced by forest in as little as 20–30 years.

Conclusion

The current phytosociological study covered five Nyungwe montane savannahs where both the savannah and its contouring savannah-forest contact zone were explored. Angiosperms cover the biggest part of the total flora; Pteridophytes come at the second place followed by Bryophytes whereas Lichens cover an insignificant part of the entire inventoried flora. Therophytes are abundant in the four communities of the savannah zone whereas Phanerophytes are abundant in the other four communities of the forest-savannah contact zone. These biological forms proportions show the persistence of ancient disturbance after-effects.
NNP montane savannahs are dominated by afro-montane and East African species which corroborates with the similarity highlighted by the montane endemism analysis. The similarity between Ki-Ru and East African montane systems confirms that there is a relationship with the floristic composition of East African savannahs located in the Lake Victoria basin mosaic. Though these Acacia dominated savannahs differ physiognomically from NNP montane savannahs, the strong similarity in floristic composition is confirmed by both Phytogeographic distribution and the montane endemism analysis. Sclerochores or light non fleshy diaspores constitute the most abundant type of diaspores, which predicts wind as another way of contact between NNP montane savannahs and East African diaspores.
Given the shallowness of humus that covers a quartz substrate and the common presence of protruding rocks in most of the savannah slopes, NNP savannahs can be qualified as ancient savannas maintained by edaphic conditions. The lack or insufficiency of humus combined with the rocky substrate unable to retain water constitutes the major explanation of the persistence of savannahs in a place expected to be occupied by a rain forest.
Savannah-forest contact zone harbours communities where species like *Pteridium aquilinum* are abundant, which indicates the initial phase of forest installation. Nyungwe montane savannahs are being progressively encroached on by their matrix. The accumulation of litter which falls from the surrounding trees increases the thickness of humus and thus gives way to the invasion of forest species which are shade tolerant at the expense of savannah ones which are shade avoiders.
In general, NNP montane savannahs' specific diversity is low where an average of one species is estimated to inhabit one plot. However, these grassy spots distributed in different corners of NNP are home to a big number of savannah typical species which cannot be found elsewhere in the forest.
With reference to the conclusions above, researchers should document the full list of Nyungwe montane savannahs, survey the speed at which forest is encroaching on the savannahs so as to take appropriate conservation measures. Nyungwe managing authorities should also avoid practicing assisted forest regeneration in these savannah natural habitats. Instead, they should strengthen the protection and increase patrols around savannah areas because they are easy targets of illegal activities due to their easy accessibility.

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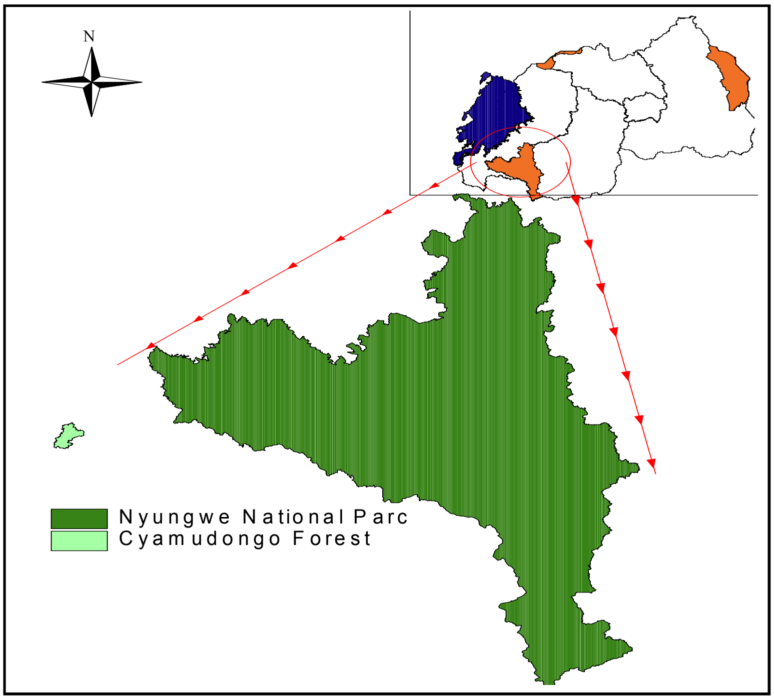
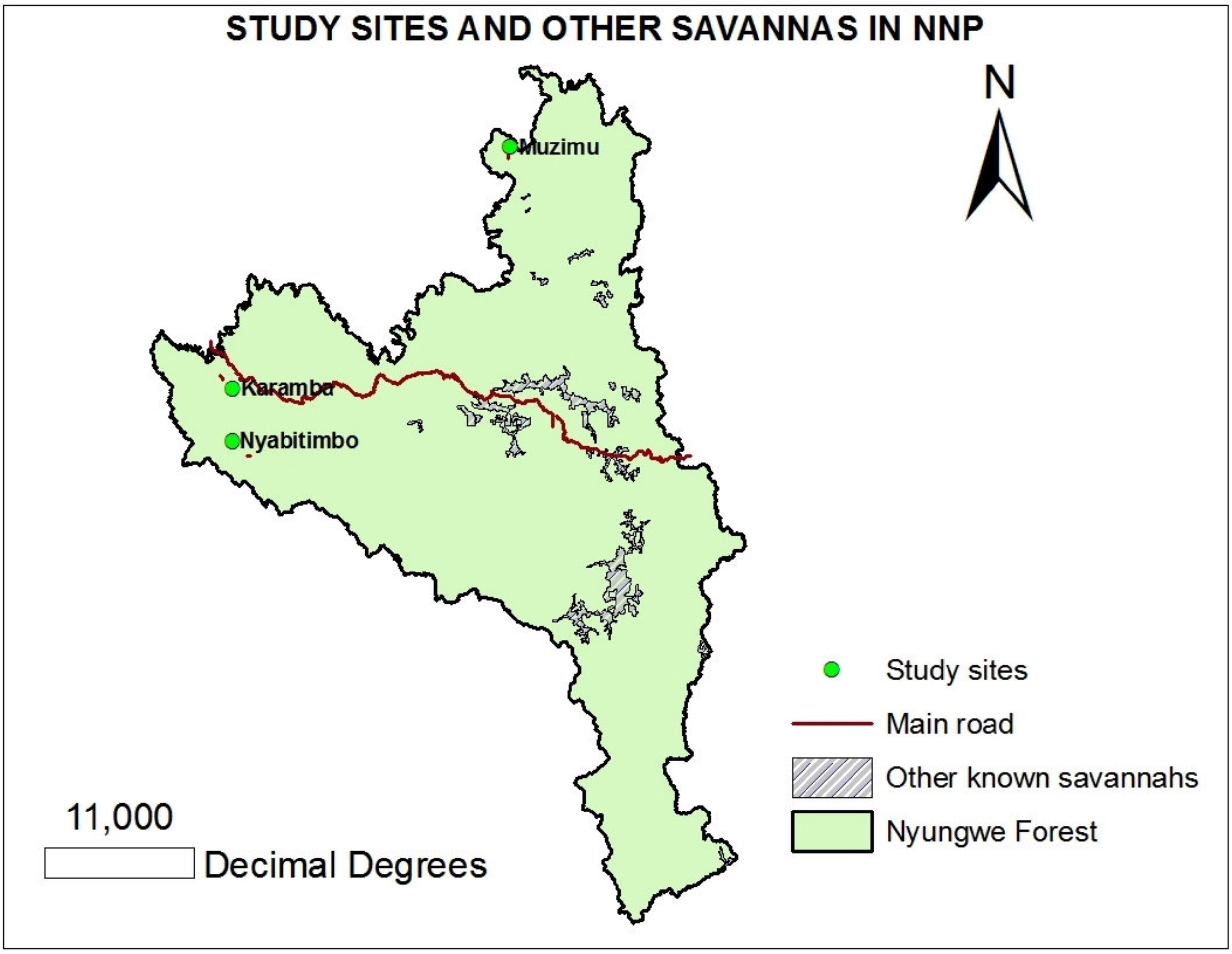
Appendices

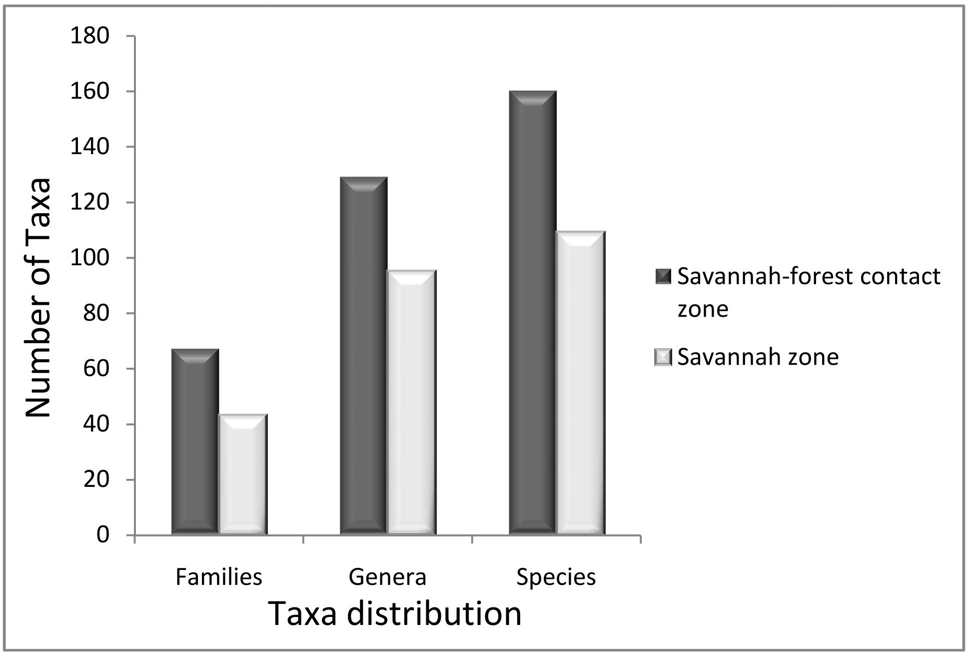
Appendix 1: Map of the location of Nyungwe National Park (NNP) in relation to other protected areas in Rwanda (ORTPN, 2005).



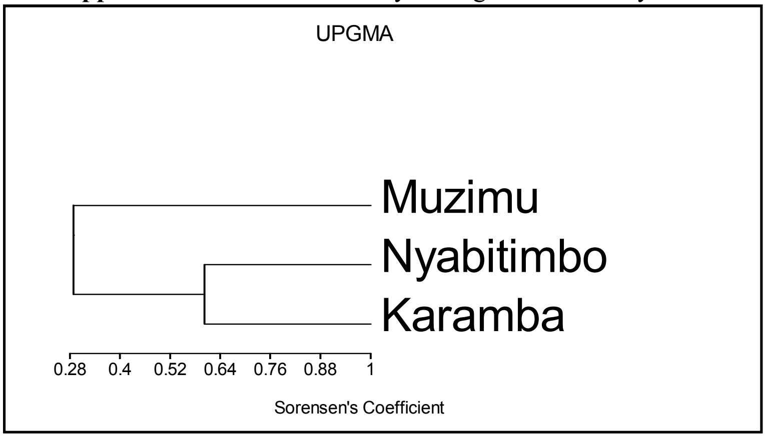
Appendix 2: *Savannas in NNP and localization of the study sites (Source: WCS/PCFN, edited)*



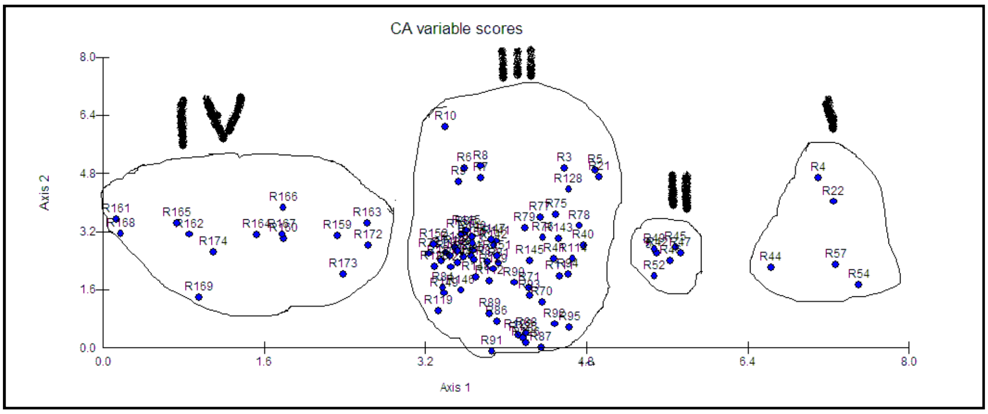
Appendix 3: Comparison of floristic diversity between the savannahs and the savannah-forest contact zone



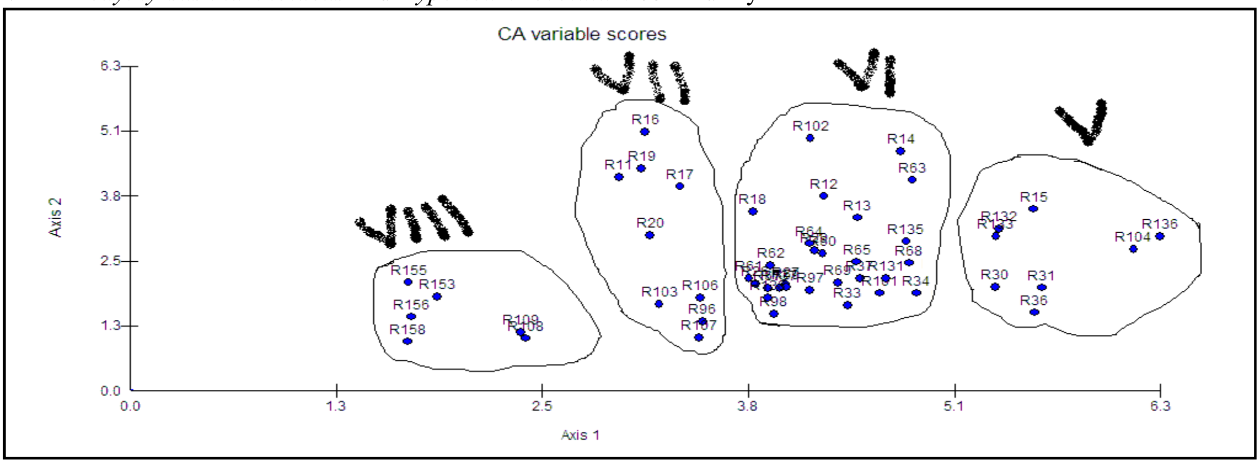
Appendix 4: Floristic similarity among the three study sites



Appendix 5: Individualization of plant communities in the savannah zone
I: *Eragrostis boehmii and Sphagnum planifolium* community
II: *Eragrostis boehmii* and *Exotheca abyssinica* community
III: *Eragrostis olivacea* and *Eragrostis boehmii* community
IV: *Erica bequaertii* and *Eragrostis olivacea* community



Appendix 6: Individualization of plant communities in the savannah-forest contact zone
V: *Clerodendrum johnstonii* and *Virectaria major* community
VI: *Pteridium aquilinum* and *Pycnostachys erici-rosenii* community
VII: *Dichaetanthera corymbosa* and *Nephrolepis undulata* community
VIII*:* *Hedythyrsus thamnoideus* and *Hypericum revolutum* community



Appendix 7: Phytogeographic distribution of afromontane species in Nyungwe montane savannas.
I:We-Af : West African System, II: Eth: Ethiopian System, III:Ki-Ru : Kivu-Ruwenzori System, IV: Im-Us :Imatongs-Usambara System, V: Ul-Mu: Uluguru–Mlanje System, VI: Chi : Chimanimani System, VII: Dra : Drakensberg System.

SPECIES	III:KI-Ru	IV:Im-Us	V:UL-Mu	II:Eth	VI:Chi	VII:Dra	I:Ou-Af
Begonia meyeri-johannis Engl.	x						
Blaeria kiwuensis (Engl.) Alm. & Th.Fries	x						
Bothriocline nyungwensis WECHUYSEN	x						
Bothriocline ruwenzoriensis (S.Moore)C.Jeffrey	x						
Cincinnobotrys oreophila Gilg	x						
Cissus sp.near oliveri(Engl)GILG.	x						
Clutia paxii Knauf	x						
Coleus edulis VATKE	x						
Cyperus denudatus L.f	x						
Cyperus dichrostachyus HOCHST	x						
Entandrophragma excelsum (Dawe & Sprague) Sprague	x						
Harungana montana Spirlet	x						
Impatiens purpureo-violacea Gilg.	x						
Isodon ramosissimus (Hook.f.) Codd	x						
Lobelia holstii Engl.	x						
Ocimum basilicum L.	x						
Pentas longiflora Oliv.	x						
Plectranthus serrulatus (Robyns) Troupin & Ayobangira	x						
Polygala engleri CHODAT	x						
Polystachya adansoniae RCHB.var. elongata SUMMERH	x						
Polystachya pachychila (SUMMERH)	x						
Polystachya woosnamii RENDLE	x						
Pycnostachys erici-rosenii ROB.E.FRIES	x						
Rhipidoglossum ovale (Summerh.) Garay	x						
Schefflera myriantha (Baker) Drake	x						
Senecio mariettae Muschl.	x						
Senecio nyungwensis Macquet	x						
Tristemma leiocalyx Cogn.	x						
Utricularia troupinii P.TAYLOR	x						
Vaccimium stanleyi Schweinf.	x						
Vernonia scaettae Humbert & Staner	x						
Agauria salicifolia (Commers.ex Lam.)Hook.f.ex Oliv.	x		x				
Agelanthus brunneus(Engl.)Balle & Hallé	x						x
Alchornea hirtella BENTH	x						x
Alectra sessiliflora (Vahl) Kuntze	x		x				
Andropogon diimeri STAPF	x			x			
Anisopappus africanus (Hook.f.) OLIV. et HIERN.	x						x
Carex echinochloe KUNZE	x			x			
Conyza hochstetterii Schultz-Bip.	x						x
Conyza sumatrensis (RETZ) E. K. WALKE	x						x
Crassocephallum paludum C.Jeffrey	x						x
Cynorkis kassneriana Kraenzlin	x						x
Dodoneya viscosa Jacq.	x			x			
Erica benguellensis Welwitsch. ex. Engl.) E.G.H.Oliv.	x				x		
Erica bequaertii De Wild.	x				x		
Erica johnstonii (SHWEINF.ex Engl.)Dorr	x				x		
Faurea saligna Harvey	x						x
Habenaria macrostele Summerh.	x				x		
Habenaria malacophylla Rchb.f.	x				x		
Harungana madagascariensis Poir.	x				x		
Hibiscus noldeae Bak.f.	x						x
Keetia gueinzii (Sond.)BRIDSON	x		x				
Laurembergia tetrandra (SCHOTT ex.SPRENG.)KANITZ	x	x					
Lindernia subracemosa De Wild.	x	x					
Lipocarpha chinensis (Osbeck) Kern	x	x					
Maytenus acuminata (L.f.) Loes.	x						x
Microglossa pyrifolia (Lam.) O.KUNTZE	x						x
Mimulopsis arborescens C.B.Clarke	x	x					
Otiophora pauciflora BAK. ssp. burtii (Milne-Redh.) Verdc.	x	x					
Panicum adenophorum SCHUMANN	x	x					
Phyllantus odontadenius Muell.Arg.	x						x
Polygala ruwenzoriensis CHODAT	x	x					

SPECIES	III:KI-Ru	IV:Im-Us	V:UL-Mu	II:Eth	VI:Chi	VII:Dra	I:Ou-Af
Sapium ellipticum (Hochst. Ex Krauss) Pax	x						x
Tabernaemontana stapfina Britten	x						x
Tapinanthus constrictiflorus (Engl.) Danser	x	x					
Triumfetta cordifolia A. Rich.	x				x		
Albizia gummifera (J. Gmelin) C.A.Smith	x			x			x
Brachiaria scalaris PILGER	x		x		x		
Bulbophyllum burtii SUMM	x				x	x	
Bulbophyllum vulcanicum Kraenzl.	x				x	x	
Clausena anisata (Willd.) Benth.	x	x		x			
Cyathea maniana Hook.	x	x	x				
Dissotis ruandensis Engl.	x	x		x			
Eragrostis boehmii (Hack)	x	x		x			
Eragrostis olivacea SCHUMANN	x	x		x			
Geranium arabicum Forssk.	x				x		x
Hedythyrsus thamnoideus (K.Schum.) Bremek.	x	x	x				
Hypoxis kilimanjarica Baker	x	x	x				
Ipomoea involucrata Beauv.	x				x		x
Kotschya aeschynomenoides (Baker) De Wit.& Duvign.	x	x	x				
Lobelia gibberoa Hemsl.	x	x		x			
Lobelia mildbraedii Engl.	x	x		x			
Macaranga Kilimandscharica Pax	x	x	x				
Maesa lanceolata Forssk.	x	x	x				
Musanga leo-errerae (Hauman & J. Léonard	x	x	x				
Ocotea usambarensis Engl.	x	x	x				
Pentadesma reyndersii Spirlet	x	x	x				
Pentas zanzibarica (Klotzsch) Vatke	x	x	x				
Pseudosabicea arborea (K.SCHUM) HALLE ssp bequaertii (DEWILD) VERDC.	x	x	x				
Psychotria mahonii C.H.WRIGHT	x	x	x				
Rubus pinnatus WILLD	x	x	x				
Rubus runssorensis Engl.	x	x	x				
Rubus steudeneri Schweinf.	x	x	x				
Rumex abyssinicum JACQ	x	x	x				
Rutidea orientalis BRIDSON	x	x	x				
Senecio maranguensis O.HOFFM	x	x	x				
Spermacoce princeae(K.Schum.)Verdc.	x	x			x		
Urera hypselodendron (Hochst. ex A. Rich.) Wedd.	x			x	x		
Anthocleista grandiflora Gilg	x	x	x	x			
Bersama abyssinica FRESEN	x	x	x	x			
Biophytum helenae Buscal. & Muschler	x	x	x	x			
Bridelia brideliifolia (Pax) Fedde	x	x	x	x			
Dalbergia lactea Vatke	x	x	x	x			
Dichaetanthera corymbosa (Cogn.) Jacq.-Felix	x	x	x	x			
Digitaria longiflora (RETZ) PERS.	x	x	x	x			
Dissotis brazae Cogn.	x	x		x			x
Gouania longispicata ENGL	x	x	x	x			
Hagenia abyssinica (Bruce) J.F.Gmelin	x	x	x	x			
Hallea stipulosa (DC.)Leroy	x	x	x	x			
Impatiens niamniamensis Gilg	x	x	x				x
Ixora burundiensis Bridson	x	x	x	x			
Lagenaria sphaerica (Sond.) Naud.	x	x	x		x		
Mimulopsis solmsii SCHWEINF	x	x	x				x
Polyscias fulva (Hiern) Harms	x	x	x		x		
Polystachya bifida Lindl.	x	x	x	x			
Polystachya lindblomii Schltr.	x	x	x	x			
Struthiola thomsonii Oliv.	x	x	x	x			
Urera trinervis (Hocst.) Friis & Immelmann	x			x	x		x
Carapa grandiflora SPRAGUE	x	x	x	x			x
Clematis simensis Fresen.	x	x	x	x			x
Clutia abyssinica Jaub.& Spach	x	x	x		x	x	
Eriosema montanum BAK.f.var.montanum	x	x	x		x	x	
Hymenodictyon floribundum (Hochst.& Steud.) Robbr.	x	x	x	x			x
Impatiens burtonii Hok.f.	x	x	x	x			x
Kyllinga stenophylla K.Schum. ex C.B. Clarke	x	x	x	x			x
Myrianthus holstii Engl.	x	x	x	x	x		
Podocarpus falcatus (Thunb.) R.Br. ex Mirb.	x	x	x	x			x
SPECIES	**III:KI-**	**IV:I**	**V:UL-**	**II:Eth**	**VI:C**	**VII:D**	**I:Ou-**

	Ru	**m-Us**	**Mu**		**hi**	**ra**	**Af**
Protea welwitschii ENGL ssp.adolphi-friderici(Engl.)BEARD	x	x	x	x			x
Pycreus nigricans (Steud.)C.B.Clarke	x	x	x		x	x	
Sericostachys scandens Gilg & Lopr.	x	x	x	x			x
Aframomum mala (K.Schum.) K.Schum.	x	x	x	x	x		x
Clerodendrum johnstonii OLIV.	x	x	x	x	x		x
Cyanotis barbata D.Don.	x	x	x	x	x		x
Cynorkis anacamptoides Kraenzl.	x	x	x	x	x		x
Embelia schimperi Vatke	x	x	x	x	x		x
Exotheca abyssinica(HOCHTS.ex A.RICH) ANDERSON	x	x	x	x	x	x	
Helichrysum forskahlii (J.F.GMEL) HILLARD	x	x	x	x	x		x
Helichrysum helvorum Moeser	x	x	x	x	x		x
Helichrysum panduratum O. HOFFM	x	x	x	x	x		x
Helichrysum schimperi (SCHULTZ-BIP) MOESER.	x	x	x	x	x	x	
Isachne mauritiana Kunth	x	x	x	x		x	x
Liparis bowkeri HARV	x	x	x	x	x	x	
Lycopodium clavatum L.	x	x	x	x	x		x
Melastomastrum capitatum (Vahl) A. & R.Fernandes	x	x	x	x	x		x
Paspalum scrobiculatum L.	x	x	x		x	x	x
Satyrium trinerve Lindl.	x	x	x	x	x		x
Secamone racemosa (Schltr.)Liede	x	x	x	x	x	x	
Virectaria major (K.Shwum.)Verdc.	x	x	x	x	x		x
Xyris capensis THUNB.	x	x	x	x	x		x
Eulophia horsfalii (Batemann) Summerh.	x	x	x	x	x	x	x
Floscopa glomerata (Willd. & Schult. Ex Schult.f.) Hassk.	x	x	x	x	x	x	x
Hypericum revolutum Vahl.	x	x	x	x	x	x	x
Melinis tenuissima STAPF	x	x	x	x	x	x	x
Myrsine melanophloeos (L.) R.Br	x	x	x	x	x	x	x
Prunus africana (Hook.f.) Kalkm.	x	x	x	x	x	x	x
Rhytachne rottboelioides DESF	x	x	x	x	x	x	x
Rubus apetalus Poir.	x	x	x	x	x	x	x
Scleria distans Poir.	x	x	x	x	x	x	x
Setaria megaphylla (Steud.) Th.Dur. & Schinz	x	x	x	x	x	x	x
Smilax anceps Willd.	x	x	x	x	x	x	x
Syzigium guineense (Willd.)D.C.ssp. parvifolium (Engl.)F.White	x	x	x	x	x	x	x
Themeda trianda FORSK	x	x	x	x	x	x	x
Tristemma mauritianum J.Gmelin	x	x	x	x	x	x	x
Total	163	97	85	68	53	25	58
%	100	59.5	52	41.7	32.5	15.3	35.5
Simpson's diversity index	0.994	0.99	0.988	0.985	0.981	0.96	0.983